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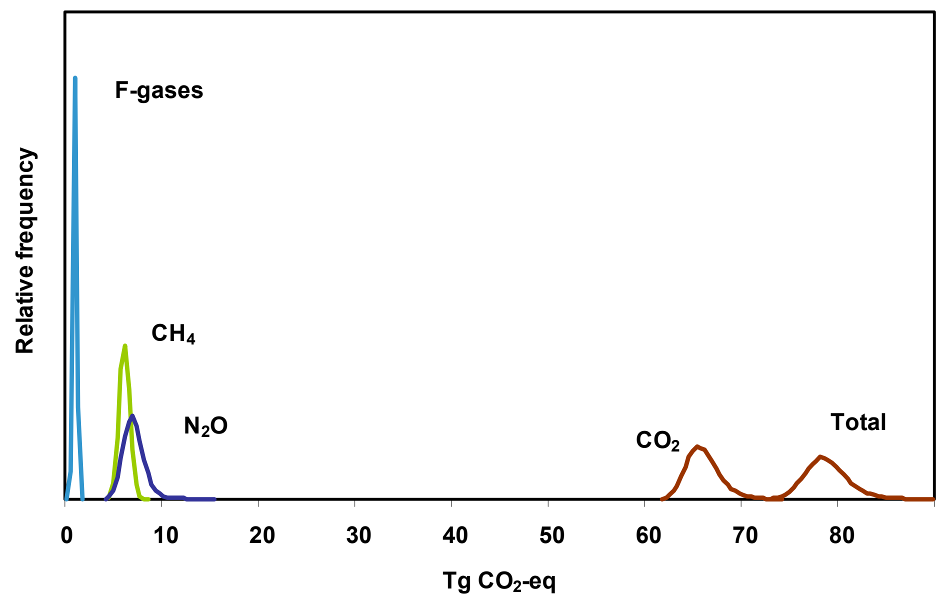

Suvi Monni & Sanna Syri

Uncertainties in the Finnish 2001 Greenhouse Gas Emission Inventory

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Abstract

This study is a part of Finland's Greenhouse Gas Emission Inventory work to the United Nations Framework Convention on Climate Change (UNFCCC). Reliable uncertainty estimates are required by the UNFCCC, and they also function as a tool for increasing the quality of national emission inventories.

Uncertainty in emission estimates can arise from inaccuracy in emission monitoring, lack of knowledge involving the emission factor and activity data estimates, or, for example, biased 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, and the other greenhouse gases of the Kyoto Protocol, CH_4, N_2O, HFCs, PFCs and SF_6, are usually rather poorly known.

This is the first time Tier 2 uncertainty assessment is used for the Finnish Greenhouse Gas Emission Inventory. For the purpose of this report it was performed concerning the years 1990 and 2001. This report presents the basis of each input parameter uncertainty estimate which were mainly 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 were combined using Monte Carlo simulation, which allows the use of asymmetrical distributions and flexible handling of correlations. The resulting total uncertainty in the 2001 emissions was -5...+6%. The asymmetry results from highly uncertain emission sources that have asymmetrical distributions. The trend uncertainty (change between 1990 and 2001) was assessed to ±5%-points. The most significant sources contributing to the total uncertainty were identified with sensitivity analysis and key source identification. The most important emission sources affecting the total uncertainty are CO_2 emissions from arable peatlands and peat production areas, and N_2O emissions from agricultural soils.

Preface

This study is a part of Finland's Greenhouse Gas Emission Inventory work to the United Nations Framework Convention on Climate Change (UNFCCC). Uncertainty estimates for the year 2001 and the trend (change in emissions between 1990 and 2001) are presented. The most important sources affecting the uncertainty, i.e. the key sources, are also identified.

This study was conducted by Suvi Monni, Sanna Syri, and Ilkka Savolainen from the Technical Research Centre of Finland (VTT). The inter-ministerial working group on greenhouse gases chaired by the Ministry of the Environment (Chairman Jaakko Ojala) has contributed significantly to the work. Especially the specialists of each emission category, Kari Grönfors (Statistics Finland), Kari S. Mäkelä (VTT), Juhani Laurikko (VTT), Teemu Oinonen (Finnish Environment Institute), Jouko Petäjä (Finnish Environment Institute), Paula Perälä (MTT Agrifood Research Finland), Martti Esala (MTT) and Kristiina Regina (MTT) have lent their expertise and contributed to the study. In addition, other national and international experts have contributed with important details.

The work was funded by the Ministry of Trade and Industry. A group chaired by Mirja Kosonen (Ministry of Trade and Industry) supervised this work. The other members of the supervising group were Jaakko Ojala, Martti Esala, Kristina Saarinen (Finnish Environment Institute) and Timo Alanko (Statistics Finland).

Contents

List of Abbreviations

Greenhouse gases:

CO_2	carbon dioxide
CH_4	methane
N_2O	nitrous oxide
HFC	hydrofluorocarbon
PFC	perfluorocarbon
SF_6	sulphur hexafluoride

Other chemical compounds:

NO_x	nitrogen oxide
SO_x	sulphur oxide

Organisations:

IPCC	Intergovernmental Panel on Climate Change
MTT	Agrifood Research Finland
VTT	Technical Research Centre of Finland

Other:

GWP	Global warming potential (GWPs are calculated as the ratio of the radiative forcing that would result from the emission of one kilogram of a greenhouse gas to that from the emission of one kilogram carbon dioxide over a period of time. In this study, a 100 year GWP is used.)
CO_2 eq	Carbon dioxide equivalents (a measure used to express the emissions of greenhouse gases weighted with their GWPs)
f(x)	probability density function
UNFCCC	United Nations Framework Convention on Climate Change

1. Introduction

Climate change that occurs because of increasing greenhouse gas concentrations in the atmosphere can be seen as one of the most serious environmental risks. Mitigation of climate change requires significant reductions of greenhouse gas emissions. The United Nations Framework Convention on Climate Change (UNFCCC) from 1992 can be seen as the first global effort to mitigate climate change. According to the Kyoto Protocol from 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% below the 1990 level by the first commitment period 2008-2012. The current emission reduction target is not enough for the atmospheric greenhouse gas concentrations to be stabilised, but is, however, a beginning of the emission reduction process. Negotiations for the second commitment period after 2012 will begin soon.

The implementation of the Kyoto Protocol and the forthcoming protocols require high-quality emission inventories. Accurate emission estimates are also essential for emission trading, and high-quality uncertainty estimates give important information on research priorities for future improvement of emission inventories. Fifth Conference of the Parties (COP5) of the UNFCCC made a decision (3/CP.5, documented in FCCC/CP/1999/7) according to which the parties should use the best available methodologies to estimate uncertainties.

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 on landfills). Uncertainties can then arise from lack of knowledge of used emission factors and activity data, from errors in models or from bias in expert judgements. Uncertainties can also be found in definitions, natural variability of the process and reference data (Penman et al. 2000). Though CO_2 emissions dominate the emission level in Finland and in many other industrial countries, non-CO_2 gases dominate the uncertainty. Sources of non-CO_2 gases are rather poorly known, and they can be highly variable in both space and time (Rypdal 2002).

Methodologies presented in Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 1996a) and in Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (Penman et al. 2000) should be followed in greenhouse gas emission inventories. Good Practice Guidance gives also advice on how to assess the uncertainties and identify key sources. For the uncertainty assessment, two different methods are given: Tier 1 and Tier 2. In Tier 1 method, 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.

One of the main purposes of uncertainty estimates is to help prioritise efforts to improve the accuracy of inventories in the future. This is done by identifying key sources of the inventory, i.e. finding source categories that contribute significantly on the overall uncertainty of the inventory (Penman et al. 2000). When these are identified, scarce resources can be allocated to reduce uncertainty in these particular emission sources. A decision tree presented in Figure 1 (Penman et al. 2000) gives advice on how to select the inventory methods for key sources and non-key sources of the inventory.

According to the Third National Communications of the Parties to the UNFCCC, only few industrial (Annex I) countries, Australia, Austria, Norway and the UK have performed a Tier 2 uncertainty analysis of recent inventories. Canada has performed an uncertainty analysis for the 1990 inventory, and the Netherlands, the USA, as well as Finland, have performed a Tier 1 uncertainty analysis. Rypdal & Winiwarter (2001) have compared the uncertainty estimates of Austria, Norway, the Netherlands, the UK and the USA. Most countries that have performed an uncertainty analysis have reported level uncertainty of ±4-21%, and trend uncertainty of ±4-5%-points, which seem rather high when compared with the emission reduction target of the Kyoto Protocol.

The uncertainty in the Finnish greenhouse gas emission inventory was first estimated for the inventory year 1998, which is reported by Pipatti (2001). The estimates were updated for the 1999 inventory by Aaltonen et al. (2001). The uncertainty estimates of source categories were based entirely on expert judgement, and all uncertainties were assumed to have a normal distribution. The uncertainties were combined with the Tier 1 method (Aaltonen et al. 2001).

This study is a part of Finland’s Greenhouse Gas Emission Inventory work to the United Nations Framework Convention on Climate Change (UNFCCC). The aim of this study was to perform an uncertainty analysis for the Finnish 2001 Greenhouse Gas Inventory in the Energy, Industry, Agriculture and Waste sectors. The Land-Use Change and Forestry sector was beyond the scope of this study.

In this study, all input parameter uncertainties are estimated, or at least the validity of the previous estimates is checked. Uncertainty estimates are based on available measurement data, domestic and international literature and expert judgement. In some source categories the uncertainty estimates are performed at a more detailed level than in the previous estimate. Tier 2 method is used to combine the uncertainties.

Chapter 2 presents general information on uncertainty estimates, the distributions used, and the choosing of distributions. Uncertainties in input parameters by sector are presented in Chapters 3-8. The corresponding IPCC source category numbers are presented in the headings of all chapters. The methods used to combine uncertainties are presented in Chapter 9, and results are presented in Chapter 10. Chapter 11 presents sensitivity analysis and Chapter 12 gives recommendations for further research. Quality Control procedures for uncertainty estimates are presented in Chapter 13. Discussion and conclusions are presented in Chapter 14.

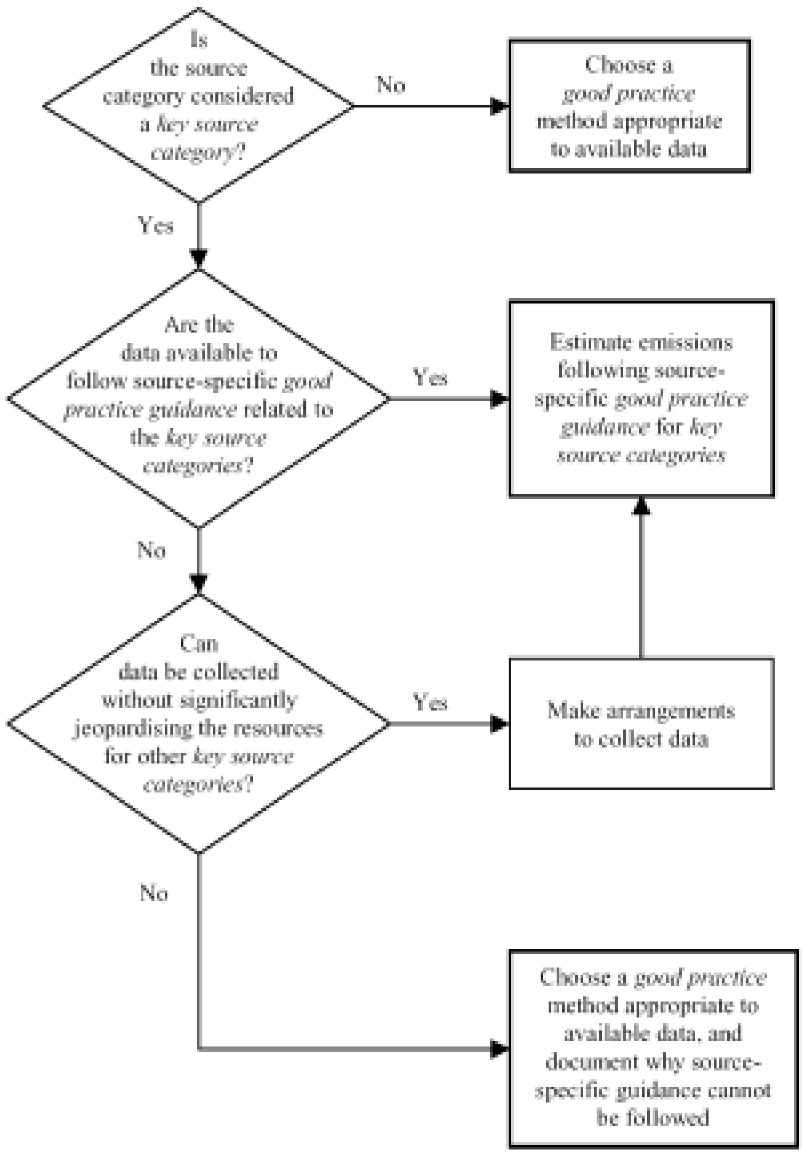

Figure 1. Decision tree to choose a good practice method (Penman et al. 2000).

2. Expressing uncertainty

The shapes and widths of estimated uncertainties are described by probability density functions.

Confidence interval is used to describe the uncertainty range of a given parameter. A 100*(1-α)% confidence interval for parameter θ is a random interval $[L_1, L_2]$ such that (Milton & Arnold 1995):

$$P[L_1 \leq \theta \leq L_2] = 1 - \alpha \qquad (1)$$

According to IPCC Good Practice Guidance (Penman et al. 2000), the parameter θ of greenhouse gas emissions is the mean value, and α=0.05. The uncertainty is expressed as 2.5 percentile and 97.5 percentile defined as percents relative to the mean value (Penman et al. 2000). As far as normal distribution goes, this can be seen as an intuitive approach, but not a very good one in the case of asymmetrical distribution. Especially distributions which are defined by three parameters (e.g. gamma, Weibull) cannot be satisfactorily described with a 95% confidence interval.

In this chapter we present some examples of probability density functions used to describe uncertainty. In this study, probability density functions are chosen so that the mean value is always equal to the value used in the greenhouse gas emission inventory. In the figures below, the 95% confidence interval is presented as the range between the 2.5 and 97.5 percentiles. In this study, the probability density functions are entered to the uncertainty calculation model using Crystal Ball (Decisioneering 2000) simulation tool. The functions are presented in the Crystal Ball Manual (Werckman et al. 2000).

Normal distribution is the most widely used distribution in this study. It is symmetrical around the mean, and defined for all values. However, because emissions cannot be negative, normal distribution is used only in the cases where uncertainty is lower than ±100%. Normal distribution is a two-parametrical distribution, and can therefore be completely described with the 95% confidence interval. Normal distribution is presented in Figure 2.

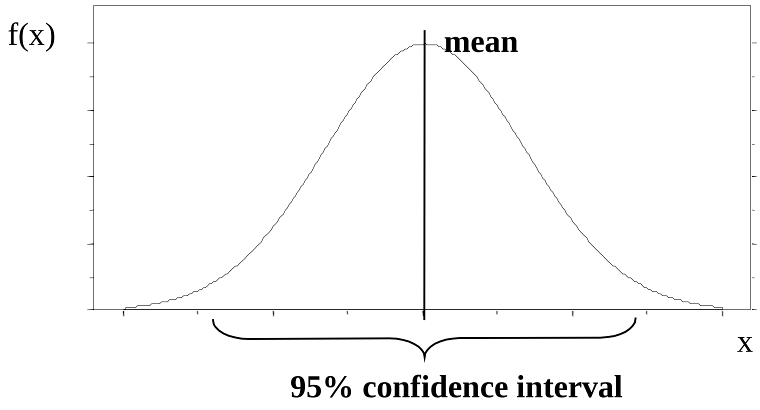

Figure 2. Normal distribution.

Lognormal distribution is positively skewed, and it is defined only for positive values, which makes it very useful in describing emissions. Lognormal distribution is a transformation of normal distribution, and is therefore also a two-parametric distribution. Lognormal distribution is presented in Figure 3.

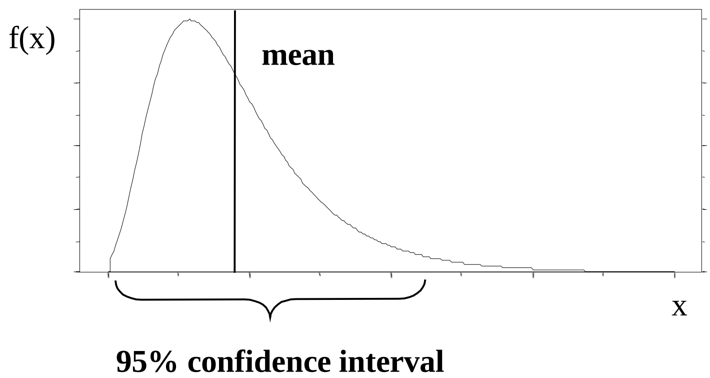

Figure 3. Lognormal distribution.

Gamma distribution is a positively skewed distribution. It has three parameters, and can therefore have various shapes. This makes it very useful in describing different types of uncertainties, especially if uncertainties are large and highly skewed. Below are two examples of possible shapes of gamma distributions in Figures 4 and 5:

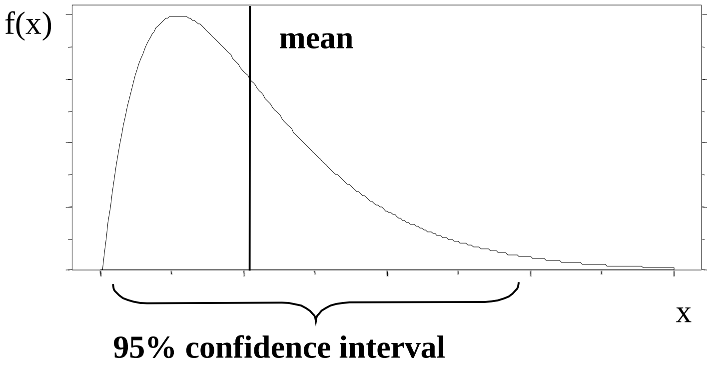

Figure 4. Gamma distribution with a shape parameter 2.

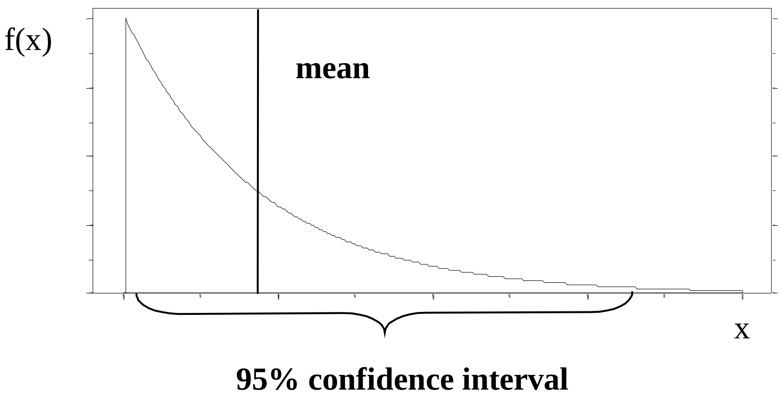

Figure 5. Gamma distribution with a shape parameter 1.

Weibull distribution is used only in a few cases in this study, mainly when distribution has been fitted into empirical data. With three parameters it is also a very flexible distribution.

Gumbel distribution (also called extreme value distribution), even though it is generally a rather rarely used distribution, has two advantages for the purposes of this study. Firstly, it is two-parametric, i.e., it can be fully described with its 95% confidence interval, and secondly, it can be either positively or negatively skewed. Negatively and positively skewed Gumbel distributions are presented in Figures 6 and 7.

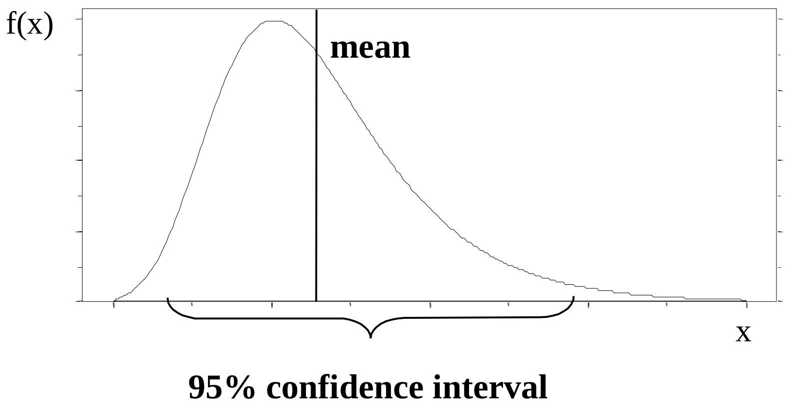

Figure 6. Positively skewed Gumbel distribution.

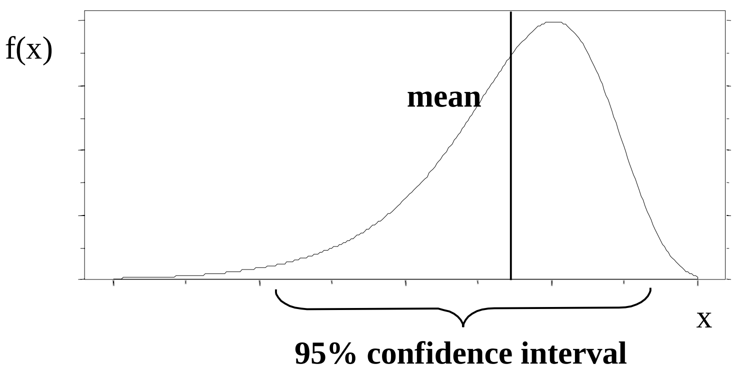

Figure 7. Negatively skewed Gumbel distribution.

Beta distribution is a three-parametric distribution which can have various shapes depending on the parameters. The distribution can be either positively or negatively skewed. Two separate beta distributions are presented in Figures 8 and 9.

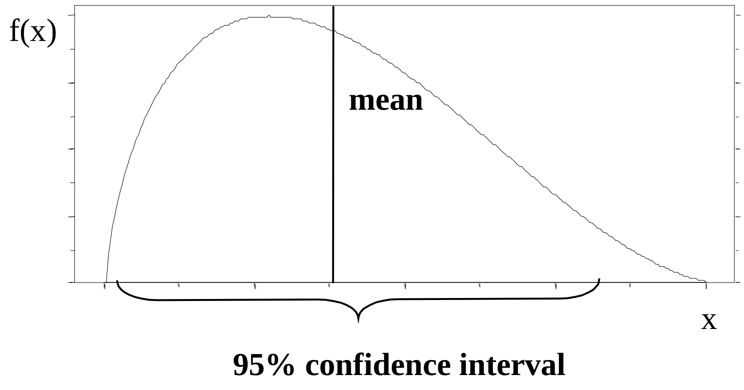

Figure 8. Positively skewed beta distribution.

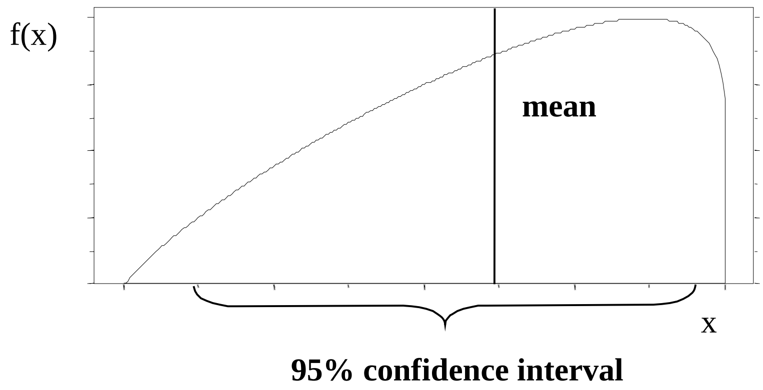

Figure 9. Negatively skewed beta distribution.

In the uncertainty estimates of greenhouse gas emission inventories, the shape of uncertainty distribution is seldom known. Therefore the chosen probability density functions must be seen as “best estimates”. Some general rules for choosing a specific distribution can, however, be found. These include a range of possible values (e.g. the non-negative real axis for lognormal distribution) and skewing of distribution (positively or negatively skewed). The main reasons for choosing specific distributions for the purpose of this study are:

- Normal distribution is used, when uncertainty can be assumed to be symmetrical. This is the most widely used distribution in this study. If the uncertainty exceeds ±50%, normal distribution is unlikely to occur in most cases. When uncertainties exceed 100%, normal distribution cannot be used, because emissions cannot be negative.

- Lognormal distribution is used, when uncertainty can be expected to be positively skewed. This distribution has positive values only. Lognormal distribution is used in cases where the uncertainty is typically large and values can be assumed positive and not limited by an upper bound.

Normal and lognormal distributions have mainly been used for describing the uncertainty. In some cases, certain characteristic features of emission sources or mean values used in the inventory cause that some other distribution type is used:

- Negatively skewed beta distribution is used mostly in cases where the value used in the inventory seems to be too high (some emission factors of N_2O and methane from combustion, N_2O emission factor of solid manure etc).

- Gamma distribution is used for various reasons. In some cases gamma distribution is a result of modelling (indirect N_2O from fuel combustion), and in some cases it is the best-fitting distribution to values obtained from different studies (N_2O from cars with catalytic converters). Sometimes gamma distribution is chosen because, with the specific parameters, it can be used to describe a highly asymmetrical uncertainty (e.g. emission factor of reindeer).

- Weibull distribution proved suitable for describing highly asymmetrical uncertainties (e.g. to describe k-value uncertainty in waste degradation). In some cases it fitted the measurement values (e.g. NO_x from railway transportation).

- Gumbel distribution is mainly used to describe negatively skewed uncertainties.

In the sensitivity analysis in Chapter 11, all distributions are replaced with normal distributions. The results show that this does not have any great effect on total uncertainty (partly due to the large amount of emission categories of which uncertainty is assumed to be normally distributed).

3. Stationary Combustion (1A1, 1A2, 1A4, 1A5)

In the Finnish Greenhouse Gas Emission Inventory, emissions from fuel combustion are calculated using the ILMARI calculation system, which uses input data from various models, databases and other information sources (Pipatti 2001). Most of the data is collected at point source level, i.e. power plant, industrial plant and boiler level. CO_2 emissions are calculated based on fuel consumption and fuel-specific emission factors, which are mainly based on IPCC default emission factors. The fraction of carbon oxidised is also taken into account. Methane and nitrous oxide emissions are calculated based on fuel consumption and emission factors, which are specific for each boiler, process or technology (Pipatti 2001). In Finland, peat is rather widely used; it is reported under Other Fuels.

In the previous uncertainty analyses, (Pipatti 2001; Aaltonen et al. 2001), uncertainty estimates were based entirely on expert judgement of National Expert Kari Grönfors from Statistics Finland. The estimates of uncertainty in activity data were based on knowledge on differences between different statistics. In this uncertainty analysis, the activity data and CO_2 emission factor uncertainties are mainly kept unchanged, but N_2O and CH_4 emission factor uncertainty estimates are based on measurement data (Korhonen et al. 2001; Fabritius et al. 2002) in addition to expert judgement.

The measurement data reviewed was obtained from a study (Korhonen et al. 2001; Fabritius et al. 2002) which aimed at evaluating methane and nitrous oxide emission factors used in the Finnish emission inventory. The measurements were made at 13 power plants. Two of the measured plants were recovery boilers, three of them were circulating fluidised bed (CFB) boilers, three bubbling fluidised bed (BFB) boilers, two pulverised coal firing (PC) boilers, two combined-cycle gas turbine plants and one was a heavy oil firing boiler. The fuels used in measurements were peat, biomass, bark, soft and hard wood, coal, gas and heavy oil. Totally 21 different process conditions were measured. The measurements present Finnish energy production rather well (Korhonen et al. 2001; Fabritius et al. 2002).

The number of measurements is still rather low, and further research is required. Therefore, the uncertainty analysis is performed only by fuel type. When there is more information (e.g. measurement results) available on emission factors, uncertainty analysis should preferably be performed also by combustion technology, because uncertainty ranges may vary significantly between different combustion technologies.

The uncertainty estimates used, and their bases are presented in Table 1. Uncertainties are assumed to be the same in the reference year 1990 as in the inventory year 2001. However, e.g. in the case of N_2O emission factors, the structure of combustion technologies has changed significantly since 1990 (e.g. the number of fluidised bed boilers, which emit more N_2O than conventional boilers, has increased). This may make the 2001 uncertainties different from those in 1990. This should be taken into account, if further research is performed at a technology-specific level.

Table 1. Estimated uncertainty distributions, their 95% confidence intervals and bases of estimates for Stationary Combustion sector.

Input	IPCC category	Distribution	95% confidence interval [1]	Basis
Activity Data				
Energy Industries				
Liquid Fuels	1A1	normal	±2%	Expert judgement
Solid Fuels	1A1	normal	±2%	Expert judgement
Gaseous Fuels	1A1	normal	±1%	Expert judgement
Biomass	1A1	normal	±20%	Expert judgement
Other Fuels	1A1	normal	±5%	Expert judgement
Manufacturing Industries and Construction				
Liquid Fuels	1A2	normal	±2%	Expert judgement
Solid Fuels	1A2	normal	±2%	Expert judgement
Gaseous Fuels	1A2	normal	±1%	Expert judgement
Biomass	1A2	normal	±15%	Expert judgement
Other Fuels	1A2	normal	±5%	Expert judgement
Other Sectors				
Liquid Fuels	1A4	normal	±30%	Expert judgement
Solid Fuels	1A4	normal	±10%	Expert judgement
Gaseous Fuels	1A4	normal	±5%	Expert judgement
Biomass	1A4	normal	±15%	Expert judgement
Other Fuels	1A4	normal	±25%	Expert judgement
Other				
Liquid Fuels	1A5	normal	±50%	Expert judgement
Gaseous Fuels	1A5	normal	±20%	Expert judgement
Biomass	1A5	normal	±25%	Expert judgement
Emission Factors				
Energy Industries				
Liquid Fuels (CO_2)	1A1	normal	±2%	Expert judgement
Liquid Fuels (CH_4)	1A1	beta	-75...+10%	Korhonen et al. 2001
Liquid Fuels (N_2O)	1A1	beta	-75...+10%	Korhonen et al. 2001
Solid Fuels (CO_2)	1A1	normal	±3%	Expert judgement
Solid Fuels (CH_4)	1A1	beta	-75...+10%	Korhonen et al. 2001
Solid Fuels (N_2O)	1A1	normal	±50%	Expert judgement
Gaseous Fuels (CO_2)	1A1	normal	±1%	Expert judgement
Gaseous Fuels (CH_4)	1A1	beta	-75...+10%	Korhonen et al. 2001
Gaseous Fuels (N_2O)	1A1	normal	±50%	Expert judgement
Biomass (CH_4)	1A1	normal	±50%	Expert judgement
Biomass (N_2O)	1A1	lognormal	-70...+150%	Expert judgement
Other Fuels (CO_2)	1A1	normal	±5%	Expert judgement
Other Fuels (CH_4)	1A1	normal	±50%	Expert judgement
Other Fuels (N_2O)	1A1	lognormal	-70...+150%	Expert judgement
Manufacturing Industries and Construction				
Liquid Fuels (CO_2)	1A2	normal	±2%	Expert judgement

Liquid Fuels (CH_4)	1A2	beta	-75...+10%	Korhonen et al. 2001
Liquid Fuels (N_2O)	1A2	beta	-75...+10%	Korhonen et al. 2001
Solid Fuels (CO_2)	1A2	normal	±3%	Expert judgement
Solid Fuels (CH_4)	1A2	beta	-75...+10%	Korhonen et al. 2001
Solid Fuels (N_2O)	1A2	normal	±50%	Expert judgement
Gaseous Fuels (CO_2)	1A2	normal	±1%	Expert judgement
Gaseous Fuels (CH_4)	1A2	beta	-75...+10%	Korhonen et al. 2001
Gaseous Fuels (N_2O)	1A2	normal	±50%	Expert judgement
Biomass (CH_4)	1A2	normal	±50%	Expert judgement
Biomass (N_2O)	1A2	lognormal	-70...+150%	Expert judgement
Other Fuels (CO_2)	1A2	normal	±5%	Expert judgement
Other Fuels (CH_4)	1A2	normal	±50%	Expert judgement
Other Fuels (N_2O)	1A2	lognormal	-70...+150%	Expert judgement
Other Sectors				
Liquid Fuels (CO_2)	1A4	normal	±2%	Expert judgement
Liquid Fuels (CH_4)	1A4	beta	-75...+10%	Korhonen et al. 2001
Liquid Fuels (N_2O)	1A4	beta	-75...+10%	Korhonen et al. 2001
Solid Fuels (CO_2)	1A4	normal	±5%	Expert judgement
Solid Fuels (CH_4)	1A4	beta	-75...+10%	Korhonen et al. 2001
Solid Fuels (N_2O)	1A4	normal	±50%	Expert judgement
Gaseous Fuels (CO_2)	1A4	normal	±1%	Expert judgement
Gaseous Fuels (CH_4)	1A4	beta	-75...+10%	Korhonen et al. 2001
Gaseous Fuels (N_2O)	1A4	normal	±50%	Expert judgement
Biomass (CH_4)	1A4	lognormal	-70...+150%	Expert judgement
Biomass (N_2O)	1A4	lognormal	-70...+150%	Expert judgement
Other Fuels (CO_2)	1A4	normal	±20%	Expert judgement
Other Fuels (CH_4)	1A4	normal	±50%	Expert judgement
Other Fuels (N_2O)	1A4	lognormal	-70...+150%	Expert judgement
Other				
Liquid Fuels (CO_2)	1A5	normal	±2%	Expert judgement
Liquid Fuels (CH_4)	1A5	beta	-75...+10%	Korhonen et al. 2001
Liquid Fuels (N_2O)	1A5	beta	-75...+10%	Korhonen et al. 2001
Gaseous Fuels (CO_2)	1A5	normal	±1%	Expert judgement
Gaseous Fuels (CH_4)	1A5	beta	-75...+10%	Korhonen et al. 2001
Gaseous Fuels (N_2O)	1A5	normal	±50%	Expert judgement
Biomass (CH_4)	1A5	lognormal	-70...+150%	Expert judgement
Biomass (N_2O)	1A5	lognormal	-70...+150%	Expert judgement
Indirect N_2O from fuel combustion[2]	-	gamma	-79...+100%	see text

[1] Expressed as 2.5 percentile and 97.5 percentile defined as percents relative to the mean value
[2]Uncertainty in indirect N_2O emissions (activity data and emission factor not separated)

Some uncertainty estimates performed in other counties, i.e. in UK (Charles et al. 1998), in Austria (Winiwarter & Rypdal 2001) in Norway, the Netherlands and the USA (reviewed in Rypdal & Winiwarter 2001) are reviewed in this study. In these, the uncertainty estimates are not divided into as many subcategories as in Finland, and are therefore not reviewed under all sectors.

In the UK uncertainty estimate (Charles et al. 1998) the uncertainties in both activity data and emission factors were estimated by each fuel. In several other uncertainty estimates i.e. Norway, the Netherlands and the USA (Rypdal & Winiwarter 2001) uncertainties in activity data are given for commercial fuel consumption and fuel wood consumption separately, and for the CO_2 emission factor, by fuel type (Rypdal & Winiwarter 2001). These estimates are reviewed in this study under sector Energy Industries. In the Austrian inventory (Winiwarter & Rypdal 2001), uncertainty estimates of activity data were given separately for IPCC source categories 1A1 (Energy Industries) and 1A2 (Manufacturing Industries and Construction).

3.1 Activity Data and CO_2 Emission Factors

3.1.1 Energy Industries (1A1)

The IPCC (Penman et al. 2000) gives an activity data uncertainty estimate of <±1%-5%. These are given both in Chapters 2.1.1.6 (CO_2 emissions) and in Chapter 2.2.1.6 (non-CO_2 emissions) (Penman et al. 2000). In the Finnish inventory, however, the same activity data is used for all greenhouse gases and therefore no gas-specific uncertainty estimate for activity data is given. The IPCC uncertainty estimate in CO_2 emission factor is <±5% (Penman et al. 2000).

3.1.1.1 Liquid Fuels

In the Energy Industries sector, fuel use is considered very well known, because it is based on reliable fuel statistics. The activity data uncertainty in the Finnish 1999 inventory was estimated at ±2% (Aaltonen et al. 2001). In the UK inventory, activity data uncertainty was estimated to be ±1-6% according to liquid fuel type (Charles et al. 1998), and in Austria ±0.5% for oil (Winiwarter & Rypdal 2001). The uncertainty in activity data of all fuel types was estimated at ±1-3% in the Netherlands and ±2-5% in the USA (Rypdal & Winiwarter 2001). In the Norwegian inventory, the uncertainty in oil activity data was assessed to ±3% (Rypdal & Zhang 2000). According to these and IPCC recommendations, the 1999 Finnish uncertainty estimate of activity data is still acceptable, and it is kept unchanged.

The uncertainty in CO_2 emission factor of oil combustion is estimated at ±2% in the UK (Charles et al. 1998), ±3% in Norway and ±2% in the Netherlands and the USA (Rypdal & Winiwarter 2001). In Austria, the uncertainty estimate is ±0.5% for all fuel combustion (Winiwarter & Rypdal 2001). In the 1999 inventory, the Finnish uncertainty estimate was ±2%, and it seems to fit well within the other estimates and the IPCC recommendations, and is therefore kept unchanged.

3.1.1.2 Solid Fuels

In the Energy Industries sector, the activity data (solid fuel use) uncertainty was estimated at ±2% in the Finnish 1999 inventory (Aaltonen et al. 2001). In the UK inventory, coal activity data uncertainty was estimated at ±1.2% (Charles et al. 1998), and in Austria ±0.5% (Winiwarter & Rypdal 2001). The uncertainty in activity data of all fuel types in Energy sector was estimated at ±3-5% in Norway, ±1-3% in the Netherlands and ±2-5% in the USA (Rypdal & Winiwarter 2001). According to these and IPCC Good Practice Guidance (Penman et al. 2000), the 1999 Finnish uncertainty estimate of activity data is still acceptable, and it is kept unchanged.

The uncertainty in CO_2 emission factor of solid fuels is estimated at ±6% in the UK (Charles et al. 1998) and ±0.5% in all fuel combustion in Austria (Winiwarter & Rypdal 2001). For the other countries, estimate is given together for coal, coke and gas, and it is ±7% in Norway, ±1-10% in the Netherlands and ±0-1% in the USA (Rypdal & Winiwarter 2001). In the 1999 inventory, the Finnish uncertainty estimate was ±3% and is kept unchanged because of the good agreement with the estimates done in other countries and in the IPCC Good Practice Guidance (Penman et al. 2000).

3.1.1.3 Gaseous Fuels

In the Energy Industries sector, the activity data (natural gas use) uncertainty was estimated at ±1% in the Finnish 1999 inventory (Aaltonen et al. 2001). In the UK inventory, the uncertainty in natural gas activity data was estimated at ±2% (Charles et al. 1998), and in Austria ±2-5% depending on the gas type (Winiwarter & Rypdal 2001). The uncertainty in activity data of all fuel types in the Energy sector was assessed to ±1-3% in the Netherlands and ±2-5% in the USA (Rypdal & Winiwarter 2001). In the Norwegian inventory, the uncertainty in activity data of gas use was assessed to ±4% (Rypdal & Zhang 2000). According to these, the 1999 Finnish uncertainty estimate of activity data (±1%) seems to be rather low. However, the fuel statistics are very accurate, and energy industries using gaseous fuels are very well known. Therefore the estimate is kept unchanged.

The uncertainty in CO_2 emission factor of natural gas is estimated at ±1% in the UK (Charles et al. 1998) and ±0.5% in all fuel combustion in Austria (Winiwarter & Rypdal 2001). For the other countries, estimate is given together for coal, coke and gas, and it is

±7% in Norway, ±1-10% in the Netherlands and ±0-1% in the USA (Rypdal & Winiwarter 2001). In the 1999 inventory, the Finnish uncertainty estimate was ±1%, and it is kept unchanged.

3.1.1.4 Biomass

In the Energy Industries sector, the activity data uncertainty was estimated at ±20% in the Finnish 1999 inventory (Aaltonen et al. 2001). In Austria the uncertainty in fuelwood activity data was estimated at ±10% (Winiwarter & Rypdal 2001), and in Norway at ±30%. The Finnish 1999 uncertainty estimate fits well between these, and is kept unchanged.

3.1.1.5 Other Fuels

In the Energy Industries sector, the activity data uncertainty of other fuels (mainly peat) was estimated at ±5% in the Finnish 1999 inventory (Aaltonen et al. 2001) and the estimate is kept unchanged. The CO_2 emission factor uncertainty was estimated also at ±5% in the 1999 inventory, and is also kept unchanged.

3.1.2 Manufacturing Industries and Construction (1A2)

IPCC recommendation of activity data uncertainty in the Manufacturing Industries and Construction sector is ±2-3% for energy intensive industries and ±3-5% for other industries. CO_2 emission factor uncertainty is estimated at <±5%.

3.1.2.1 Liquid Fuels

In the Austrian inventory, the uncertainty in activity data of oil used in industry is estimated at ±1% (Winiwarter & Rypdal 2001). In the Finnish 1999 uncertainty estimate the uncertainty in liquid fuel activity data was estimated at ±2% (Aaltonen et al. 2001). This estimate fits well within IPCC Good Practice Guidance (Penman et al. 2000) and estimates done in other countries. Therefore the estimate is kept unchanged. Uncertainty in CO_2 emissions factor was estimated in the 1999 inventory at ±2%, and is also kept unchanged.

3.1.2.2 Solid Fuels

In the Austrian inventory, the uncertainty in activity data of coal used in industry is estimated at ±1% (Winiwarter & Rypdal 2001). The uncertainty in solid fuel activity data was estimated at ±2% in the Finnish 1999 inventory (Aaltonen et al. 2001), and this estimate is also used in the 2001 inventory. The CO_2 emission factor uncertainty of solid fuels in Manufacturing Industries and Construction is estimated at ±3%, which fits well within uncertainties estimated in other countries and by the IPCC. It is the same estimate as given in the 1999 inventory (Aaltonen et al. 2001).

3.1.2.3 Gaseous Fuels

The use of natural gas in Manufacturing Industries and Construction sector is well known in Finland. The estimated uncertainty is ±1% as it was in the 1999 inventory (Aaltonen et al. 2001). In the Austrian inventory, an estimate of ±5% is used (Winiwarter & Rypdal 2001). CO_2 emission factor uncertainty is also estimated at ±1% in Finland, because the composition of natural gas is well known, and the fraction of carbon oxidised is nearly 100% (0.995) (Pipatti 2001).

3.1.2.4 Biomass

Estimated uncertainty in biomass use (activity data) in Manufacturing Industries and Construction Sector is estimated at ±15%, as in the 1999 inventory (Aaltonen et al. 2001). Biomass use is usually not as well known as fossil fuel use, because statistics are not as accurate as in the case of fossil fuels, and the composition of fuel may vary a lot. However, biomass use is estimated to be better known in Manufacturing Industries and Construction Sector than in Energy Industries Sector, because in this sector, the main user of biomass fuel is pulp and paper industry, which gets fuel as a by-product of pulp and paper production.

3.1.2.5 Other Fuels

Uncertainty in Other fuels (mainly peat) activity data and CO_2 emission factor is estimated at ±5%, the same estimate as in the 1999 inventory (Aaltonen et al. 2001).

3.1.3 Other Sectors (1A4)

In this sector, IPCC Good Practice Guidance (Penman et al. 2000) gives an uncertainty estimate of CO_2 activity data of ±3-5% for commercial, residential and institutional combustion. Agriculture/forestry/fisheries is not included in this estimate. In addition to these, biomass combustion in small sources is assumed to contain an uncertainty of ±10-30% in activity data. CO_2 emission factor uncertainty is estimated at <±5% in all subsectors and fuels (Penman et al. 2000).

3.1.3.1 Liquid Fuels

In Finland, Other Sectors (commercial/institutional, residential, agriculture, forestry, fisheries) comprises many small point sources. Though the fuel statistics are very accurate in Finland, the share of fuel used in this sector is quite poorly known. Therefore the uncertainty in liquid fuel activity data is estimated at ±30%, as in the 1999 inventory (Aaltonen et al. 2001). This is a much higher uncertainty than in other countries and the IPCC recommendations, but it reflects the uncertainty in the sectoral shares, not in the total fuel use. However, this estimate should be subjected into further study. CO_2 emission factor uncertainty is assumed to be the same in this sector as in the other energy sectors using liquid fuels, i.e. ±2%.

3.1.3.2 Solid Fuels

The uncertainty in solid fuels activity data in Other Sectors is estimated to be ±10%, as in the 1999 inventory (Aaltonen et al. 2001). Uncertainty associated with CO_2 emission factor is ±5%, which is a higher uncertainty than in Energy Industries and Manufacturing Industries and Construction sectors, mainly because of smaller emission sources, in which combustion can be more incomplete than in big plants.

3.1.3.3 Gaseous Fuels

Gaseous fuels activity data is estimated to be more accurately known than the use of liquid and solid fuels, mainly due to better allocation of gaseous fuel use into subsectors arising from quite a few fuel suppliers. The uncertainty in activity data is the same as in the 1999 inventory, i.e. ±5%. The CO_2 emission factor of gas is very well known because of the high quality of the fuel. Therefore the uncertainty in CO_2 emission factor is ±1%.

3.1.3.4 Biomass

The main user of biomass in Other Sectors is residential sector. The uncertainty in activity data was estimated at ±15% in the 1999 inventory (Aaltonen et al. 2001). According to the IPCC Good Practice Guidance (Penman et al. 2000) the uncertainty in activity data in biomass combustion in small sources is ±10-30%. The Finnish estimate is in accordance with this, and is therefore kept unchanged.

3.1.3.5 Other Fuels

The activity data uncertainty in other fuels was estimated at ±25% in the 1999 inventory (Aaltonen et al. 2001) and this estimate is kept unchanged. Also the CO_2 emission factor is estimated to contain a rather high uncertainty, i.e. ±20%, because of combustion in small point sources. The moisture of peat (and biomass) also varies, thus increasing the variability of emission factor.

3.1.4 Other (1A5)

3.1.4.1 Liquid Fuels

The sector Other comprises mainly the residue of fuel sold, so the activity data in this sector is quite poorly known. The uncertainty in activity data is estimated at ±50%, because liquid fuels are used in a great number of subsectors (i.e. energy production, industries, transport etc). This estimate is the same as in the 1999 inventory (Aaltonen et al. 2001). CO_2 emission factor is estimated to have the same uncertainty as in all sectors using liquid fuels, i.e. ±2%.

3.1.4.2 Gaseous Fuels

The residue of natural gas sold (activity data) has also quite a high uncertainty, i.e. ±20%, but it is, however, better known than e.g. liquid fuels because of smaller number of end-users and fuel suppliers. The CO_2 emission factor uncertainty is the same as in all sectors using gas, i.e. ±1%. These estimates are the same as in the 1999 inventory (Aaltonen et al. 2001).

3.1.4.3 Biomass

Uncertainty in biomass use in Other sector (1A5) is estimated at ±25%, the same uncertainty as in the sector Other Sectors (1A4).

3.2 CH_4 and N_2O Emission Factors (1A1, 1A2, 1A4, 1A5)

The CH_4 and N_2O emission factors are presented here together for all source categories, because in most cases the estimates are the same regardless of source category. The IPCC uncertainty estimate of CH_4 emission factor is ±50-150% and that of N_2O emission factor an order of magnitude (Penman et al. 2000). The other countries reviewed have not split the uncertainty estimate in as many subcategories as is done here.

3.2.1 Liquid Fuels

The uncertainty in CH_4 emissions from combustion (activity data and emission factor together) was estimated at ±50% in UK (Charles et al. 1998) and the same value was used for emission factor in Austria (Winiwarter & Rypdal 2001). In Norway, the emission factor uncertainty was estimated to be lognormally distributed with a 95% confidence interval of -50...+100%, in the Netherlands ±25%, and in the USA an order of magnitude (Rypdal & Winiwarter 2001). In addition, in the Norwegian inventory, the uncertainty in CH_4 emissions factor of Other Sectors is assessed to have a truncated normal distribution with a 95% confidence interval of -50...+100% (Rypdal & Zhang 2000). In the Finnish 1999 uncertainty estimate the uncertainty in liquid fuels CH_4 emission factor was estimated at ±30% (Aaltonen et al. 2001).

Finland uses a country-specific emission factor of 8mg/MJ (Ministry of the Environment 2002) for CH_4 from oil-fired boilers. The IPCC factor is 3mg/MJ, and the measurements show that emission factor could be less than 1 mg/MJ (Korhonen et al. 2001). The number of measurements is low, however, but it seems that Finnish emission factor is far too high. Therefore an uncertainty estimate of -75...+10% is used. Beta distribution is chosen to describe the situation, where the used mean value seems to be too large. This uncertainty estimate has to be considered very preliminary, and more accurate uncertainty estimation should be performed when measurement data is available.

The uncertainty in N_2O emission factor was estimated to be 140% for liquid fuels in the UK (Charles et al. 1998). In the other countries N_2O emission factor uncertainty was estimated to be the same for all sectors and fuel types. The estimated uncertainty was ±20% in Austria (Winiwarter & Rypdal 2001), beta distributed with a 95% confidence interval of –66...+200% in Norway, ±75% in the Netherlands, and –55...+200% in the USA (Rypdal & Winiwarter 2001). In the Finnish 1999 uncertainty estimate the uncertainty in liquid fuels N_2O emission factor was estimated at ±50% (Aaltonen et al. 2001).

In the case of N_2O, Finland uses a country specific emission factor of 2mg/MJ (Ministry of the Environment 2002). IPCC emission factor is 0.6mg/MJ, and according to measurement data the emission factor could be less than 1mg/MJ. Therefore a preliminary uncertainty estimate of -75...+10% is used.

3.2.2 Solid Fuels

In Norway, the uncertainty in CH_4 emission factor was assessed to -50...+100% lognormally distributed (Rypdal & Zhang 2000). In the Finnish 1999 uncertainty estimate the uncertainty in CH_4 emission factor was ±30% (Aaltonen et al. 2001).

In the case of coal fired boilers, a national CH_4 emission factor 4-5 mg/MJ is used depending on the combustion technology (Ministry of the Environment 2002). The IPCC emission factor is 1mg/MJ, and the measurements done with a pulverised coal firing boiler (PC-boiler) result in an emission factor of less than 1mg/MJ (Korhonen et al. 2001). A preliminary uncertainty estimate of -75...+10% for CH_4 emission factor is used based on these.

The uncertainty in N_2O emission factor was estimated to be 195% for coal in the UK (Charles et al. 1998). In the Finnish 1999 uncertainty estimate the uncertainty in solid fuels N_2O emission factor was estimated at ±50% (Aaltonen et al. 2001).

N_2O emission factor used in Finland is 2mg/MJ in the case of burners and pressurised fluidised beds (Ministry of the Environment 2002). This emission factor is exactly the same as the measurement results of pulverised coal firing boilers (PC-boilers). The IPCC emission factor is slightly lower, namely 1.4mg/MJ (Korhonen et al. 2001). However, bubbling fluidised beds, as well as cycling fluidised beds result in far higher N_2O emissions. A national emission factor of 70mg/MJ is used for them (Ministry of the Environment 2002). Combustion technology has a great effect on N_2O emissions. Coal combustion is not divided into subcategories according to combustion technology in this uncertainty analysis (it is, however, divided in subcategories in the original calculation). Therefore, an uncertainty estimate of ±50% is used according to expert judgement of Kari Grönfors from statistics Finland.

3.2.3 Gaseous Fuels

In Finland, a national CH_4 emission factor of 3mg/MJ is used for gas-fired boilers, gas turbine plants and gas turbines with combined cycle (Ministry of the Environment 2002). The IPCC emission factor is 1mg/MJ, and measurements show that the emission factor could be less than 1mg/MJ in normal process conditions (higher emissions occurred in the case of problems with a supplementary firing system) (Korhonen et al. 2001). More measurement data is, however, needed to give a reliable uncertainty estimate, but a preliminary estimate of -75...+10% is used based on above mentioned results. The uncertainty in N_2O emission factor was estimated to be 110% for natural gas in the UK (Charles et al. 1998).

A national N_2O emission factor of 1mg/MJ is used in Finland (Ministry of Environment 2002). This is ten times higher than the IPCC emission factor, and no accurate measurement data is available. Therefore an uncertainty estimate of ±50% is used based on expert judgement of Kari Grönfors.

3.2.4 Biomass

In Norway, the uncertainty in CH_4 emission factor of wood combustion was assessed to -50...+100% lognormally distributed (Rypdal & Zhang 2000). In the Finnish 1999 uncertainty estimate the uncertainty in CH_4 emission factor was estimated at ±50% for large point sources and ±100% for other sources.

Finland has different national emission factors for different biomass types and combustion technologies. CH_4 emission factor used varies between 4-50mg/MJ. According to measurements, the emission factors is <1-72 mg/MJ depending on process conditions, fuel type and combustion technology. Because the uncertainty estimate is not divided into technology level, though the technologies have a great effect on emissions and uncertainty, the uncertainty estimate is based entirely on expert judgement of Kari Grönfors. The estimated uncertainty is ±50% in big plants (Energy Industries and Manufacturing Industries and Construction sectors), and -70...+150% in small plants (Other Sectors).

N_2O emission factors depend even more on combustion technology than CH_4 emission factors. The national emission factors used vary between 1-30mg/MJ. The measurement data shows far lower emissions, namely <2-10mg/MJ. However, the uncertainty range depends on technology, and measurements do not cover all possible technologies, process conditions and fuels. Therefore the uncertainty is estimated at –70...+150%

based on expert judgement of Kari Grönfors. This estimate might, however, overestimate the uncertainty in the upper bound.

3.2.5 Other Fuels

In Finland, national emission factors for peat are used for different combustion technologies. CH_4 emission factors vary between 2-7mg/MJ (Ministry of the Environment 2002). According to measurements, the emission factor is <1-3mg/MJ. According to expert judgement of Kari Grönfors, the uncertainty in emission factors is ±50%. This estimate is used, because a more sophisticated uncertainty estimate would need the dividing of emission sources into smaller subcategories according to combustion technology.

National N_2O emission factors vary between 2-30 mg/MJ (Ministry of the Environment 2002). According to measurements, the emission factor is <1-26mg/MJ (Korhonen et al. 2001). Emission factors fit well between the measurement results, but due to the lack of technology-specific knowledge, the uncertainty estimate is based on expert judgement of Kari Grönfors (-70...+150%).

3.3 Indirect N_2O from Fuel Combustion

Indirect N_2O emissions from fuel combustion occur, when NO_x (NO_2 and NO_3) molecules turn into N_2O in the atmosphere. In the Finnish inventory, indirect N_2O emissions are estimated separately from direct N_2O emissions to keep the N_2O emission factors comparable with countries where indirect N_2O emissions are not estimated at all. This source category, "Indirect N_2O emissions from fuel combustion", is reported in the Finnish uncertainty analysis under the IPCC source category 1A (Fuel Combustion), and was identified as a key source in the Finnish 1999 inventory.

When estimating indirect N_2O emissions, NO_x emissions are multiplied with a coefficient that describes the formation of N_2O from NO_x in the atmosphere. The factor is defined as an emission factor for N_2O from atmospheric deposition of nitrogen. Though the coefficient is defined for agricultural emissions, the factor can be assumed to be the same for NO_x formed in fuel combustion.

Estimation of uncertainty in indirect N_2O from fuel combustion contains three different types of uncertain components: activity data, NO_x emission factor and the conversion coefficient from NO_x to N_2O. Uncertainty in activity data is the same as in assessing uncertainty for direct greenhouse gas emissions (in navigation, an uncertainty of ±15%

is used instead of dividing it into subcategories), but here, all combustion from stationary sources (i.e. Energy Industries, Manufacturing Industries and Construction, Other Sectors and Other) are calculated together. The average emission factor for NO_x is obtained by dividing the total NO_x emissions by the total energy use of stationary combustion. The uncertainty of NO_x emissions from stationary sources is estimated to be ±15% (Syri et al. 2000; Suutari et al. 2001). NO_x emission measurements have been conducted in Finland, and results from these studies could be taken into account in the future to obtain a more reliable uncertainty estimate.

For mobile combustion, the assumed uncertainties in NO_x emission factor have been taken from Rypdal (2002) in all cases except in railway traffic, where accurate measurement data was available, because measurements of NO_x emissions from locomotive diesel engines were performed in 1999 (Korhonen & Määttänen 1999). In the future, better estimates could also be done for other mobile sources, because also in other mobile sources some measurements of NO_x emissions have been done. The used uncertainty ranges are presented in Table 2. These estimates seem quite high, when compared, for example, with Syri et al. (2000), who estimated an uncertainty of ±15% for all country-specific NO_x emission.

The uncertainty estimate of conversion coefficient is the same as in the agricultural sector for emission factor of atmospheric deposition of NO_x and NH_4, namely -80...+100% (see chapter 7.4).

Table 2. Uncertainties in NO_x emission factors.

NO_x Emission Source	**Uncertainty[1]**	**Distribution**	**Source**
Stationary combustion	± 15%	normal	Syri et al. 2000; Suutari et al. 2001
Road transportation	± 30%	normal	Rypdal 2002
Waterborne navigation	± 15%	normal	Rypdal 2002
Aircraft	± 20%	normal	Rypdal 2002
Off-road machinery	± 30% [2]	normal	Rypdal 2002
Railways	-40...+49%	Weibull	[3]

[1] defined as upper and lower bounds of 95% confidence interval expressed as percents relative to the mean value
[2] for off-road machinery, uncertainty estimate of road transportation has been used because of the similarity of combustion conditions
[3] based on Korhonen & Määttänen (1999)

The resulting uncertainty in indirect N_2O-emissions was calculated using Monte Carlo simulation (15 000 simulations), and 10 most common continuous distributions were fitted to resulting data using Crystal Ball simulation tool (Decisioneering 2000). Best fitting distribution was gamma distribution with a 95% confidence interval of -79...+100% and a scale parameter of 0.1. It can be seen that the uncertainty in conversion coefficient dominates the total uncertainty. Therefore the improvement of uncertainty estimates of other parameters would not affect results notably.

3.4 Differences between this study, the 1999 uncertainty estimates and the IPCC estimates

In Table 3, uncertainty estimates are compared with uncertainty estimates done in the 1999 inventory (Aaltonen et al. 2001) and with IPCC recommendations.

Table 3. Comparison of estimates with the 1999 inventory estimates and IPCC estimates for Stationary Combustion sector.

Input	IPCC category	1999 estimate[1]	2001 estimate	IPCC[2]
Activity Data				
Energy Industries				
Liquid Fuels	1A1	±2%	normal ±2%	< ±1 – 5%[3]
Solid Fuels	1A1	±2%	normal ±2%	< ±1 – 5%[3]
Gaseous Fuels	1A1	±1%	normal ±1%	< ±1 – 5%[3]
Biomass	1A1	±20%	normal ±20%	< ±1 – 5%[3]
Other Fuels	1A1	±5%	normal ±5%	< ±1 – 5%[3]
Manufacturing Industries and Construction				
Liquid Fuels	1A2	±2%	normal ±2%	±2 – 5%[4]
Solid Fuels	1A2	±2%	normal ±2%	±2 – 5%[4]
Gaseous Fuels	1A2	±1%	normal ±1%	±2 – 5%[4]
Biomass	1A2	±15%	normal ±15%	±2 – 5%[4]
Other Fuels	1A2	±5%	normal ±5%	±2 – 5%[4]
Other Sectors				
Liquid Fuels	1A4	±30%	normal ±30%	±3 – 5%[5]
Solid Fuels	1A4	±10%	normal ±10%	±3 – 5%[5]
Gaseous Fuels	1A4	±5%	normal ±5%	±3 – 5%[5]
Biomass	1A4	±15%	normal ±15%	±3 – 30%[6]
Other Fuels	1A4	±25%	normal ±25%	±3 – 30%[6]
Other				
Liquid Fuels	1A5	±50%	normal ±50%	-
Gaseous Fuels	1A5	±20%	normal ±20%	-
Biomass	1A5	-	normal ±25%	±3 – 30%[6]
Other Fuels	1A5	-	normal ±25%	±3 – 30%[6]
Emission Factors				
Energy Industries				
Liquid Fuels (CO_2)	1A1	± 2%	normal ±2%	< ±5%
Liquid Fuels (CH_4)	1A1	± 30%	beta -75...+10%	±50 – 150%
Liquid Fuels (N_2O)	1A1	± 50%	beta -75...+10%	order of magnitude
Solid Fuels (CO_2)	1A1	± 3%	normal ± 3%	< ±5%
Solid Fuels (CH_4)	1A1	± 30%	beta -75...+10%	±50 – 150%
Solid Fuels (N_2O)	1A1	± 50%	normal ±50%	order of magnitude
Gaseous Fuels (CO_2)	1A1	± 1%	normal ±1%	< ±5%
Gaseous Fuels (CH_4)	1A1	± 30%	beta -75...+10%	±50 – 150%
Gaseous Fuels (N_2O)	1A1	± 50%	normal ±50%	order of magnitude
Biomass (CH_4)	1A1	± 50%	normal ±50%	±50 – 150%
Biomass (N_2O)	1A1	± 100%	lognormal -70...+150%	order of magnitude
Other Fuels (CO_2)	1A1	± 5%	normal ±5%	< ±5%
Other Fuels (CH_4)	1A1	± 50%	normal ±50%	±50 – 150%
Other Fuels (N_2O)	1A1	± 100%	lognormal -70...+150%	order of magnitude

Manufacturing Industries and Construction				
Liquid Fuels (CO_2)	1A2	± 2%	normal ±2%	< ± 5%
Liquid Fuels (CH_4)	1A2	± 30%	beta -75...+10%	± 50 – 150%
Liquid Fuels (N_2O)	1A2	± 50%	beta -75...+10%	order of magnitude
Solid Fuels (CO_2)	1A2	± 3%	normal ±3%	< ±5%
Solid Fuels (CH_4)	1A2	± 30%	beta -75...+10%	±50 – 150%
Solid Fuels (N_2O)	1A2	± 50%	normal ±50%	order of magnitude
Gaseous Fuels (CO_2)	1A2	± 1%	normal ±1%	< ±5%
Gaseous Fuels (CH_4)	1A2	± 30%	beta -75...+10%	±50 – 150%
Gaseous Fuels (N_2O)	1A2	± 50%	normal ±50%	order of magnitude
Biomass (CH_4)	1A2	± 50%	normal ±50%	±50 – 150%
Biomass (N_2O)	1A2	± 100%	lognormal -70...+150%	order of magnitude
Other Fuels (CO_2)	1A2	± 5%	normal ±5%	< ±5%
Other Fuels (CH_4)	1A2	± 50%	normal ±50%	±50 – 150%
Other Fuels (N_2O)	1A2	± 100%	lognormal -70...+150%	order of magnitude
Other Sectors				
Liquid Fuels (CO_2)	1A4	± 2%	normal ±2%	< ±5%
Liquid Fuels (CH_4)	1A4	± 30%	beta -75...+10%	±50 – 150%[5]
Liquid Fuels (N_2O)	1A4	± 50%	beta -75...+10%	order of magnitude[5]
Solid Fuels (CO_2)	1A4	± 5%	normal ± 5%	< ±5%
Solid Fuels (CH_4)	1A4	± 30%	beta -75...+10%	±50 – 150%[5]
Solid Fuels (N_2O)	1A4	-	normal ±50%	order of magnitude[5]
Gaseous Fuels (CO_2)	1A4	± 1%	normal ±1%	< ±5%
Gaseous Fuels (CH_4)	1A4	± 30%	beta -75...+10%	±50 – 150%[5]
Gaseous Fuels (N_2O)	1A4	± 50%	normal ±50%	order of magnitude[5]
Biomass (CH_4)	1A4	± 100%	lognormal -70...+150%	±50 – 150%[5]
Biomass (N_2O)	1A4	± 100%	lognormal -70...+150%	order of magnitude[5]
Other Fuels (CO_2)	1A4	± 20%	normal ±20%	< ±5%
Other Fuels (CH_4)	1A4	± 50%	normal ±50%	±50 – 150%[5]
Other Fuels (N_2O)	1A4	± 100%	lognormal -70...+150	order of magnitude[5]
Other				
Liquid Fuels (CO_2)	1A5	± 2%	normal ±2%	< ±5%
Liquid Fuels (CH_4)	1A5	± 30%	beta -75...+10%	-
Liquid Fuels (N_2O)	1A5	± 50%	beta -75...+10%	-
Gaseous Fuels (CO_2)	1A5	± 1%	normal ±1%	< ±5%
Gaseous Fuels (CH_4)	1A5	± 30%	beta -75...+10%	-
Gaseous Fuels (N_2O)	1A5	± 50%	normal ±50%	-
Biomass (CH_4)	1A5	-	lognormal -70...+150%	-
Biomass (N_2O)	1A5	-	lognormal -70...+150%	-
Indirect N_2O from fuel combustion[7]	-	± 153%	gamma -79...+100%	see text

[1](Aaltonen et al. 2001). All uncertainties are assumed normally distributed
[2](Penman et al. 2000). Sectoral uncertainties, not divided into fuel-specific level
[3]Range of uncertainty estimates in Chapters 2.1.1.6 and 2.2.1.6 in (Penman et al. 2000)
[4]The IPCC (Penman et al. 2000) gives an uncertainty of ±2-3% for energy intensive industries and ±3-5% for other industries.
[5]Only for commercial, institutional and residential combustion, not for agriculture/forestry/fisheries
[6]The IPCC recommends activity data uncertainty for biomass in small sources ±10-30%
[7]Uncertainty in indirect emissions, not divided to activity data and emission factor. In 1999 (Aaltonen et al. 2001) uncertainties were estimated at ±30% for activity data and ±150% for emission factor.

4. Transport (1A3)

CO_2 calculation in the transport sector is based on activity data (fuel consumed) and emission factor. Calculation of CH_4 and N_2O emissions from road transportation is based on vehicle mileage driven with different vehicle types and different road types. Emission factors are defined as emissions per mileage driven (g/km). Activity data for waterborne navigation is based on port traffic service data and for railway traffic on traffic service data of each railway section and marshalling yard. Civil aviation activity data is also based on traffic statistics. Activity data of the sector “other off-road machinery” is based on the estimated work (kWh) done (Pipatti 2001; Mäkelä et al. 2001a; Mäkelä et al. 2001b; Mäkelä et al. 2001c; Mäkelä et al. 2000). In the end, CH_4 and N_2O emissions are fitted to correspond with fuel consumption. Because of this, activity data of CH_4 and N_2O emissions can be assumed to be as well know as that of CO_2.

Uncertainty estimates of the 1999 inventory were based mainly on expert judgement of Kari Grönfors from Statistics Finland. In this study, uncertainty estimates are based on interviews of National Experts Juhani Laurikko from VTT Technical Research Centre of Finland (emission factors), Kari S. Mäkelä from VTT Technical Research Centre of Finland (activity data), and Kari Grönfors. Available domestic and international literature of emission measurements was also used (Becker et al. 1999; Egebäck & Bertilson 1983; Korhonen & Määttänen 1999; Perby 1990; Potter 1990; Pringent & de Soete 1989; Sjöberg et al. 1989; Tarantola & Kioutsioukis 2001). The estimates and their bases are presented in Table 4. Most of the uncertainty estimates of activity data and CO_2 emission factors have not been changed. All uncertainties, which were assumed in the 1999 inventory as >±60%, have now assumed to have an asymmetrical distribution. Especially all uncertainties which were assumed normally distributed with a 95% confidence interval of ±100% are now assumed to be lognormally distributed with a 95% confidence interval of -70...+150% in the cases of lack of advanced knowledge. Uncertainties are assumed to be the same in the reference year 1990 as in the inventory year 2001.

Table 4. Estimated uncertainty distributions, their 95 % confidence intervals and bases of estimates for Transport sector.

Input	IPCC category	Distribution	95 % confidence interval [1]	Basis
Activity Data				
Civil Aviation	1A3a	normal	±5%	expert judgement
Road Transportation (gasoline)	1A3b	normal	±1%	expert judgement
Road Transportation (diesel)	1A3b	normal	±1%	expert judgement
Road Transportation (natural gas)	1A3b	normal	±1%	expert judgement

Railways	1A3c	normal	±5%	expert judgement
Navigation (residual oil, gas/diesel oil)	1A3d	normal	±10%	expert judgement
Navigation (other fuels)	1A3d	normal	±20%	expert judgement
Other Transportation (gasoline)	1A3e	normal	±30%	expert judgement
Other Transportation (diesel)	1A3e	normal	±30%	expert judgement
Emission Factor				
Civil Aviation CO_2	1A3a	normal	±2%	expert judgement
Civil Aviation CH_4	1A3a	lognormal	-57...+100%	Penman et al. 2000
Civil Aviation N_2O	1A3a	lognormal	-70...+150%	expert judgement
Road Transportation CO_2 (gasoline)	1A3b	normal	±2%	expert judgement
Road Transportation CO_2 (diesel)	1A3b	normal	±2%	expert judgement
Road Transportation CO_2 (natural gas)	1A3b	normal	±2%	expert judgement
Road Transportation CH_4 (gasoline)	1A3b	normal	±50%	Tarantola & Kioutsioukis 2001
Road Transportation CH_4 (diesel)	1A3b	normal	±50%	Tarantola & Kioutsioukis 2001
Road Transportation CH_4 (natural gas)	1A3b	normal	±50%	Tarantola & Kioutsioukis 2001
Road Transportation N_2O (gasoline) cars with catalytic converters	1A3b	lognormal	-70...+150%	Pringent & De Soete 1989; Potter 1990; Becker et al. 1999; Perby 1990; Egebäck & Bertilson 1983
Road Transportation N_2O (gasoline) cars without catalytic converters	1A3b	gamma (shape 1.66)	-82...+179%	Perby 1990; Pringent & De Soete 1989; Egebäck & Bertilson 1983
Road Transportation N_2O (diesel)	1A3b	lognormal	-80...+200%	Pringent & De Soete 1989; Sjöberg et al. 1989; Becker et al. 1999
Road Transportation N_2O (natural gas)	1A3b	lognormal	-70...+150%	expert judgement
Railways CO_2	1A3c	normal	±2%	Korhonen & Määttänen 1999
Railways CH_4	1A3c	lognormal	-60...+110%	Korhonen & Määttänen 1999
Railways N_2O	1A3c	lognormal	-70...+150%	expert judgement
Navigation CO_2 (residual oil, gas/diesel oil)	1A3d	normal	±2%	expert judgement
Navigation CO_2 (other fuels)	1A3d	normal	±2%	expert judgement
Navigation CH_4 (residual oil, gas/diesel oil)	1A3d	lognormal	-57...+100%	Penman et al 2000
Navigation CH_4 (other fuels)	1A3d	lognormal	-57...+100%	Penman et al 2000
Navigation N_2O (other fuels)	1A3d	lognormal	-70...+150%	expert judgement
Navigation N_2O (residual oil, gas/diesel oil)	1A3d	lognormal	-70...+150%	expert judgement
Other Transportation CO_2 (gasoline)	1A3e	normal	±2%	expert judgement
Other Transportation CO_2 (diesel)	1A3e	normal	±2%	expert judgement
Other Transportation CH_4 (gasoline)	1A3e	normal	±50%	expert judgement

Other Transportation CH_4 (diesel)	1A3e	normal	±50%	expert judgement
Other Transportation N_2O (diesel)	1A3e	neg skew Gumbel	-90...+55%	see text
Other Transportation N_2O (gasoline)	1A3e	lognormal	-70...+150%	expert judgement

[1] Expressed as 2.5 percentile and 97.5 percentile defined as percents relative to the mean value

4.1 Civil Aviation (1A3a)

In civil aviation, there are two fuel types used in Finland: jet kerosene and gasoline. They are treated together in this uncertainty analysis, because activity data and emission factors are equally well known for both fuels. Activity data for civil aviation is quite well known, because of accurate traffic and fuel statistics. Uncertainty in activity data is assumed to be ±5%. This is the same uncertainty as estimated in the 1999 inventory (Aaltonen et al. 2001) by Kari Grönfors from Statistics Finland, and it fits well within the IPCC Good Practice Guidance (Penman et al. 2000).

In the 1999 inventory, uncertainty in CO_2 emission factor was assumed to be ±2%. The estimate was done by Kari Grönfors from Statistics Finland, and is based on the good knowledge of fuel composition in Finland. The estimate is assumed to be the same in the 2001 inventory. This estimate is slightly smaller than in the IPCC Good Practice Guidance which gives an uncertainty of ±5% (Penman et al. 2000). National Expert Niina Rusko from CAA Finland was also asked for judgement, and she was satisfied with the estimates of activity data and CO_2 emission factor uncertainties (Rusko 2002).

In the 1999 inventory, uncertainty in CH_4 emission factor was assumed to be ±50%. In the IPCC Good Practice Guidance (Penman et al. 2000) the uncertainty is estimated to be of factor of two. Because of lack of measurement data, the uncertainty is now estimated at -57...+100% with a lognormal distribution.

In the 1999 inventory, N_2O emission factor from civil aviation was assumed to be ±100%. Because Monte Carlo simulation enables the use of asymmetrical distributions, the uncertainty is assumed to be lognormally distributed with a 95% confidence interval of -70...150%. In the IPCC Good Practice Guidance, the uncertainty in emission factor is assumed to be order of magnitude or several magnitudes (Penman et al. 2000).

4.2 Road Transportation (1A3b)

In the case of road transportation there are three fuel types used in Finland: gasoline, diesel oil and natural gas. All these are treated as separate subcategories. In addition to that, N_2O emissions from cars with and without catalytic converters are treated separately, because also the knowledge of emission factors is different.

In the UK, activity data uncertainty in road transportation is estimated at ±0.8% for gasoline and ±1.4% for diesel (Charles et al. 1998). In the Finnish 1999 inventory, uncertainty was estimated to be ±1%, and this estimate is kept unchanged also in this study. Division into subcategories is not assumed to increase uncertainty, because activity data are assumed to be 100% correlated, so uncertainties in allocating emissions to different categories do not affect emissions in the upper level.

In the UK inventory, the CO_2 emission factor uncertainty is estimated to be ±2% (Charles et al. 1998). Similar estimate was used also in the Finnish 1999 inventory (Aaltonen et al. 2001) and this estimate is kept unchanged for all fuel types. The quality of fuel (i.e. density and carbon content) affects the uncertainty of the emission factor. Suitability of ±2% uncertainty estimate to Finnish conditions was checked from National Expert Aimo Rautiola (Rautiola 2002) from Fortum Oil and Gas, which is the most important oil refinery company in Finland. The IPCC recommends a ±5% overall uncertainty estimate for CO_2 emissions of transportation (Penman et al. 2000).

In the ARTEMIS project (Tarantola & Kioutsioukis 2001), sensitivity ranges of the emissions of volatile organic compounds were modelled. In “Country test case: Italy” for the year 1990 variation was -55...+66%, for 2000 -56...+84% and in “Frejust tunnel case” variation was -19...+25%. Variation of these emissions can be used to approximate the variation of methane emissions. In the IPCC Good Practice Guidance (Penman et al. 2000) uncertainty in CH_4 emissions from transportation is estimated at ±40%. In the Finnish 1999 inventory the uncertainty in methane emission factor was estimated to be ±50%. This fits quite well within the results of the ARTEMIS project and the IPCC estimate, so the estimate is kept unchanged for all fuel types.

To estimate uncertainties in N_2O emissions from road transportation, especially to differentiate between emission factors from cars with and without catalytic converter, several studies were reviewed. According to the IPCC Good Practice Guidance, uncertainty in N_2O emissions from transportation is >±50% (Penman et al. 2000). In Austria, triangular distribution (–70...+170 %) is assumed for N_2O emission factor (Winiwarter & Rypdal 2001), and in UK the estimated uncertainty is 170% in the upper bound (Charles et al. 1998).

In the ARTEMIS Project, also NO_x emissions were studied. Variation in “Country Test case: Italy” for 1990 was -32...+33 %, for 2000 -40...+42 % and for “Frejus Tunnel Case” -10...+9% (Tarantola & Kioutsioukis 2001). These results show quite a small variance compared with the uncertainty estimates. However, there is not clear evidence of the link between variation of NO_x and N_2O emissions.

The N_2O emission factors for road transportation used in the Finnish inventory are the same as used in Atmospheric Emission Inventory Guidebook (EMEP 1999). This publication is based on the review of available studies. Most of the studies reviewed in the Atmospheric Emission Inventory Guidebook were analysed also in this study to estimate the uncertainty of the N_2O emission factor. Results from some of these studies were referred in (Perby 1990), i.e. results from (Pringent & de Soete 1989), (Potter 1990), (Sjöberg et al. 1989) and (Egebäck & Bertilsson 1983). In addition, results from Becker et al. (1999) were also reviewed in this study. Results from these six measurement studies were divided into three categories: diesel vehicles and gasoline vehicles with and without catalytic converters. Data points (emission factors mg/km) from these studies were plotted, and a probabilistic distribution was fitted to data. The studies cannot, however, be considered independent. For example, Perby (1990) has based on the other studies, and when plotting data, some studies have not been taken into account because of their clearly too high results. Weighting of data points from different studies is also difficult because of lack of original measurement data (most studies were reported as maximum and minimum values). An example of the variation in measurement data is presented in Figure 10.

For cars with catalytic converters the resulting distribution was normal distribution with 95% confidence interval ±107% and with the same mean value as the one used in the inventory. Therefore, the chosen uncertainty distribution for this study is lognormal distribution (-70...+150%), because normal distribution is not suitable for large uncertainties. For cars without catalytic converters, the resulting distribution was gamma distribution –35...+70% with a shape parameter of 2.12. However, the mean value of this distribution was 8.3 mg/km, whereas the emission factor used in the Finnish inventory is 5 mg/km. This is taken into account by choosing an uncertainty distribution with mean value 5 and same 97.5%-tile as in the resulting distribution. The chosen distribution is gamma distribution with a shape parameter of 1.66 and a 95% confidence interval of -82...179 %. For diesel engines, only results for passenger cars were used, and the resulting distribution was normal distribution with a mean value of 27 mg/km and a 95% confidence interval of ±143 %. The emission factor used in emission estimates is 10 mg/km. The number of measurements is very small, and the emission factor seems to be highly uncertain. The uncertainty distribution chosen is lognormal with a 95% confidence interval of -80...+200%. For cars using natural gas the estimated uncertainty distribution is lognormal with a 95% confidence interval of -70...+150%, based on expert judgement, because no measurement data was available.

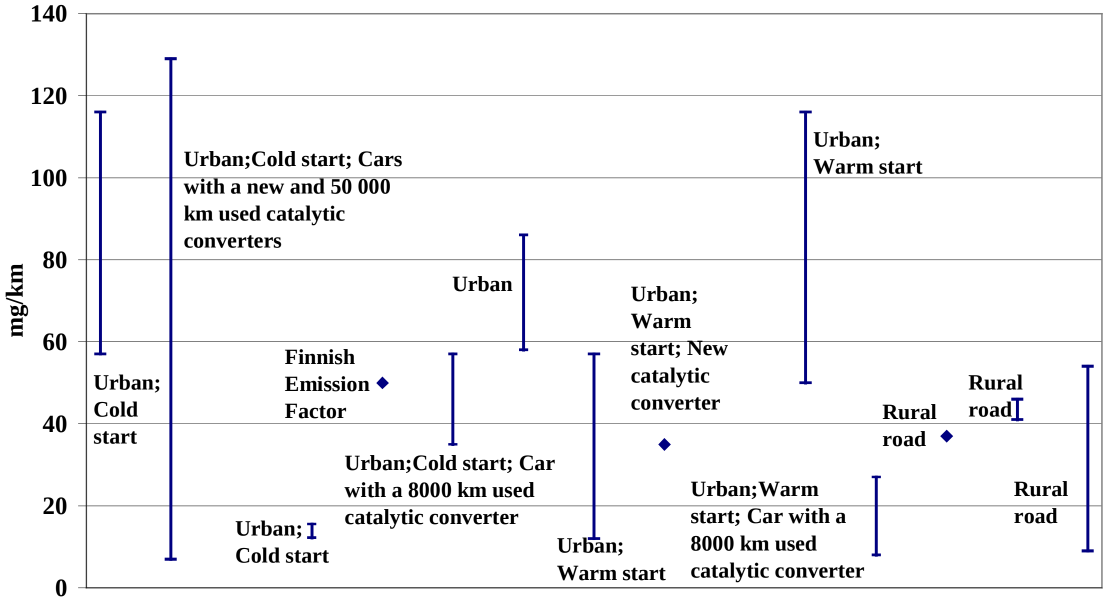

Figure 10. Measurement results of N_2O emission factors [mg/km] of cars with catalytic converters in different studies (Potter 1990; Pringent & de Soete 1989; Becker et al, 1999; Perby 1990; Egebäck & Bertilsson, 1983) and the emission factor used in the Finnish inventory.

4.3 Railways (1A3c)

In Finland, all non-electric locomotives use diesel oil as a fuel. Activity data uncertainty was estimated at ±5% in the 1999 inventory (Aaltonen et al. 2001), and this estimate is kept unchanged. In the 1999 measurements of emissions from diesel locomotives were performed in Kymenlaakso Polytechnic as a part of MOBILE program. The aim of the measurements was to determine specific emissions of locomotive diesel engines. For this work, the measurement data from the report of that study (Korhonen & Määttänen 1999) was used, and probabilistic distributions were fitted to the results. For the CO_2 emission factor, the spread of emission factor (g/kg fuel) was ±0.06%. The measurement results do not include the variation in fuel quality. Therefore, the uncertainty estimate used in the 1999 inventory, ±2%, is used also in this study.

Methane emissions were not measured separately, but instead total hydrocarbon emissions were measured in the MOBILE project. The spread of emission factors (g/kg fuel) was -87...+111% Weibull distributed. The uncertainty estimate used in previous estimate (±50%) seems to be too optimistic. A lognormal distribution with a 95%

confidence interval of -60...110 % was chosen to describe the uncertainty in methane emissions.

In the study performed in the Kymenlaakso Polytechnic, also NO_x emissions were measured. The spread in data (g/kg fuel) was Weibull distributed with a 95% confidence interval of -44...+49 %. But there is lack of evidence of the link between the correlation of NO_x emissions and N_2O emissions, though they can in some cases be estimated to behave quite similarly. Because of lack of better knowledge, an estimate of lognormally distributed uncertainty (-70...+150 %), which is used also in cases of several other diesel engine emissions, is assumed to be valid also for the locomotive emission factor.

4.4 Navigation (1A3d)

In Finland, fuels used in waterborne navigation are residual oil, gas/diesel oil and gasoline. Gasoline use is reported under sector Other fuels and it is used mainly by leisure boats. The share of sold gasoline used in boats is quite poorly known due to lack of statistics. For this reason, waterborne navigation is divided into two subcategories: one concerning residual oil and gas/diesel oil and the other concerning other fuels (i.e. gasoline). This is done for two reasons: firstly, the uncertainties in these two sectors are different, and secondly, gasoline used in leisure boats can be correlated with gasoline used in e.g. road traffic. In the 1999 inventory, uncertainty in total activity data of navigation was assumed to be ±10% (Aaltonen et al. 2001), which seems a too low uncertainty for gasoline. Now activity data uncertainty is estimated at ±10% in fuels other than gasoline and ±20% in gasoline.

In the 1999 uncertainty estimate, the uncertainty in CO_2 emission factor was estimated at ±2%, and this estimate is kept unchanged also in this study. This estimate is slightly less than the IPCC (Penman et al. 2000) estimate ±5%. The Good Practice Guidance gives an uncertainty estimate for N_2O emission factor as an order of magnitude, and for the CH_4 emission factor, an uncertainty of a factor of two. Estimated uncertainties in the Finnish inventory are lognormally distributed -57...+100% for methane emission factor and -70...+150 % for nitrous oxide emission factor, based on expert judgement.

4.5 Other Transportation (1A3e)

Other Transportation in the Finnish Greenhouse Gas Inventories comprises off-road machinery using both gasoline and gas oil (diesel engines). Off-road machinery is divided into two subcategories according to fuel used for two reasons: uncertainty in N_2O emission factor is significantly different, and dividing into subcategories allows the use of correlation with other sources using same fuels. In the 1999 inventory, uncertainty in total activity data was estimated at ±30%. In this study, activity data uncertainty is estimated to be ±30% for both gas oil and gasoline use. The CO_2 emission factor uncertainty estimate is also kept unchanged, i.e., ±2%. Uncertainty associated with methane emission factor is assumed to be the same as in road traffic (and as in 1999 inventory), ±50%. For N_2O emission factor of off-road machinery using gasoline, the uncertainty assumed is -70...+150 % lognormally distributed.

The N_2O emission factor used for diesel engines of off-road machinery is ten times higher than usually used in transportation. Also a small number of measurements done in Finland indicate that the emission factor used is too high (Pipatti 2001). Based on this information, the uncertainty associated with diesel engine N_2O emission factors in off-road machinery is described with a negatively skewed Gumbel distribution with a 95% confidence interval of -90...+55 %.

4.6 Differences between this study, the 1999 uncertainty estimates and the IPCC estimates

The changes of estimates compared with the 1999 estimates are presented in Table 5. In page 2.49 in Penman et al. (2000) it is said that uncertainty in emissions of transportation sector is ±5% in the case of CO_2, ±40% in the case of CH_4 and >±50% in the case of N_2O. More detailed uncertainty estimates are also given for some subsectors, and they are presented in the table below.

Table 5. Comparison of estimates with the 1999 inventory estimates and the IPCC estimates for Transport sector.

Input	IPCC Category	1999 estimate[1]	2001 estimate	IPCC [2]
Activity Data				
Civil Aviation	1A3a	± 5%	normal ±5%	< ±5%
Road Traffic (gasoline)	1A3b	±1%	normal ±1%	-
Road Traffic (diesel)	1A3b	±1%[3]	normal ±1%	-
Road Traffic (natural gas)	1A3b	±1%[3]	normal ±1%	-
Railways	1A3c	±5%	normal ±5%	-
Navigation (residual oil, gas/diesel oil)	1A3d	±10%	normal ±10%	-
Navigation (other fuels)	1A3d	±10%[3]	normal ±20%	-
Other Transportation (gasoline)	1A3e	±30%	normal ±30%	-
Other Transportation (diesel)	1A3e	±30%[3]	normal ±30%	-
Emission Factors				
Civil Aviation CO_2	1A3a	±2%	normal ±2%	±5%
Civil Aviation CH_4	1A3a	±50%	lognorm -57...+100%	factor of 2
Civil Aviation N_2O	1A3a	±100%	lognorm -70...+150%	factor of 10, 100 or more

Road Traffic CO_2 (gasoline)	1A3b	±2%	normal ±2%	-
Road Traffic CO_2 (diesel)	1A3b	±2%[3]	normal ±2%	-
Road Traffic CO_2 (natural gas)	1A3b	±2%[3]	normal ±2%	-
Road Traffic CH_4 (gasoline)	1A3b	±50%	normal ±50%	-
Road Traffic CH_4 (diesel)	1A3b	±50%[3]	normal ±50%	-
Road Traffic CH_4 (natural gas)	1A3b	±50%[3]	normal ±50%	-
Road Traffic N_2O (gasoline) cars with catalytic converters	1A3b	±100%	lognorm -70...+150%	-
Road Traffic N_2O (gasoline) cars without catalytic converters	1A3b	±100%[3]	gamma -82...+179%	-
Road Traffic N_2O (diesel)	1A3b	±100%[3]	lognorm -80...+200%	-
Road Traffic N_2O (natural gas)	1A3b	±100%[3]	lognorm -70...+150%	-
Railways CO_2	1A3c	±2%	normal ±2%	-
Railways CH_4	1A3c	±50%	lognorm -60...+110%	-
Railways N_2O	1A3c	±100%	lognorm -70...+150%	-
Navigation CO_2 (residual oil, gas/diesel oil)	1A3d	±2%	normal ±2%	±5%
Navigation CO_2 (other fuels)	1A3d	±2%[3]	normal ±2%	±5%[3]
Navigation CH_4 (residual oil, gas/diesel oil)	1A3d	±50%	lognorm -57...+100%	factor of 2
Navigation CH_4 (other fuels)	1A3d	±50%[3]	lognorm -57...+100%	factor of 2[3]
Navigation N_2O (residual oil, gas/diesel oil)	1A3d	±100%	lognorm -70...+150%	order of magnitude
Navigation N_2O (other fuels)	1A3d	±100%[3]	lognorm -70...+150%	order of magnitude [3]
Other Transportation CO_2 (gasoline)	1A3e	±2%	normal ±2%	-
Other Transportation CO_2 (diesel)	1A3e	±2%[3]	normal ±2%	-
Other Transportation CH_4 (gasoline)	1A3e	±50%	normal ±50%	-
Other Transportation CH_4 (diesel)	1A3e	±50% [3]	normal ±50%	-
Other Transportation N_2O (diesel)	1A3e	±100%	neg Gumbel -90...+55 %	-
Other Transportation N_2O (gasoline)	1A3e	±100%[3]	lognorm -70...+150%	-

[1](Aaltonen et al. 2001). All uncertainties are assumed normally distributed
[2](Penman et al. 2000)
[3]Treated together with the sector above

5. Fugitive Emissions from Fuels (1B)

Uncertainty estimates in this category are based on expert elicitation of National Expert Kari Grönfors from Statistics Finland, and on previous estimates of National Expert Riitta Pipatti from VTT Technical Research Centre of Finland. Some domestic literature of emissions from peatlands are also reviewed. Uncertainties are assumed to be the same in the reference year 1990 as in the inventory year 2001. The estimated uncertainties are presented in Table 6.

Table 6. Estimated uncertainty distributions, their 95% confidence intervals and the bases of estimates for Fugitive Emissions sector.

Input	IPCC category	Distribution	95% confidence interval [1]	Basis
Activity Data				
Fugitive emissions from solid fuels (peat production areas)	1B1	normal	±10%	expert judgement
Fugitive emissions from solid fuels (arable peatlands)	1B1	lognormal	-60...+109%	Minkkinen & Laine 2001
Fugitive emissions from oil and natural gas	1B2	normal	±10%	expert judgement
Emission Factors				
Fugitive emissions from solid fuels (CO_2) (peat production areas)	1B1	lognormal	-80...+208%	expert judgement
Fugitive emissions from solid fuels (CH_4) (peat production areas)	1B1	lognormal	-80...+208%	expert judgement
Fugitive emissions from solid fuels (CO_2) (arable peatlands)	1B1	normal	±50%	Minkkinen & Laine 2001
Fugitive emissions from oil and natural gas (CO_2)	1B2	normal	±20%	expert judgement
Fugitive emissions from oil and natural gas (CH_4)	1B2	normal	±20%	expert judgement

[1] Expressed as 2.5 percentile and 97.5 percentiles defined as percents relative to the mean value

5.1 Fugitive Emissions from Solid Fuels (1B1)

Fugitive emissions from solid fuels in Finland arise from peat production, which contains preparation and profiling of peat soils as well as stockpiling of peat. CO_2 emissions have been estimated for both peatlands currently used for peat production and 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 (Pipatti 2001), because methane emissions from arable peatlands are nearly zero (Minkkinen & Laine 2001). N_2O emissions have not been estimated (Pipatti 2001). For the uncertainty estimate of CO_2 emissions, the sector is divided into two subcategories: emissions from arable peatlands and peatlands already in use for peat production.

Activity data for peat production areas is assessed to be 50 000-60 000 ha, so the uncertainty is estimated at ±10%. The area of arable peatlands is estimated to be 60 000-250 000 ha (Minkkinen & Laine 2001) of which 150 000 ha is used for inventory purposes. The uncertainty in arable peatland area is modelled with a lognormal distribution, which has 60 000 as the lower 2.5%-tile. The 95% confidence interval is -60...+109%.

Some measurements of fugitive emissions from peatlands have been performed in Finland (Nykänen et al. 1996; Laine et al. 1998; Selin 1999; Maljanen et al. 2001). They are reviewed in the methodology report of the Finnish inventory (Pipatti 2001).

In the case of CO_2 emission factor of arable peatlands, the number of measurements is rather small. When also the regional representativeness of measurement data is taken into account, the resulting uncertainty in emission factor is ±50% according to Minkkinen & Laine (2001). This estimate is used also in this study. Further research in this area is however needed.

The number of measurement data from peat production areas is even smaller than from arable peatlands. Because of lack of accurate data, the uncertainty in emission factors (CO_2 and CH_4) of peat production areas is estimated to be -80...+208% lognormally distributed. It is possible, that CO_2 emissions can be estimated more accurately than CH_4 emissions, but as long as there is not enough measurement data, both emission factors are assumed to be equally poorly known. This estimate could be improved, when the results of the research program on greenhouse gas effect of peat production will be available in a couple of years.

In the future, fugitive emissions from peat production will probably be reported under LULUCF (Land-use, Land Use Change and Forestry) sector according to the Good Practice Guidance on LULUCF which will be available in near future. The report will probably also give more advice on calculation of fugitive emissions from peat. Therefore the uncertainty estimates reported here are rather preliminary.

5.2 Fugitive Emissions from Oil and Natural Gas (1B2)

Fugitive emissions from oil and natural gas include CO_2 emissions from venting and flaring from oil refineries, and CH_4 emissions from leakage from emptying natural gas pipelines for extension work (Pipatti 2001). Activity data is based on information from oil and gas companies, and the uncertainty of the activity data is estimated at ±10%. Emission factors are based on plant-specific information. The uncertainty in emission factors of both CO_2 and CH_4 are estimated to be ±20%. The estimates are the same as in the 1999 uncertainty estimate (Aaltonen et al. 2001).

5.3 Differences between this study and the 1999 uncertainty estimates

The changes of estimates compared with the 1999 estimates are presented in Table 7. The IPCC Good Practice Guidance (Penman et al. 2000) gives some uncertainty estimates of oil and gas operations in page 2.92, but they are not straight comparable with the Finnish inventory.

Table 7. Comparison of estimates with the 1999 inventory estimates for Fugitive Emissions sector.

Input	IPCC category	1999 estimate[1]	2001 estimate
Activity Data			
Fugitive emissions from solid fuels (peat production areas)	1B1	±100% [2]	normal ±10%
Fugitive emissions from solid fuels (arable peatlands)	1B1	see [3]	lognormal -60...+109%
Fugitive emissions from oil and natural gas	1B2	±10%	normal ±10%
Emission Factors			
Fugitive emissions from solid fuels (CO_2) (peat production areas)	1B1	±10%[2]	lognormal -80...+208%
Fugitive emissions from solid fuels (CH_4) (peat production areas)	1B1	±10%[2]	lognormal -80...+208%
Fugitive emissions from solid fuels (CO_2) (arable peatlands)	1B1	see [3]	normal ±50%
Fugitive emissions from oil and natural gas (CO_2)	1B2	±20%	normal ±20%
Fugitive emissions from oil and natural gas (CH_4)	1B2	±20%	normal ±20%

[1](Aaltonen et al. 2001). All uncertainties are assumed normally distributed
[2] Seems as if emission factor and activity data estimates should be vice versa
[3] Treated together with the above sector

6. Industry, Solvent and Other Product Use and Non-Energy use of Fuels (2, 3, 7)

In the Finnish greenhouse gas emission inventory, emissions from Industrial Processes are estimated using the general methodology of the IPCC Guidelines, i.e. activity data multiplied with emission factor (Pipatti 2001). Uncertainty estimates in Industry, Solvent and Other Product Use and Non-energy Use of Fuels are mainly based on expert elicitation of National Expert Kari Grönfors from Statistics Finland in the case of CO_2, CH_4 and N_2O. In the 1999 inventory, uncertainties in industry (CO_2, CH_4 and N_2O emissions) were also based on expert judgement of Kari Grönfors, and most of these estimates are kept unchanged also in this study. The only sector with significant additional information (measurement data) is N_2O emissions from nitric acid production. Uncertainties are assumed to be the same in the reference year 1990 as in the inventory year 2001. The estimated uncertainties in CO_2, CH_4 and N_2O are presented in Table 8. The uncertainty estimates of F-gases, which are presented in Chapter 6.6, are obtained from Teemu Oinonen from the Finnish Environment Institute.

Table 8. Estimated uncertainty distributions, their 95% confidence intervals and bases of estimates for Industry, N_2O Use and Non-energy Use of Fuels.

Input	IPCC category	Distribution	95% confidence interval [1]	Basis
Activity Data				
Cement production	2A1	normal	±5%	expert judgement
Lime production	2A2	normal	±10%	expert judgement
Nitric acid Production	1B2	normal	±5%	expert judgement
Ethylene production	2B5	normal	±5%	expert judgement
Iron and steel production – coke	2C	normal	±3%	expert judgement
N_2O Use	3	normal	±30%	expert judgement
Non-energy Use of Fuels	7	normal	±50%	expert judgement
Emission Factors				
Cement production	2A1	normal	±5%	expert judgement
Lime production	2A2	normal	±5%	expert judgement
Nitric Acid production	2B2	lognormal	-57...+100%	measurement data
Ethylene production	2B5	normal	±20%	expert judgement
Iron and steel production – coke	2C	normal	±20%	expert judgement
N_2O Use	3	normal	±20%	expert judgement
Non-energy Use of Fuels (CO_2)	7	normal	±5%	expert judgement

[1] Expressed as 2.5 percentile and 97.5 percentile defined as percents relative to the mean value

6.1 CO_2 from Cement Production (2A1)

The activity data for CO_2 emissions from cement production are obtained from both Manufacturing Industry Statistics and from the industrial plants directly (Pipatti 2001).

The emission factors used are IPCC default emission factors according to the Tier 1 method of the IPCC Good Practice Guidance (Penman et al 2000). In the IPCC Good Practice Guidance the uncertainties in estimating CO_2 emissions from cement production are defined for several steps, and the resulting maximum uncertainty in emission estimates is ±20-40%. In Finland, most of the factors are well known, so the estimated uncertainty is ±5% for both emission factor and activity data. In Norway, the uncertainty in activity data was assessed to ±3% (Rypdal & Zhang 2000). In Austria the uncertainty associated with both cement production activity data and emission factor is ±0.5% (Winiwarter & Rypdal 2001), and in the UK the activity data uncertainty was estimated at ±1%, and the emission factor uncertainty at ±2% (Charles et al. 1998). In Norway, uncertainty in emission factor was estimated to be ±7%, in the Netherlands ±5% and in the USA ±3% (Rypdal & Winiwarter 2001). This shows that variation of uncertainty estimates is large, and the Finnish estimates fit quite well within the estimates from other countries.

6.2 CO_2 from Lime Production (2A2)

Activity data for lime production is obtained from both Manufacturing Industry Statistics and from the industrial plants directly, and the emission factors are obtained from the IPCC Guidelines (Pipatti 2001). In the IPCC Good Practice Guidance, the uncertainty in emission factors is estimated at ±2%-15% according to the lime type, and the uncertainty in activity data is assumed to be much higher. In the UK, the activity data uncertainty was estimated at ±1%, and the emission factor uncertainty at ±5% (Charles et al. 1998). In the Finnish inventory, the uncertainty in emission factor is assumed to be ±5% and in activity data ±10%. Both estimates are based on expert judgement, and are the same as in the 1999 uncertainty estimate (Aaltonen et al. 2001).

6.3 N_2O from Nitric Acid Production (2B2)

Activity data of nitric acid production is obtained from the nitric acid production plants directly. In the Austrian inventory the uncertainty in activity data was assumed to be ±20% (Winiwarter & Rypdal 2001) and in the UK ±10-20% (Charles et al 1998). In the Finnish 1999 inventory, the estimated uncertainty in activity data was smaller than in the other countries reviewed, i.e. ±5% (Aaltonen et al. 2001). The number of nitric acid producers is small in Finland, and the data can be considered reliable. Therefore the estimate is kept unchanged.

Finland has country-specific emission factors for N_2O emission from nitric acid production. Emission factors are based on measurements from nitric acid production plants (Pipatti 2001). Uncertainty in the emission factor in the 1999 inventory was estimated at ±20% (Aaltonen et al. 2001). In this study, the uncertainty estimate is based on confidential measurement data from nitric acid production plants of Kemira Agro Oy. The uncertainty estimate is based on variation between different measurement periods, variation within individual measurement series and information on measurement instruments. Based on these, the uncertainty is estimated to be lognormally distributed with a 95% confidence interval of -57...+100%.

Emission factor uncertainty of nitric acid production was assumed to be 230% in UK (Charles et al 1998), ±7% in Norway, ±35% in the Netherlands and –55...200% in the USA and -20...120% uniformly distributed in Austria (Rypdal & Winiwarter 2001). According to these, the N_2O emission factor can be considered highly uncertain. The Finnish estimate fits well between these estimates.

6.4 CH_4 from Ethylene Production (2B5)

In the Finnish inventory, the only emission source under 2B5, Chemical Industry, is CH_4 emissions from ethylene production. The company producing ethylene gives activity data for ethylene production. Uncertainty in activity data is estimated to be ±5% based on expert judgement. The emission factor used is the IPCC default emission factor, and its uncertainty is estimated at ±20%.

6.5 CH_4 from Iron and Steel Production - coke (2C)

Activity data of coke production is obtained from Energy Statistics, and the emission factor used is the IPCC default emission factor (Pipatti 2001). Uncertainty in activity data is assumed to be ±3% and in emission factor ±20%. Both estimates are based on expert judgement.

6.6 F-gases (2C, 2F)

In Finland, the emissions of F-gases (HFCs, PFCs and SF_6) are calculated following the IPCC Good Practice Guidance, and are documented in a report “Finnish 2001 Inventory of HFC, PFC and SF_6 Emissions” (Oinonen 2003). The uncertainty analysis of F-gases was entirely performed by National Expert Teemu Oinonen from Finnish Environment Institute. In the selection of probability density functions, the IPCC Good Practice Guidance (Penman et al. 2000) was followed. Empirical data was used as far as possible, though in some categories uncertainty estimates were based on expert judgement (for instance, figures for 1990 (Table 9) were based entirely on expert judgement). Combining uncertainties was performed using the same methods and tools as in the total inventory: Monte Carlo simulation was used with the help of Crystal Ball (an add-in to Microsoft Excel). The estimated uncertainties in emissions are presented in Table 9. The uncertainties are presented by category, and different gases are not separated. More information is available from Oinonen (2003).

Table 9. Estimated uncertainty distributions, their 95% confidence intervals and bases of estimates for F-gases (Oinonen 2003).

Input	IPCC category	1990[1] estimates	2001[1] estimates	Basis
Emissions				
Refrigeration and Air Conditioning Equipment	2F1	NA[2]	neg. skew. Gumbel -73...+44%	Oinonen 2003
Foam Blowing	2F2	NA	normal ±26%	Oinonen 2003
Aerosol/Meter Dose Inhalers	2F4	NA	normal ±4%	Oinonen 2003
Electrical Equipment	2F7	normal ±50%	pos. skew. Gumbel -7...+12%	Oinonen 2003
Other	2F, 2C	normal ±50%	normal ±39%	Oinonen 2003

[1] Expressed as 2.5 percentile and 97.5 percentile defined as percents relative to the mean value
[2] NA = not applicable. Emissions from categories 2F2 and 2F3 did not occur in 1990. Emissions from 2F1 were also practically zero in 1990.

6.7 N_2O Use (3)

In Finland, N_2O use is the only emission source reported under source category 3, Solvent and Other Product Use. The emission estimate of N_2O use in Finland (industrial, medical and other applications) is based on the information on N_2O sales, which is confidential information at company level (Pipatti 2001). In the 1999 inventory the uncertainty in activity data was assumed to be ±30%, and the uncertainties in emission factor ±20% (Aaltonen et al. 2001). These estimates are kept unchanged also in the 2001 inventory. In the Austrian inventory (Winiwarter & Rypdal 2001), uncertainty in solvent use activity data is assumed to be ±50%. In Finland, however, there are quite few emission sources in the sector, which can be assumed to be rather well known.

6.8 Non-energy Use of Fuels (7)

In the Finnish emission inventory, Non-energy Use of Fuels is reported as the only emission source under category 7, Other. This sector contains CO_2-emissions from non-energy use of oil products and natural gas. Activity data is based on energy statistics, but it contains rather large uncertainties. In the 1999 uncertainty estimate the assumed uncertainty was ±100%. This seems to be too large an uncertainty. Therefore the estimate is reduced to ±50%. The uncertainty in emission factor was estimated to be ±5% in the 1999 inventory, and this estimate is kept unchanged.

6.9 Differences between this study, the 1999 uncertainty estimates and the IPCC estimates

The changes of estimates in the case of other gases than F-gases compared with the 1999 estimates and the IPCC recommendations are presented in Table 10. In the 1999 inventory, the uncertainties in emissions of HFCs, PFCs and SF_6 were treated as a single figure. Estimated uncertainty in activity data was ±10% and in emission factor ±40%. These estimates were based entirely on expert judgement.

Table 10. Comparison of estimates with the 1999 inventory estimates and the IPCC estimates for Industry, N_2O Use and Non-energy Use of Fuels.

Input	IPCC category	1999 estimate[1]	2001 estimate	IPCC[2]
Activity Data				
Cement production	2A1	±5%	normal ±5%	see [3]
Lime production	2A2	±10%	normal ±10%	-
Nitric Acid production	1B2	±5%	normal ±5%	see [4]
Ethylene production	2B5	±5%	normal ±5%	-
Iron and steel production – coke	2C	±3%	normal ±3%	-
N_2O Use	3	±30%	normal ±30%	-
Non-energy Use of Fuels	-	±100%	normal ±50%	
Emission Factors				
Cement production (CO_2)	2A1	±5%	normal ±5%	±20-40%[3]
Lime production (CO_2)	2A2	±5%	normal ±5%	±2%-15%
Nitric Acid production (N_2O)	1B2	±20%	lognormal -57...+100%	see [4]
Ethylene production (CH_4)	2B5	±20%	normal ±20%	-
Iron and steel production: coke (CH_4)	2C	±20%	normal ±20%	-
N_2O Use (N_2O)	3	±20%	normal ±20%	-
Non-energy Use of Fuels (CO_2)	-	±5%	normal ±5%	

[1](Aaltonen et al. 2001). All uncertainties are assumed normally distributed
[2](Penman et al. 2000)
[3] Estimate given for emissions, not separately for emission factor and activity data
[4] In the IPCC Good Practice Guidance (Penman et al. 2000) uncertainty in nitric acid production is treated together with adipic acid production, and an uncertainty estimate applicable for Finnish conditions is not available

7. Agriculture (4)

In Finland, agricultural emissions are calculated according to the IPCC Good Practice Guidance. Activity data is based on national values; the emission factors and other parameters are partly IPCC default factors, partly national factors. Uncertainty estimates are mainly based on expert judgements in the case of national data. In the case of IPCC default factors, uncertainty estimates are based on possible ranges of emission factors (IPCC 1996a), or default uncertainty estimates given in the IPCC Good Practice Guidance report (Penman et al. 2000). In many cases, however, default uncertainty estimates for IPCC default emission factors are not available.

The uncertainties are estimated to be the same in the reference year (1990) as in the inventory year (2001) in most cases. The assessed uncertainties and the bases of estimates are presented in Table 11. However, further study is needed to improve the estimates of most uncertainties in the Agriculture sector.

Table 11. Estimated uncertainty distributions, their 95 % confidence intervals and the bases of estimates for Agriculture sector.

Input	IPCC category	Distribution	95 % confidence interval [1]	Basis
Activity Data				
Livestock population (cattle)	4A1, 4B 4D	normal	±3% (2001) ±5% (1990)	Expert judgement, statistic methods
Livestock population (horses)	4A6, 4B6 4D	normal	±5% (2001) ±3% (1990)	Expert judgement
Livestock population (reindeer)	4A10	normal	±10%	Expert judgement
Livestock population (other)	4A3, 4A4, 4A8, 4A10, 4B, 4D	normal	±5%	Expert judgement statistic methods
Fos (area of organic soils cultivated)	4D	normal	±30%	Expert judgement
N_{fert} (synthetic fertiliser application)	4D	normal	±10%	Expert judgement
Crop residues returned to soils (N-load)	4D	normal	±30%	Expert judgement (Riitta Pipatti)
N Fixed by crops	4D	normal	±30%	Expert judgement (Riitta Pipatti)
t_p (length of pasture season)	4B	beta	-75...+25%	Finnish Grassland Society 2002, Expert judgement
$N_{SEWSLUDGE}$	4D	normal	±30%	Preliminary estimate
Emission Factors				
Enteric fermentation (CH_4) (swine, sheep, goats, horses, cattle)	4A1, 4A3, 4A4, 4A6, 4A8	normal	±50%	Penman et al. 2000

Enteric fermentation (CH_4) (reindeer)	4A10	gamma	-26...+250%	Nieminen et al. 1998
Manure management (CH_4)	4B	normal	±30%	see text
Manure management (N_2O)				
EF (solid manure)	4B1	beta	–85...+15%	Dustan 2002; Amon et al. 2001; Hüther 1999; Amon et al. 1997
EF (liquid/slurry manure)	4B	lognormal	-50...+100%	Penman et al. 2000
N_{EX}	4B, 4D	normal	±25%,	Penman et al. 2000
MS	4B	normal	±20%	preliminary estimate
Direct N_2O emissions from agricultural soils				
$Frac_{GASF}$	4D	normal	±30%	Expert judgement (Riitta Pipatti)
$Frac_{GASM}$	4D	normal	±40%	Expert judgement (Riitta Pipatti)
EF (organic soils cultivated)	4D	gamma	-75...+87.5%	IPCC 1996a
EF (synthetic fertiliser application, animal manure nitrogen used as fertiliser, crop residues returned to soils)	4D	normal	±80%	IPCC 1996a
Indirect N_2O emissions from agricultural soils				
EF (atmospheric deposition of NH_4 and NO_x)	4D	gamma	-80...+100%	IPCC 1996a
EF (leaching/runoff)	4D	gamma	-92...+380%	IPCC 1996a
$Frac_{LEACH}$	4D	gamma	-66...+166%	IPCC 1996a; Expert judgement (Martti Esala)
Other N_2O emission from Agricultural soils	4D	normal	±80%	IPCC 1996b

[1] Expressed as 2.5 percentile and 97.5 percentile defined as percents relative to the mean value

7.1 Enteric Fermentation (4A)

The emissions from enteric fermentation are calculated based on information on animal numbers and emission factors. Uncertainty in activity data (animal number) is estimated at ±5-10% in most countries reviewed, namely ±10% in Austria (Winiwarter & Rypdal 2001), ±5-10% in Norway, <±5% in the Netherlands and ±5% in the USA (Rypdal & Winiwarter 2001).

In Finland, the activity data (animal numbers) are obtained from registries which cover all farms. The number of cattle is obtained from a cattle registry. All Finnish bovine animals have an individual earmark, according to which all births, sales, and slaughters are registered. This register has been used in Finland since 1995, and therefore the uncertainty in the number of cattle in 2001 is assessed to ±3%.

To assess the uncertainty in other animal numbers (number of cattle in 1990, numbers of swine, sheep, goats, and poultry in 1990 and 2001), National Expert Mirja Kokkinen from the Information Centre of the Ministry of Agriculture and Forestry was interviewed. According to Mirja Kokkinen, 98% of Finnish farms (in 2001) apply for agricultural subsidy. Farms applying for agricultural subsidy have to fill forms covering the number of all animals for statistical reasons regardless if they are applying for a subsidy for all animal groups or not. In addition, the rest remaining 2% of farms have to fill in a form of their animal numbers. The 1990 was a year of agricultural accounting, and therefore the animal numbers are equally well known in 1990 as in 2001 (Kokkinen 2003). Animal number statistics are very accurate in Finland, and the uncertainty is estimated at ±5% for both the inventory year and the base year.

The uncertainty in the number of horses was estimated based on information obtained from National Expert Terttu Peltonen from Finnish trotting and breeding association (Suomen Hippos). According to Terttu Peltonen, the number of horses was calculated in 1987. After 1987, all horses were registered, and all slaughters were also registered until 1995 (Peltonen 2003). Therefore the uncertainty in 1990 is estimated at ±3%. After 1995, when Finland joined European Union, the registering of imported saddle horses was not compulsory anymore, and all the slaughters are not registered anymore (Peltonen 2003). This is estimated to increase the uncertainty into ±5% in 2001.

The number of reindeer is also well known in Finland, and therefore the uncertainty is estimated at ±10%.

The uncertainty in CH_4 emission factor from enteric fermentation was assessed to ±25% in Norway and the Netherlands, ±36% in the USA (Rypdal & Winiwarter 2001) and ±50% in Austria (Winiwarter & Rypdal 2001). In the UK the total uncertainty in emissions was estimated at ±20% (Charles et al. 1998).

In Finland, methane emissions from enteric fermentation of swine, sheep, goats and horses are calculated using the Tier 1 Method of the IPCC Guidelines and IPCC default emission factor. The IPCC gives an uncertainty estimate of emission factor of ±30-50%. In Finland, an uncertainty of ±50% is used. The emissions from cattle are calculated using the Tier 2 method. Some preliminary estimates have been performed defining uncertainties for all calculation parameters of the Tier 2 method except empirical coefficients as the origin of the coefficients is not known. According to these calculations, the uncertainty was still near ±50%, and therefore this uncertainty estimate is used also for cattle.

CH_4 emissions from reindeer were calculated first time in the Finnish 2001 inventory. The used method was Tier 1 with a national emission factor which is based on literature on reindeer feeding (Nieminen et al. 1998). The uncertainty is estimated based on information on possible ranges of factors used to calculate emissions factor. The uncertain parameters are methane conversion rate, gross energy intake, digestible energy (as percents of gross energy) and energy losses through enteric fermentation and urine. The gross energy intake is different in summer- and wintertime, and the length of these seasons increases the uncertainty. The uncertainty is estimated at -26...+250%. This estimate is very preliminary.

7.2 Manure Management (4B)

The uncertainty in manure management activity data is estimated at ±20% in Norway, ±10-50% in the Netherlands and ±2% in the USA (Rypdal & Winiwarter 2001). The uncertainty in CH_4 emission factor was assessed to ±25% in Norway and the Netherlands and ±36% in the USA (Rypdal & Winiwarter 2001). In the UK the total uncertainty in emissions was estimated at ±30% (Charles et al. 1998). In Finland, the uncertainty in animal numbers is the same as in the category 4A, Enteric Fermentation.

Emission factors of CH_4 for all animals are calculated using IPCC default parameters for VS, B_0 and MCF-coefficients. In the case of cattle, VS is calculated using GE (gross energy intake), ash content of manure (ASH) and digestible energy of the feed (DE). GE and DE are national values, and ASH is an IPCC default factor. The only national factor used for all species is the fraction of animal category’s manure handled using a specific manure management system. Because most of the parameters are IPCC default values without an IPCC uncertainty estimate, parameter-specific uncertainty estimates have not been made in this study. Instead, a total emission factor uncertainty of ±30% is used. This estimate fits well with the uncertainty estimates performed in other countries and is the same number as used in the Finnish 1999 inventory uncertainty estimate, which was based on expert judgement of National Expert Riitta Pipatti.

In Finland, N_2O emissions from manure management are calculated using IPCC default emission factors, i.e. 0.1% for liquid/slurry and 2% for solid manure. According to Dustan (2002) N_2O emission factors are at some extent dependent on temperature. However, the effect of temperature is more significant in the case of solid manure than in the case of liquid/slurry. Another parameter influencing emissions is slurry surface cover, which seems to increase nitrous oxide emissions (Dustan 2002). In Finland, 40% of manure stores were covered in 1995-1997 (Seppänen & Matinlassi 1998). Dustan (2002) has reviewed studies concerning N_2O emission factors from slurry/liquid manure (Monteny et al. 2001; Jungbluht et al. 2001; Amon et al. 1999; Sommer & Møller, 2000; Petersen et al. 1996). These studies show N_2O emission factors of <<1%, 0.14% and 0.5%. However, peak values of 2.3% have also been measured (Dustan 2002). The

IPCC (Penman et al. 2000) gives an uncertainty estimate (for all manure N_2O emissions) with a 95% confidence interval of -50...+100%. This estimate is used also in Finland, because it fits rather well with the above mentioned studies. The effect of surface covers into the emission factor is clearly an area of further research. This uncertainty estimate is used also in other species than cattle.

In the case of N_2O emissions from solid cattle manure, Dustan (2002) reviews many studies (Amon et al. 2001; Hüther 1999; Amon et al. 1997). These studies have resulted in emission factors from 0.3% to 1.5%. This shows, that the used emission factor (2%) might be too high. Therefore an uncertainty estimate of -85...+15% is used for all solid manure (i.e. for other species than cattle, also).

Other calculation parameters of N_2O emissions from manure management are $Nex_{(T)}$ (annual average N excretion per head) and $MS_{(T,S)}$ (fraction of total annual excretion for each livestock species T that is managed in manure management system S). The latest information of manure management systems is from the years 1995-1997 (Seppänen & Matinlassi 1998). Pipatti et al. (2000) have compared two different studies of manure management systems used in Finland in 1990. The studies compared by Pipatti et al. (2000) show a variation of 33% in the fraction of liquid/slurry of total manure in the case of dairy cattle. The variation in the case of other cattle and other animal species is even larger. In inventory calculations, however, the results from a study, which seems to be the more accurate one, are used. Therefore the uncertainty in manure management system used (MS) is estimated smaller than the variation between different studies, i.e. ±20%. This is a very preliminary estimate.

$Nex_{(T)}$ is obtained from (Gröönroos et al. 1998). IPCC gives an uncertainty of ±25% for national factor. This estimate is used also in Finland. The length of pasture season (t_p) is estimated by a National Expert Juho Kyntäjä from Rural Advisory Centres. According to Finnish Grassland Society (2002), the length of pasture season in Finland varied from 90 days in Lapland to 130 days in the Southern Finland in 2000. According to Juho Kyntäjä, the length of pasture season of cattle may vary between 0-150 days (Kyntäjä 2003). In the Finnish inventory, the length of pasture season used is 130 days for dairy cows, and 120 days for other cattle and other animal species. Based on this information, the uncertainty in pasture season is estimated at -75...+25%.

7.3 Agricultural Soils: Direct N_2O Emissions (4D)

The estimated uncertainty in activity data in this category is ±5% in Austria (Winiwarter & Rypdal 2001). Activity data uncertainty was assessed in Norwegian inventory to ±5%

in the case of fertiliser use, ±20% in manure use and ±50% in other activities (Rypdal & Zhang 2000).

The uncertainty in N_2O emission factor was assessed to have a triangular distribution with a 95% confidence interval of -32...+143% in the Austrian inventory (Winiwarter & Rypdal 2001). In Norway and the UK the uncertainty was estimated to be lognormally distributed with an uncertainty of two orders of magnitude. In the Netherlands the estimated uncertainty is ±75% and in the USA -90...+100% (Rypdal & Winiwarter 2001).

In Finland, direct N_2O emission from agricultural soils include emissions from synthetic fertiliser application, emissions from animal manure nitrogen used as fertiliser, emissions from crop residues returned to soils, emissions from N fixed by crops and emissions from organic soils cultivated. All the emission factors used in the Finnish inventory are IPCC default emissions factors.

The uncertainty in crop residues returned to soils (N-load) and N fixed by crops is estimated at ±30% by National Expert Riitta Pipatti (Pipatti 2003).

According to the IPCC (1996a), the emission factor of synthetic fertiliser application, animal manure nitrogen used as fertiliser and crop residues returned to soils, is 0.0125 with a possible range of 0.0025-0.0225. Therefore an uncertainty estimate of ±80% is used in Finland.

In synthetic fertiliser application, the uncertainty estimate of activity data (the amount of synthetic fertiliser consumed) is obtained from the sales statistics of Kemira Agro Oy in 1990. In 2001, this activity data was obtained from Information Centre of the Ministry of Agriculture and Forestry (2002). For the purposes of this uncertainty estimate, Mikael Brannback from Kemira Agro Oy was asked for further information. According to him, the N content of fertilisers is well known. He also told that the market share of Kemira Agro is very significant (Brannback 2003), which implies that the exclusion of imported fertilisers from the estimates does not increase uncertainty. The amount of fertiliser sold during the fertiliser year (e.g. 1.7.2000-30.6.2001) is estimated to be used during one calendar year (e.g. 2001) in the inventory calculations (Information Centre of the Ministry of Agriculture and Forestry 2002). This assumption made in the inventory increases the uncertainty of the fertiliser use. Thus, the uncertainty in fertiliser use is estimated at ±10%. According to the second order draft of Good Practice Guidance on Land-Use, Land Use Change and Forestry, the uncertainty in statistics for fertiliser applied is <±10%, which is the same number as estimated here.

In the case of emissions from animal manure nitrogen used as fertiliser, the same activity data uncertainty estimate is used as in categories 4A and 4B. In the annual average N excretion (N_{EX}), the uncertainty estimate used is also the same as in N_2O emissions from manure management. The uncertainty in fraction that volatilises as NH_3 and NO_x ($Frac_{GASM}$) is estimated at ±40% and based on studies on Finnish NH_3 emissions (Pipatti 1992; Gröönroos et al. 1998; Savolainen et al. 1996; Tähtinen et al. 1997). The estimate is obtained from a National Expert Riitta Pipatti. The uncertainty in $Frac_{GASF}$ is estimated at ±30% by Riitta Pipatti (Pipatti 2003).

The emission factor of organic soils cultivated is between 2-15 according to the IPCC (1996a). In Finland, a value of 8 is used. Therefore the uncertainty range is estimated at -75...+87.5% gamma distributed. Activity data of organic soils cultivated is obtained from Merja Myllys, MTT Agrifood Research Finland. According to Merja Myllys, the area is determined using soil samples, which represent 90% of the field area in Finland. It is assumed that also the remaining 10% have a similar distribution of soil types than the measured 90%. 80% of soil samples were analysed by Finnish Soil Analysis Service (Viljavuuspalvelu Oy). According to this information, it can be estimated that the analysed samples represent 70% of field area in Finland. In the estimation of land area it is also assumed, that all samples sent to Finnish Soil Analysis Service represent equally large soil areas, which increases the uncertainty. Based on this information, the uncertainty in land area is estimated at ±30%. However, this estimate has to be considered very preliminary. More information will possibly be available in a few years, if calculations will be done based on maps of soil types.

7.4 Agricultural Soils: Indirect N_2O emissions (4D)

In the calculation of indirect N_2O emissions from atmospheric deposition of NH_4 and NO_x, many parameters (and thus, uncertainty estimates) used are the same as used above (N_{fert}, number of animals, N_{EX}, $N_{SEWSLUDGE}$). The emission factor used is IPCC default emission factor 0.01. According to the IPCC (1996a), the possible emission factor range is 0.002-0.02. Therefore the uncertainty estimate used is -80%...+100% gamma distributed.

Indirect N_2O emissions from leaching/runoff of applied or deposited nitrogen are calculated using the same parameters (and thus, uncertainty estimates) as above (N_{fert}, number of animals, N_{EX}, $N_{SEWSULDGE}$). The emission factor used is IPCC default emission factor 0.025. IPCC (1996a) gives a possible range of 0.002-0.12. Therefore an uncertainty estimate of –92%...380% (gamma distributed) is used.

The parameter $Frac_{LEACH}$ describes the fraction of N-input, that is lost through leaching or runoff. IPCC default value is 0.3 with a range of 0.1-0.8 (IPCC 1996a). According to this, uncertainty range would be -66%...+166%. In Finland, the used $Frac_{LEACH}$ value is 0.15 based on expert judgement of National Experts Martti Esala (Agrifood Research Finland) and Riitta Pipatti (VTT Technical Research Centre of Finland) and on recent studies (Vuorenmaa et al. 2002). According to expert judgement of Martti Esala, the relative uncertainty in Finland is the same as in the IPCC estimate, though the value used is lower.

7.5 Agricultural Soils: Other (4D)

This sector consists of sewage sludge applied to soils. Activity data ($N_{SEWSLUDGE}$) was obtained from the Finnish Environment Institute. In the waste sector, the uncertainty in N-input in human sewage is estimated at ±10% in sparsely populated areas, and ±5% in densely populated areas. An additional uncertainty origins from the use of sewage sludge. According to National Expert Tarja Siika-aho from the Finnish Environment Institute, data is obtained from sewage treatment plants directly. A very preliminary uncertainty estimate of ±30% is used, but this might overestimate the uncertainty. According to the second order draft of the LULUCF Good Practice Guidance, an uncertainty of <±20% in the amount of organic waste used as fertiliser is given.

The used emission factor in the Finnish inventory is obtained from (IPCC 1996b). The emission factor used is 0.0125. IPCC gives a possible range of 0.0025–0.0225. Therefore an uncertainty estimate of ±80% is used.

7.6 Differences between this study, the year 1999 uncertainty estimates and the IPCC estimates

For the purposes of this study, rather than estimating uncertainties only for activity data and emission factors, the uncertainties were estimated for different parameters. The calculated total uncertainties by source category compared with the 1999 uncertainty estimate are presented in Table 12. The presented uncertainties in 1999 are a combination of emission factor and activity data uncertainties. The 2001 uncertainties were calculated using Monte Carlo simulation. The uncertainties given by the IPCC (Penman et al. 2000) for emission factors are also presented in the table.

Table 12. Comparison of 2001 uncertainty estimates with the year 1999 inventory estimates for Agriculture sector.

Source Category	IPCC category	1999 estimate[1]	2001 estimate	IPCC EF uncertainty[2]
Enteric Fermentation (CH_4)	4A	±32%	±30%	±20-50%[3]
Manure management (CH_4)	4B	±32%	±17%	-
Manure management (N_2O)	4B	±100%	-82...+35%	-50...+100%[4]
Direct N_2O from agricultural soils	4D1	±104%	-58...+73%[6]	-80...+400%[5]
Indirect N_2O from agricultural soils	4D3	±155%	see [6]	>order of magnitude
(CO_2 from agricultural soils)		±104%	see [7]	-

[1](Aaltonen et al. 2001). All uncertainties are assumed normally distributed
[2]Uncertainty estimates of emission factors, which are the most uncertain components of emission estimates
[3]Uncertainty in Tier 1 method is larger than in Tier 2 method. In Finland, both methods are used.
[4]In this emission source, also the activity data uncertainties are rather large
[5]Uncertainty in applied nitrogen
[6]Direct and indirect emissions together
[7]Uncertainty not estimated in this study

8. Waste (6)

In the Finnish inventory, emissions from solid waste disposal are calculated using a First Order Decay Method (FOD) according to the Tier 2 method in the IPCC Good Practice Guidance (Penman et al. 2000). The emissions from wastewater are calculated using emission factors and activity data. The uncertainty estimates of waste sector are mainly based on expert elicitation of National Expert Jouko Petäjä from the Finnish Environment Institute and on the IPCC Good Practice Guidance. Some changes related to expert judgement of Jouko Petäjä presented in Appendix B are made based on additional data. In maximum methane producing capacity (B_0) in wastewater sector, a default uncertainty value of IPCC (Penman et al. 2000) is used. The uncertainty estimates of emission factors for N-input from wastewater and fish farming are based on estimates done in agriculture sector. The estimated uncertainties are presented in Table 13.

Table 13. Estimated uncertainty distributions, their 95% confidence intervals and bases of estimates for Waste sector.

Input	IPCC category	Distribution	95% confidence interval [1]	Basis
Activity Data				
Managed Waste Disposal on Land	6A1			
years 1900-1930		lognormal	-75...+170%	index for waste amount
years 1931-1950		lognormal	-64...+124%	index for waste amount
years 1951-1970		gamma	-33...+82%	index for waste amount
years 1971-1996		normal	±30%	Hietanen 2001; expert judgement
years 1997-2001		normal	±15%	Hietanen 2001; expert judgement
Other	6A3			
Municipal Sludge		gamma	-50...+100%	expert judgement
Industrial Sludge 1900-1996 1997-2001		 normal normal	 ±50% ±30%	 expert judgement expert judgement
Industrial Solid Waste & Construction and Demolition Waste 1900-1996 1997-2001		 normal normal	 ± 30% ±15 %	 expert judgement expert judgement
Industrial wastewater (COD)	6B1	normal normal	±10% (2001) ±15% (1990)	expert judgement expert judgement
Domestic wastewater (BOD)	6B2	normal	-5...+10%	expert judgement
N-input (Fish Farming)	6B3	normal	±10%	expert judgement
N-input (industry)	6B3	normal	±5%	expert judgement

N-input from human sewage sparsely pop. areas densely pop. areas	6B2	 normal normal	 ±10% ±5%	 expert judgement expert judgement
Emission Factors				
Industrial wastewater B_0 MCF	6B1	 normal gamma	 ±30% -50...+100%	 Penman et al. 2000 expert judgement
Domestic and commercial wastewater B_0 MCF	6B2	 normal gamma	 ±30% -50...+100%	 Penman et al. 2000 expert judgement
N-input (Fish Farming)	6B3	gamma	-92...+380%	IPCC 1996a
N-input (industry)	6B3	gamma	-92...+380%	IPCC 1996a
N-input from human sewage (sparsely pop.areas)	6B2	gamma	-92...+380%	IPCC 1996a
N-input from human sewage (densely pop. areas)	6B2	gamma	-92...+380%	IPCC 1996a
Other Calculation Parameters of FOD Model				
k=0.03 k=0.05 k=0.2	6A1 & 6A3	Weibull Weibull beta	-40...+300% -40...+300% -75...+10%	expert judgement
MCF	6A1 & 6A3	neg skew Gumbel	-3 %...+1.8	expert judgement
DOC	6A1	normal	±20%	expert judgement
DOC	6A3	normal	±15%	expert judgement
DOC_F	6A1 & 6A3	normal	±10%	expert judgement
R	6A1 & 6A3	normal	±5%	expert judgement
F	6A1 & 6A3	normal	±22%	measurement data
OX	6A1	gamma, scale=9	-50...+10%	expert judgement

[1] Expressed as 2.5 percentile and 97.5 percentile defined as percents relative to the mean value

8.1 Managed Waste Disposal on Land (6A1)

In Finland, the emissions from solid waste disposal on land (6A) are estimated using the Tier 2 method of the IPCC Good Practice Guidance (Penman et al. 2000). Emissions are calculated with a First Order Decay (FOD) model, which takes into account also the emissions originating from waste disposed in landfills before the inventory year (in Finland, the first year of calculation is 1900). Nowadays the amount of waste is obtained from Finnish Environment Institute using information from VAHTI database and the Register of Landfill Sites (Ministry of the Environment 2002).

Historical activity data (the amount of municipal waste) can be 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 in the case of 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 for the years 1970-2001 are based on expert judgement of Jouko Petäjä. In Finland, improved statistics of the amount of waste have been available from 1997 onwards, thus resulting in clear decrease in the inventory uncertainty. Hietanen (2001) has studied waste amounts in Finland in the year 2000. The study based on statistics used in national greenhouse gas emission inventory, surveys and some additional information. In that study, the difference between municipal solid waste disposed in landfills calculated in different methods was ±10%.

According to Austrian emission inventory, the uncertainty in activity data of landfills (6A) is ±15% in 1990's, and ±20–30% for older information (Winiwarter & Rypdal 2001). In the Norwegian inventory the uncertainty in activity data is estimated at ±20% (Rypdal & Zhang 2000). In the Netherlands, the uncertainty in activity data is estimated at ±10% and in the USA at -10...+30% (Rypdal & Winiwarter 2001). According to the IPCC Good Practice Guidance (Penman et al. 2000) the uncertainty in activity data is >±10%. Finnish uncertainty estimate of current activity data is in good accordance with these estimates.

In the Austrian emission inventory the FOD model was also used (Winiwarter & Rypdal 2001). The uncertainty estimate was, however, performed in a different way than in Finland, and therefore the results cannot be straight compared. The uncertainty in FOD model (without activity data uncertainty) was assessed to ±35%.

In the Norwegian inventory the uncertainty in CH_4 emission factor is ±30% with a lognormal distribution (Rypdal & Zhang 2000). In the UK inventory the uncertainty associated with methane emissions from landfills is modelled with a positively skewed empirical distribution with a 95% confidence interval of around 39% (Charles et al. 1998). In the Netherlands, the uncertainty in CH_4 emission factor is estimated at ±30% and in the USA -50...+14% (Rypdal & Winiwarter 2001).

In the Finnish calculation, a correction to equation 5.1 in the IPCC Good Practice Guidance (Penman et al. 2000) has been made. According to the Finnish calculation, only MCF in the inventory year (not the historical MCF values) has an effect on emissions. In Finland, almost all landfill sites were managed in the inventory year 2001, as well as in the reference year 1990. Therefore the methane correction factor (MCF) used for the year 2001 is 0.994 and in the year 1990 it is 0.982. MCF value cannot exceed 1, which gives an upper bound to uncertainty estimates. The uncertainties in MCF factors are small related to other uncertainties, and therefore the uncertainty range used for both years is -3%...+1.8% (though the uncertainty range would actually be slightly larger in 1990 than in 2001). The uncertainties are assumed to be gamma distributed. The use of only current and base year MCF values results in smaller uncertainties than in the IPCC estimates (from -10...+0% for MCF=1 to -50...+60% for MCF=0.06). This occurs, because MCF factor is nowadays much better known than in the past years, when landfills were not managed.

The IPCC default value for fraction of degradable organic carbon dissimilated (DOC_F) is 0.77, and the uncertainty is estimated at –30...+0%. In Finland, a lower estimate for DOC_F (0.5) is used, resulting in smaller uncertainty in lower bound, and higher in the upper bound. The Finnish uncertainty estimate is ±10% based on expert judgement.

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 ±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 (Penman et al. 2000), no uncertainty estimate for oxidation factor (OX) is given, because the value can be zero. In Finland, a non-zero value (0.1) is used, and the uncertainty is estimated to have a 95% confidence interval of -50...+10% with a shape of negatively skewed Gumbel distribution.

The uncertainty in methane generation rate constant (k=0.05) is estimated at -40...+300% in the IPCC Good Practice Guidance (Penman et al. 2000). This uncertainty estimate is also used in Finland, but it is assumed to be gamma distributed. The same estimate is also used for a constant k=0.03. For the highest methane generation rate constant (k=0.2) an uncertainty of –75%...+10% (beta distributed with beta=0.1) is used based on expert judgement. These uncertainty estimates are also assumed to contain the uncertainty associated with dividing waste into the categories with different k-values.

The IPCC default value of fraction of methane in landfill gas (F) is 0.5 and the uncertainty is estimated at -0...+20%. In Finland, the default value for F is used, but the uncertainty is estimated at ±22%. The fraction of methane is measured in 12 different landfills in Finland (Leinonen & Kuittinen 2001), and the uncertainty estimate is based on the deviation of the average fraction of methane in these sites. However, this estimate might overestimate the uncertainty, because the fraction of methane in landfill gas is difficult to measure. The uncertainty in measurements might be larger than the physical variation of the fraction of methane in landfill gas.

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 Finnish Biogas Plant register. This data is considered very accurate, and the uncertainty is estimated at ±5%.

The overall uncertainty in the Finnish inventory of solid waste disposal is around ±30%, which is quite a low estimate compared with Austria (42%) and UK (40%) (Winiwarter & Rypdal, 2001).

8.2 Other (6A3)

This sector consists of municipal sludge, industrial sludge, industrial solid waste and construction and demolition waste. In the UK inventory the uncertainty associated with methane emissions from sewage sludge is modelled with a truncated normal distribution with a 95% confidence interval of ±50% (Charles et al. 1998).

In the Finnish inventory, the amount of municipal sludge is estimated similarly based on GDP and population as the amount of domestic waste. However, the uncertainties also in current activity data are large. Therefore and uncertainty estimate -50...+100% (gamma distributed) 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 much more reliable estimate than e.g. the corresponding estimates of the municipal solid waste, that is estimated based on population and GDP. The uncertainty in the activity data of industrial sludge is estimated at ±50% until 1996 and ±30% 1997 onwards, because in 1997 improved statistics of the amount of waste was taken into use. In the case of industrial solid waste as well as construction and demolition waste, respective numbers are ±30% and ±15%. However, according to Hietanen (2001), different statistics differ by nearly 100% in the case of organic construction waste in 1997. This indicates that the estimated uncertainty in 2001 might be too low.

In this sector, the uncertainties in methane generation rate constant (k), in methane correction factor (MCF), in fraction of degradable organic carbon dissimilated (DOC_F), in methane recovery (R) and in oxidation factor (OX) is estimated to be the same as in the category 6A1, Solid waste disposal on land.

In this sector, however, the degradable organic carbon (DOC) value is estimated to be better known as in the case of municipal solid waste. The uncertainty is estimated at ±15%.

8.3 Industrial Wastewater (6B1)

Methane emissions from industrial and domestic wastewater are calculated multiplying three factors: organic load in wastewater (COD in industry, BOD in domestic), maximum methane producing capacity (B_0), and the methane conversion factor (MCF). COD and BOD are often referred as activity data, whereas the emission factor consists of B_0 and MCF.

According to Austrian emission inventory, the uncertainty in CH_4 emission factor from wastewater treatment is ±50% (Winiwarter & Rypdal 2001). In the Norwegian inventory the uncertainty in activity data of wastewater treatment (6B) is estimated at ±25%, and the corresponding CH_4 emission factor uncertainty at ±70% with a lognormal distribution (Rypdal & Zhang 2000).

The IPCC (Penman et al. 2000) gives an uncertainty estimate of -50%...+100% for COD/unit production, and ±25% for industrial production. In Finland, however, the activity data (COD) is based on VAHTI database and the Register for industrial Water Pollution Control. However, only the COD load into waters is measured (the incoming flow is not measured). The COD from pulp and paper industry is measured only in one year, and it is estimated constant in all years. Because the measurements are rather extensive, the uncertainty is estimated smaller than in IPCC recommendations and in other countries reviewed. The estimated uncertainties in the Finnish inventory are ±10% in 2001 and ±15% in 1990.

In the Finnish inventory, the value used as maximum methane producing capacity (B_0) is IPCC default factor. Therefore the uncertainty given by the IPCC for the factor (±30%) is also used in Finland. Methane conversion factor (MCF) is country-specific in Finland, and the uncertainty is estimated at -50...+100% gamma distributed based on expert judgement.

8.4 Domestic and Commercial Wastewater (6B2)

The IPCC Good Practice Guidance recommends an activity data uncertainty of ±30% for BOD/person and ±5% for population. The activity data for domestic and commercial wastewater sector (BOD) is based on accurate measurement data (both the incoming and outgoing flows are measured) in Finland. Therefore the uncertainty associated with BOD value is rather small, -5...+10%. The uncertainty in the upper bound is larger than in the lower bound, because small sewage treatment plants are not taken into account in the emission estimates.

CH_4 emissions from domestic wastewater in sparsely populated areas are calculated with a different method than CH_4 emissions from densely populated areas (one fifth of the population in Finland lives in sparsely populated areas). In sparsely populated areas, the IPCC check method is used, but in the uncertainty estimate, these are treated together according to the calculation of densely populated areas. The uncertainty in BOD/person is estimated to be the same in densely and sparsely populated areas, because the values used correspond well with measured values. However, the emission factors in the check method are too high according to national Expert Jouko Petäjä from Finnish Environment Research Institute. Therefore the uncertainty in the emission factors in sparsely populated areas should be negatively skewed. The current uncertainty estimate might therefore slightly overestimate the uncertainty in the upper bound. The CH_4 emissions from domestic wastewaters in densely and sparsely populated areas should therefore be differentiated in the forthcoming uncertainty estimates.

The used factor for maximum methane producing capacity (B_0) is the IPCC default factor. Therefore the uncertainty given for the factor by the IPCC (±30%) is also used in Finland. Methane conversion factor (MCF) is country-specific in Finland, and the uncertainty is estimated at -50...+100% gamma distributed based on expert judgement.

In N_2O emissions, the activity data for N input from human sewage is obtained from VAHTI database in densely populated areas, and the uncertainty is estimated at ±5%. In sparsely populated areas, the N input is calculated according to protein consumption. The uncertainty is estimated at ±10% based on expert judgement. This estimate might underestimate the uncertainty, but the total uncertainty is, however, dominated by the emission factor uncertainty. The emission factors, as well as the uncertainty estimates are obtained from the agriculture sector. The estimated uncertainty in emission factor is -92...+380% gamma distributed.

8.5 N input from Fish Farming (6B3)

In Finland, the activity data for N input from Fish Farming is obtained from VAHTI database. Because of the accuracy of the data, the uncertainty is estimated at ±10%. The emission factor contains much higher uncertainties. The estimated uncertainty in emission factor is the same as in domestic and commercial wastewater.

8.6 N input from Industrial Wastewater (6B3)

In Finland, the activity data for N input from industrial wastewater is obtained from VAHTI database. Because the data is seen very accurate, the uncertainty is estimated at ±5%. The emission factor used is the same as in domestic and commercial wastewater.

8.7 Differences between this study, the year 1999 uncertainty estimates and the IPCC estimates

In the year 1999 inventory, the emissions from solid waste disposal were estimated using mass balance model, whereas in the current inventory, a Tier 2 method, First Order Decay model (FOD), is taken at use. Therefore the changes in uncertainty estimates cannot be straight compared. However, the uncertainty estimates in 1999 and in this study, as well as the estimates of the IPCC are presented in Table 14.

Table 14. Comparison of estimates with the year 1999 inventory estimates and the IPCC estimates for Waste sector.

Input	IPCC category	1999 estimate[1]	2001 estimate	IPCC
Activity Data				
Managed Waste Disposal on Land	6A1	± 30%[2]	see text	> ± 10%
Municipal Sludge (d.m.)	6A3	± 30%[2]	-50...+100% (gamma)	> ± 10%
Industrial Sludge (d.m.), Industrial Solid Waste, Constr. and Demolition Waste	6A3	± 30%[2]	± 50% (-1996) ± 30% (1997-)	> ± 10%
Industrial Wastewater (COD)	6B1	± 30% [3]	±10% (2001) ±15% (1990)	-50...+100%[4]
Domestic and Commercial Wastewater (BOD)	6B2	± 30% [3]	-5...+10%	± 30%[4]
N input from Fish Farming	6B3	± 30% [3]	± 10 %	-
N input from Ind. Wastewater	6B3	± 30% [3]	± 5 %	-
N-input from human sewage (sparsely pop.areas)	6B3	± 30% [3]	± 10 %	-

N-input from human sewage (densely pop. areas)	6B3	± 30% [3]	± 5 %	-
Emission Factors				
Solid waste disposal on land (CH_4)	6A	± 40%[2]	-	-
Industrial Wastewater, Domestic and Commercial Wastewater (CH_4)[5]	6B	± 40%[3]	±30% (B_0) -50...+100% (MCF)	± 30% (B_0) -
Domestic and Commercial Wastewater, N input from Fish Farming, N input from Ind Wastewaters (N_2O)	6B2	± 100%[3]	-92...+380% (gamma)	see [6]
Calculation parameters for FOD model				
k	6A	-	see Table 13	k=0.05 -40...+300%
MCF	6A	-	-3 %...+1.8 neg Gumbel	MCF=1: –10...+0% MCF=0.4: –30...+30% MCF=0.6: –50...+60%
DOC	6A	-	±20% normal (6A1) ±15% normal (6A3)	-50...+20%
DOC_F	6A	-	±10% normal	-30...+0%
R	6A	-	±5% normal	relatively small
F	6A	-	±22% normal	-0...+20%
OX	6A	-	-50...+10% gamma	-

[1](Aaltonen et al. 2001). All uncertainties are assumed normally distributed
[2] Estimate given totally for sector 6A
[3] Estimate given totally for sector 6B
[4]These values refer to BOD/person and COD/unit production
[5]emission factor consists of B_0 and MCF
[6]The used estimates are the same as in IPCC 1996a for agriculture sector

9. Combining uncertainties

In the IPCC Good Practice Guidance, two methodologies (Tier 1 and Tier 2) for combining uncertainties are defined. Tier 1 uses error propagation equations. The equations are appropriate, when uncertainties are relatively small, have normal distributions and have no significant covariance (though the method can be extended to allow covariances). Tier 2 is more sophisticated method using Monte Carlo simulation, and it is the main method used in this study. However, according to the IPCC Good Practice Guidance (Penman et al. 2000), countries performing an uncertainty analysis according to Tier 2 should also report the Tier 1 results.

To obtain the total inventory uncertainty, different gases are weighted according to their Global Warming Potential (GWP) values. Uncertainties in the GWP-values were not taken into account in inventory uncertainty estimates.

9.1 Error Propagation Equations (Tier 1)

Tier 1 method combines uncertainties using error propagation equations. If uncertainties are combined by multiplication (for example, activity data is multiplied with emission factor), the Equation (2) is used (Penman et al. 2000),

$$U_{total} = \sqrt{(U_1^2 + U_2^2 + U_3^2 + ... + U_n^2)} \qquad (2)$$

where U_{total} is the percentage uncertainty in the product of the quantities (half the 95% confidence interval divided by the total and expressed as percentage) U_i is the percentage uncertainty associated with each of the quantity

If quantities are combined by addition (e.g. summation of different gases or sectors), the Equation (3) is used (Penman et al. 2000)

$$U_{total} = \frac{\sqrt{(U_1 x_1)^2 + (U_2 x_2)^2 + ... + (U_n x_n)^2}}{x_1 + x_2 + ... + x_n} \qquad (3)$$

where x_i is the uncertain quantity.

In the case of asymmetrical distributions, the larger uncertainty is used.

9.2 Monte Carlo Simulation (Tier 2)

For the 2001 inventory Monte Carlo simulation was used 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 tens of thousands of times to obtain the probability distribution of total emissions.

Monte Carlo simulation allows the use of asymmetrical distributions. They occur when uncertainties are large, because emissions cannot be negative, but the upper bound of possible emissions may be poorly known. Asymmetrical distributions occur mainly with methane and nitrous oxide emission factors.

A number of commercial software packages enabling Monte Carlo simulation were tested, and Crystal Ball (Decisioneering 2000) was chosen. It is an add-in for Microsoft Excel. In Crystal Ball, the number of simulations is not limited, and correlations are easy to add. In most emission sources, emissions are expressed as an emission factor multiplied by activity data. For both variables, the upper and lower percentiles, as well as the shape of distribution (e.g. normal, lognormal) must be defined. In some three-parametric distributions (e.g. gamma, Weibull) also a shape parameter must be determined.

For the purposes of this study, calculating was continued until a precision level of total emissions and trend of emissions reached 1%, both in mean value and upper (97.5) percentile. The selected precisions were obtained after about 40 000 trials. A fixed seed value (i.e. 999) was used in the generation of random numbers. Fixed seed value is essential in proper calculation of the trend (corresponding random numbers are selected for both years).

9.3 Correlations

Correlations may have a significant effect on the overall inventory uncertainty. For example, total fuel use is often accurate, but the sectoral shares of fuel use are often rather poorly known. When the use of same fuel type is correlated in several categories, the overall uncertainty can be kept at a lower level, because the uncertainty at the upper level is small.

When calculating trend, it was assumed that all emission factors of 1990 and 2001 correlate, whereas activity data are assumed not to correlate. There is, however, one exception: peat production areas and arable peatlands are assumed to correlate between the years 1990 and 2001, because the same activity data is used for the whole time series.

In the calculation of Solid Waste Disposal on Land using the First Order Decay Method (FOD), same parameters (decay factors, fraction of methane in landfill gas etc) were used throughout.

The use of gasoline is assumed fully (100%) correlated in road transportation (in cars with or without catalytic converters), waterborne navigation (leisure boats) and off-road machinery.

The use of liquid fuels in Other Sectors (residential/commercial, agriculture, forestry, fisheries etc.), Other (residue of fuel used), Navigation (residual oil & gas/diesel oil) and Other Transportation (off-road machinery with diesel engines) is assumed to correlate negatively with a correlation coefficient of -0.25, as the total fuel use is better known than sectoral shares. This is only a preliminary correlation estimate, and further research is required for a more accurate estimate of the correlation.

The same activity data has been used in all gases of a specific source category, and therefore the activity data of a specific source category fully correlates between gases.

10. Results

This chapter presents the results of uncertainty analysis performed for the Finnish 2001 Greenhouse Gas Emission Inventory. Results are presented by sector and gas. The total level and trend uncertainties are also presented together with identified key source categories. The results reported in the National Inventory Report (NIR) (Ministry of the Environment 2003), are presented in Appendix A. Results of Tier 2 (Monte Carlo simulation), which was the main method used in this study, are presented in Table A.

The emissions in 1990 and 2001 in this study differ from the sums reported in the inventory. There are three reasons for this: rounding and simulation may alter the mean value slightly. Secondly, CO_2 emissions from agricultural soils are not taken into account in the uncertainty estimation, because they are not dealt with in the "Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Emission Inventories" (Penman et al. 2000), but will be covered by the LULUCF Good Practice Guidance (these emissions may be reported in Agriculture or LUCF sector). Thirdly, the uncertainty estimates are based on figures sent to the European Commission in December 2002. Thus, some minor differences with the submission to the UNFCCC might occur.

One of the main purposes of this work was to develop an uncertainty calculation model for the Finnish greenhouse gas emission inventory, which could be used annually. The model prepared during this project is being developed further to make it easy to use.

10.1 Sectoral Uncertainties

In the paragraphs below, uncertainties resulting from Monte Carlo simulation are presented sector by sector. For most sectors, sensitivity charts are presented. The sensitivities are calculated by computing rank correlation coefficients between all input parameters by the simulation tool Crystal Ball. The uncertainty distributions in figures 16-18 have been fitted to the data from Monte Carlo simulation, which makes the distributions smoother than those that derive from the simulation.

10.1.1 Energy – Fuel Combustion (1A)

Fuel combustion releases CO_2, CH_4 and N_2O. In the fuel combustion sector, the uncertainty in the 2001 emissions is ±3%. Fuel statistics are accurate in Finland, but the allocation of total fuel use into sectoral shares is less accurate. The factors affecting the uncertainty most are presented in Figure 11. It can be seen that the three most important factors affecting uncertainty are activity data values. This is due to the fact that uncertainty in activity data also affects uncertainty in CO_2 emissions that have a substantial share of total emissions. The CH_4 and N_2O emission factors have larger uncertainties than activity data values, but the effect on total emissions is smaller.

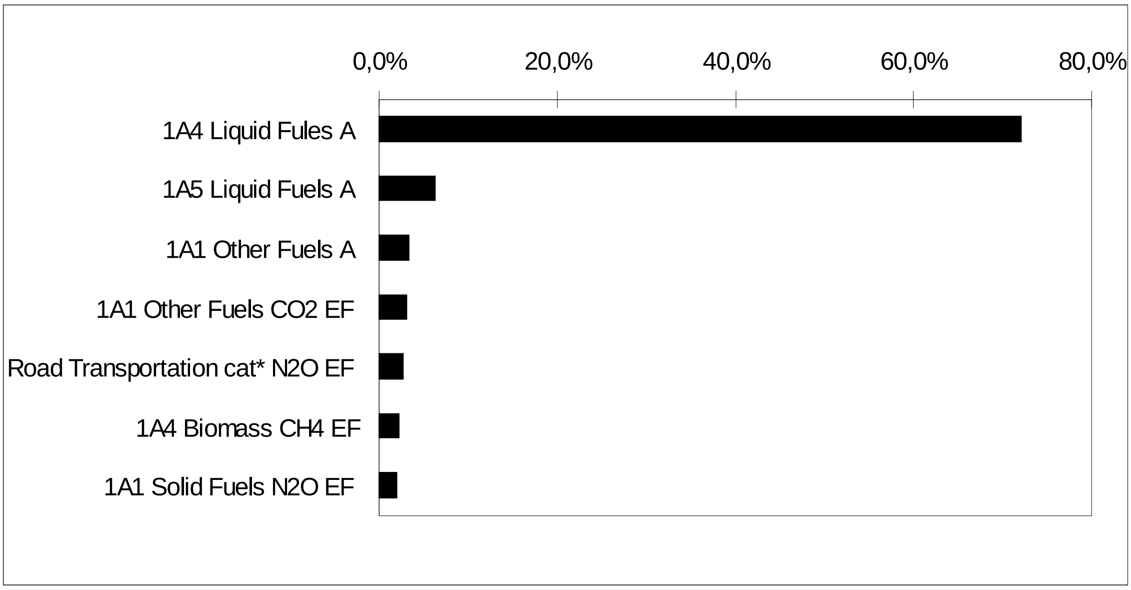

Figure 11. Factors affecting uncertainty most significantly in the fuel combustion sector, presented by the contribution to variance. A denotes activity data and EF emission factor. Cat denotes cars with catalytic converters.*

The uncertainties gas by gas in fuel combustion sector are as follows: ±3% for CO_2, -43...+94% for CH_4 and -25...+36% for N_2O. The N_2O emissions are usually less well known than the CH_4 emissions. In this uncertainty estimate, many of the N_2O emission factor uncertainties are negatively skewed (due to too large emission factors used), thus causing in smaller total uncertainty, because positively and negatively skewed distributions seem to cancel each other. The most important factor affecting the uncertainty in methane emissions is the emission factor in biomass combustion in Other sectors, with a 96% contribution to variance. However, it must be noted that the uncertainty in this emission factor was based on expert judgement (-70...+150%) due to lack of measurement data, whereas most of the other emission factors were assumed negatively distributed based on a few measurements. The most important factors affecting the uncertainties in nitrous oxide, in turn, are presented in Figure 12.

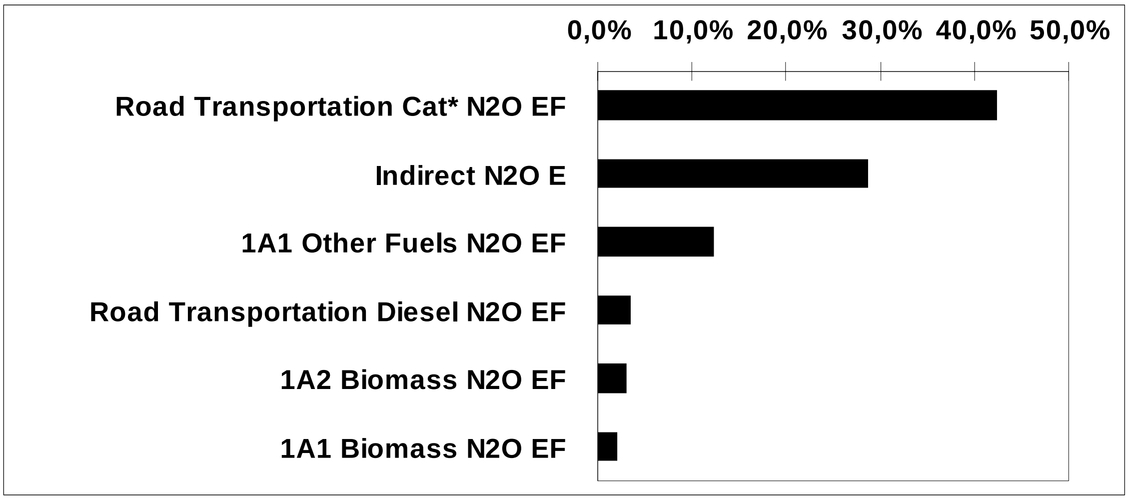

Figure 12. Factors affecting uncertainty most significantly in N_2O emissions from fuel combustion, presented by the contribution to variance. E denotes emissions and EF emission factor. Cat denotes cars with catalytic converters.*

The uncertainties by subsector and gas are presented in Table 15.

Table 15. Uncertainties by subsector and gas in Fuel Combustion.

Sector	Gas	Uncertainty
Energy Industries (1A1)	CO_2	±2%
	CH_4	-25...+20%
	N_2O	-38...+65%
Manufacturing Industries and Construction (1A2)	CO_2	±2%
	CH_4	-41...+21%
	N_2O	-34...+40%
Transport (1A3)	CO_2	±1%
	CH_4	-35...+36%
	N_2O	-51...+97%
Other Sectors (1A4)	CO_2	±28
	CH_4	-67...+144%
	N_2O	-58...+47%
Other (1A5)	CO_2	-40...+39%
	CH_4	-67...+52%
	N_2O	-70...+54%

If transport sector (1A3) is considered separately, the most important factors affecting uncertainty in CO_2 emissions are (in descending order of importance) emission factor of diesel in road transportation, emission factor of gasoline in road transportation, activity data of diesel in road transportation and activity data of gasoline in road transportation. In the case of methane, emission factor of gasoline in road transportation alone represents nearly 90% of the contribution to variance, whereas in the case of nitrous oxide, emission factor of cars with catalytic converters also represents nearly 90% of the contribution to variance. This shows the significance of road transportation in the case of uncertainties in the transport sector.

10.1.2 Energy – Fugitive Emissions (1B)

The largest source of fugitive emissions from fuels is CO_2 emissions from peat production. Peat production releases also CH_4. The uncertainties in these can be seen from Table A in Appendix A. Fugitive emissions from oil and gas are better known than the emissions of peat production, and can also be seen from the above mentioned table. The total uncertainty in fugitive emissions from fuels is -59...+106%. The most important factors affecting the uncertainty are the area of arable peatlands, CO_2 emission factor for peat production areas and CO_2 emission factor for arable peatlands.

10.1.3 Industry (2)

Industrial processes release all greenhouse gases of the Kyoto Protocol. The total uncertainty in Industrial processes in 2001 was -27...+43%. Nitric acid production is the only N_2O source in the industrial sector. Uncertainty in this sector is -57...+99% and it dominates the total uncertainty of the sector. The uncertainty in CH_4 emissions from industrial sector (ethylene production and iron and steel production) is ±15%. The CO_2 emissions from industrial processes occur in cement and lime production, and their uncertainty together is ±6%. The emissions of F-gases from the industrial sector are discussed in Chapter 10.2.4.

10.1.4 Agriculture (4)

The agriculture sector releases methane and nitrous oxide. Agricultural soils release also CO_2, but the uncertainties in these emissions are not considered in this uncertainty estimate, because they are not included in the “Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Emission Inventories” (Penman et al. 2000), but will be covered in the LULUCF Good Practice Guidance (these emissions can be reported in either Agriculture or LUCF sector). The total uncertainty in Agriculture sector is -37...+47%. The uncertainties by subsectors are presented in the Table A of Appendix A. The factors affecting the total uncertainty most in the Agriculture sector are presented in Figure 13.

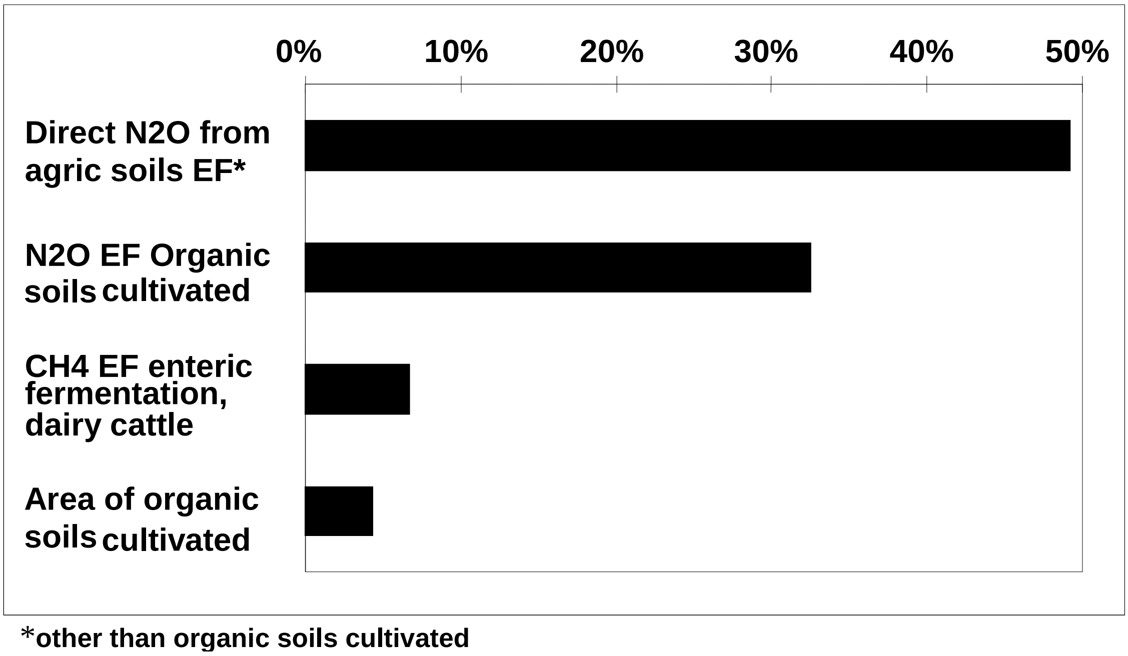

Figure 13. Factors contributing 90% of the variance in Agricultural sector. EF denotes emission factor.

10.1.5 Waste (6)

Waste sector releases CH_4 and N_2O. The share of methane emissions is large, but the N_2O emissions contain higher uncertainties. The total uncertainty in the waste sector in 2001 was -28...+30%, gamma distributed. Total emissions are dominated by Solid Waste Disposal on Land. The uncertainty of this sector was -29...+31%, also gamma distributed. The uncertainty in Wastewater treatment was clearly higher, i.e. -55...+118% lognormally distributed.

Figure 14 presents a sensitivity chart of solid waste disposal on land. It can be seen that the factor clearly affecting the uncertainty most is F, 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 can be larger than the real uncertainty in the fraction of methane in landfill gas. The second most important factor is DOC_F, 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 k. If we look at the five most important factors affecting the total waste sector uncertainty, four main factors are the same as above, deriving from solid waste disposal on land, but the fifth one is N_2O emission factor from wastewater treatment of densely populated areas.

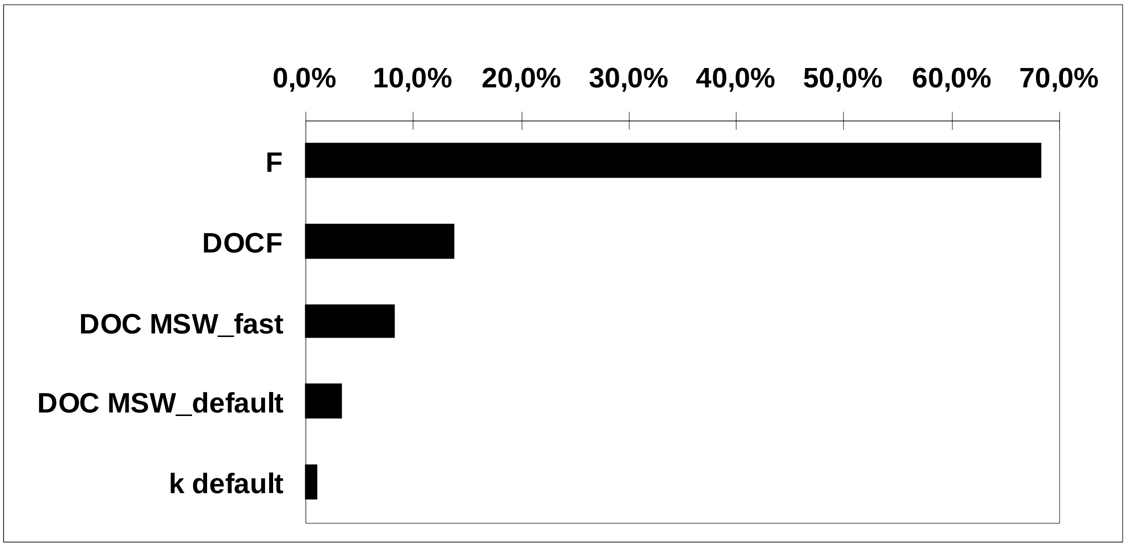

Figure 14. Sensitivity chart of solid waste disposal on land.

In the sensitivity chart (Figure 15) of Wastewater Handling Sector (6B), three of the six most important factors affecting the total uncertainty are N_2O emission factors of different wastewater sources. Two of the factors are methane conversion factors (MCF) for domestic and industrial wastewater. The maximum methane production capacity (B_0) of domestic and commercial wastewater is also one of the most important factors.

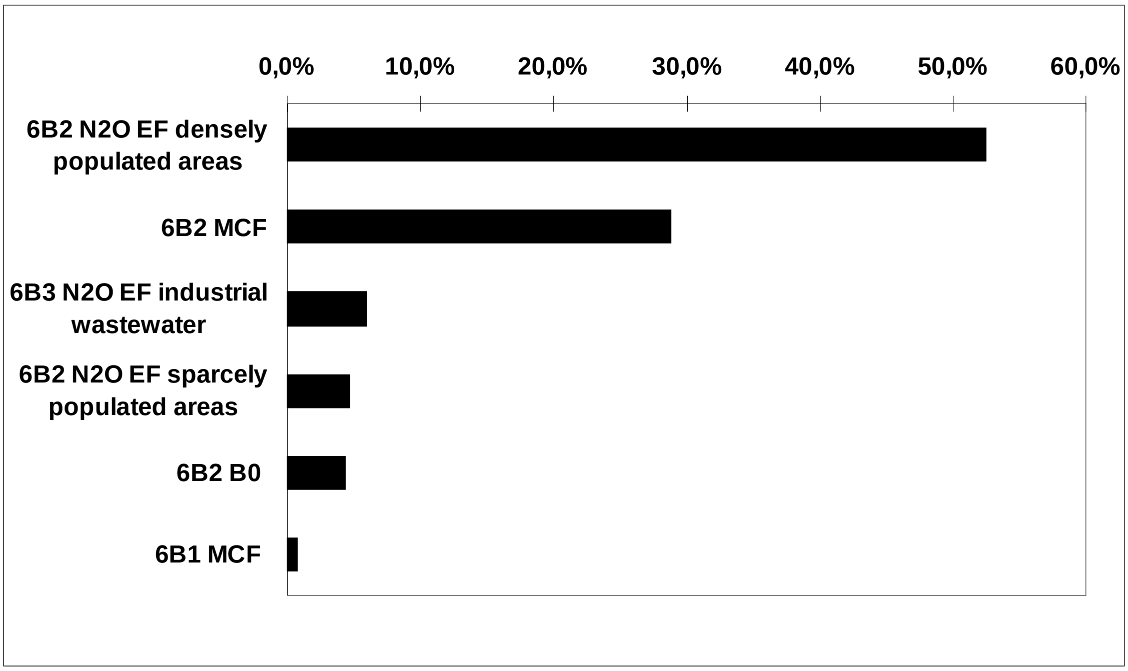

Figure 15. Sensitivity chart of wastewater handling. EF denotes emission factor.

In Figure 16, uncertainty distributions of Solid Waste Disposal on Land (6A) and Wastewater Handling (6B) are presented, as well as the distribution of the sum. It can be seen that distribution of Wastewater Handling is 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).

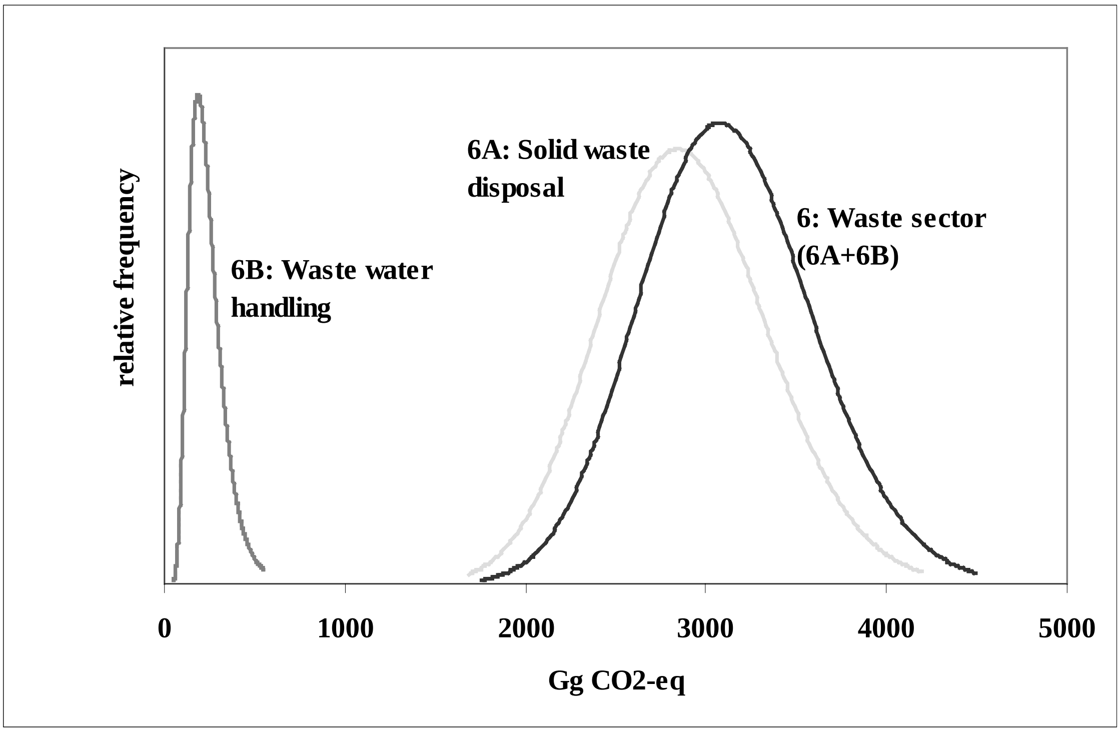

Figure 16. Uncertainty distributions in the waste sector.

When emissions from waste sector are considered gas by gas, we notice that the uncertainty in CH_4 emissions is almost the same as the uncertainty in Solid Waste Disposal on Land. Uncertainty in N_2O emissions (which come entirely from the wastewater sector) is -84...+264%. Uncertainty distributions by gas are presented in Figure 17.

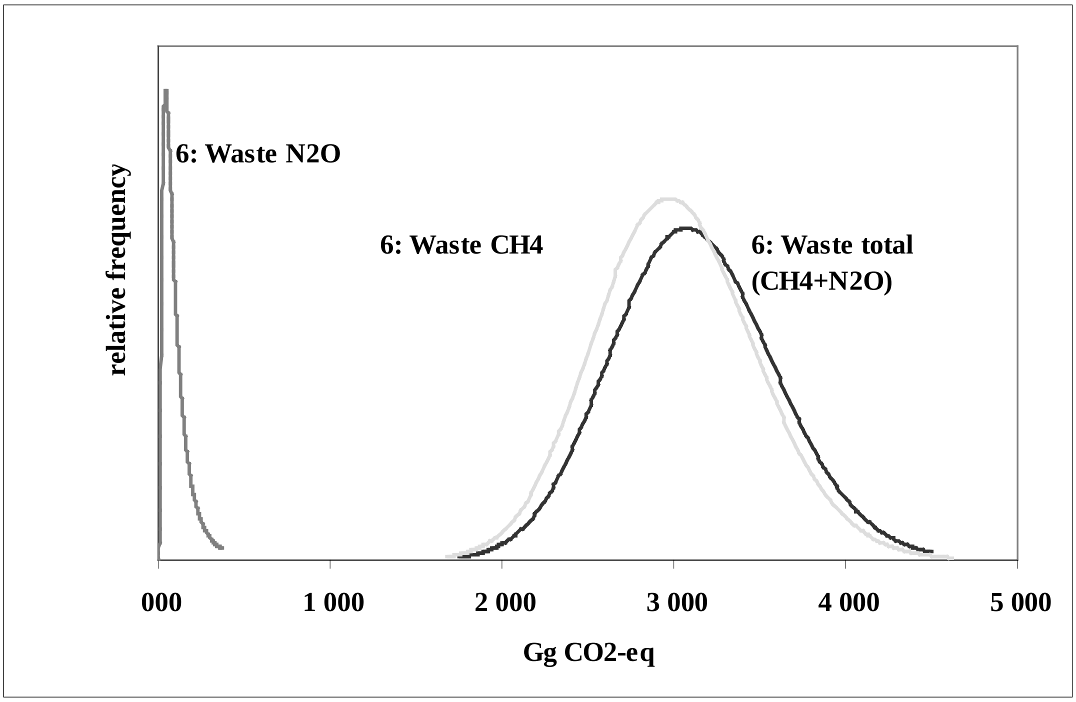

Figure 17. Uncertainty distributions of CH_4 and N_2O emissions in the waste sector.

10.2 Uncertainties by Gas

Uncertainties by gas in the 2001 inventory are as follows: -4...+6% for CO_2, -19...+20% for CH_4, -33...+40% for N_2O and –53...+32% for HFCs, PFCs and SF_6 together. The share of CO_2 emissions is substantial. Figure 18 shows the uncertainty distributions by gas.

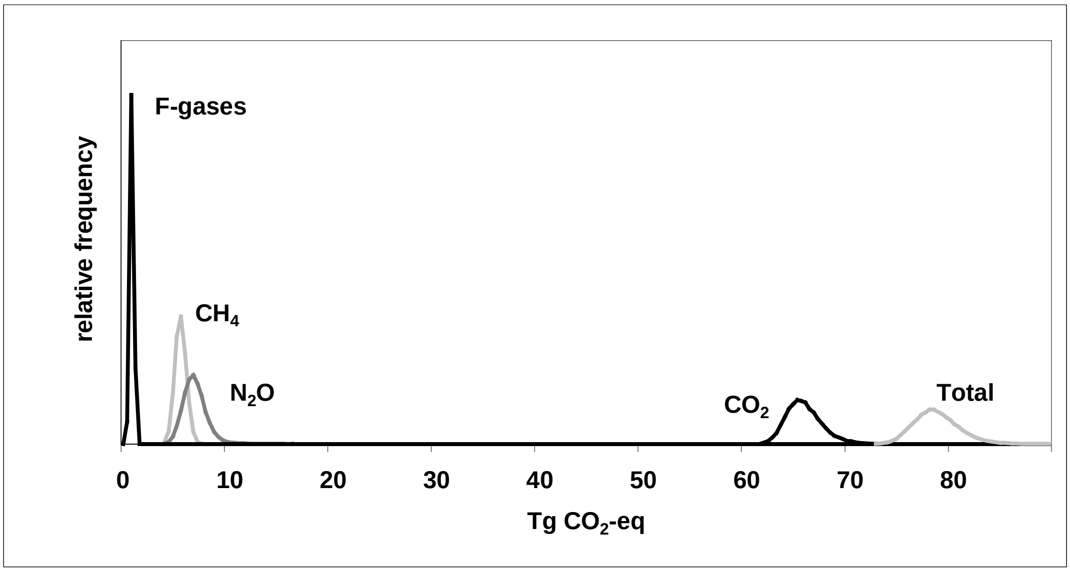

Figure 18. Uncertainty distributions by gas in the 2001 emission inventory.

10.2.1 CO_2

The total uncertainty in CO_2 emissions is -4...+6%. The most important source of CO_2 is emissions from fossil fuel combustion. These emissions are accurately known. The other sources of CO_2 are fugitive emissions from fuels, and emissions from industrial processes. The factors affecting the uncertainty in CO_2 emissions most (in a descending order of importance) are area of arable peatlands, activity data in Other sectors (1A4), emission factor of peat production areas and emission factor of arable peatlands.

10.2.2 CH_4

CH_4 emissions occur in all sectors (except solvent use): fuel combustion, fugitive emissions from fuels, industrial processes, agriculture and waste. The total uncertainty in CH_4 emissions in the year 2001 inventory 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 CH_4 emissions come from various sectors. The factor affecting the uncertainty in CH_4 emissions most is solid waste disposal on land with a 57% contribution to variance. 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 other sectors. The remaining CH_4 emission sources are only of minor importance.

10.2.3 N_2O

N_2O emissions occur in fuel combustion, industrial processes, solvent and other product use, agriculture and waste sectors. The total uncertainty in N_2O emissions is -33...+40%. Due to apparently too high emission factors, negatively skewed distributions are used to describe some N_2O emission factors from fuel combustion. In forthcoming inventories, if the emission factors are adjusted, or if additional information indicates correctness of emission factors, the uncertainty in the upper bound increases.

Most of the factors affecting the N_2O uncertainty most come from the emissions from agricultural soils. The most important factor is the emission factor of direct N_2O emissions from agricultural soils. The following ones are emission factor of nitric acid production and the emission factor of cars with catalytic converters.

10.2.4 HFCs, PFCs and SF_6

The emissions of F-gases (HFCs, PFCs and SF_6) occur entirely in the industrial sector. The total uncertainty in F-gas emissions is -53...+32%. The uncertainty is nearly Gumbel distributed. The most important source of F-gas emissions in Finland is refrigeration and air conditioning equipment which also affects uncertainty most, with a 99% contribution to variance. The uncertainties in F-gases are described in more detail in (Oinonen 2003).

10.3 Overall Inventory Uncertainty in 2001 (Tier 2)

The total uncertainty in the 2001 emissions is -5...+6%. Uncertainty is rather low, because the CO_2 emissions from fuel combustion, which are accurately known, dominate the emission level. The most important source categories affecting total uncertainty (key sources) are presented in Chapter 10.6. In addition to key source identification, the factors affecting total uncertainty most are identified with a national method that uses sensitivity analysis in a very disaggregated level. The most significant factors affecting uncertainty, measured by their contribution to variance, are presented in Figure 19. Three of five most important factors are related to peat production. The second most important factor is activity data in Other sectors (residential, commercial, agriculture, forestry, fisheries etc. fuel use). The possibilities to reduce uncertainties in these sectors are discussed in the Chapter 12, Recommendations for further studies.

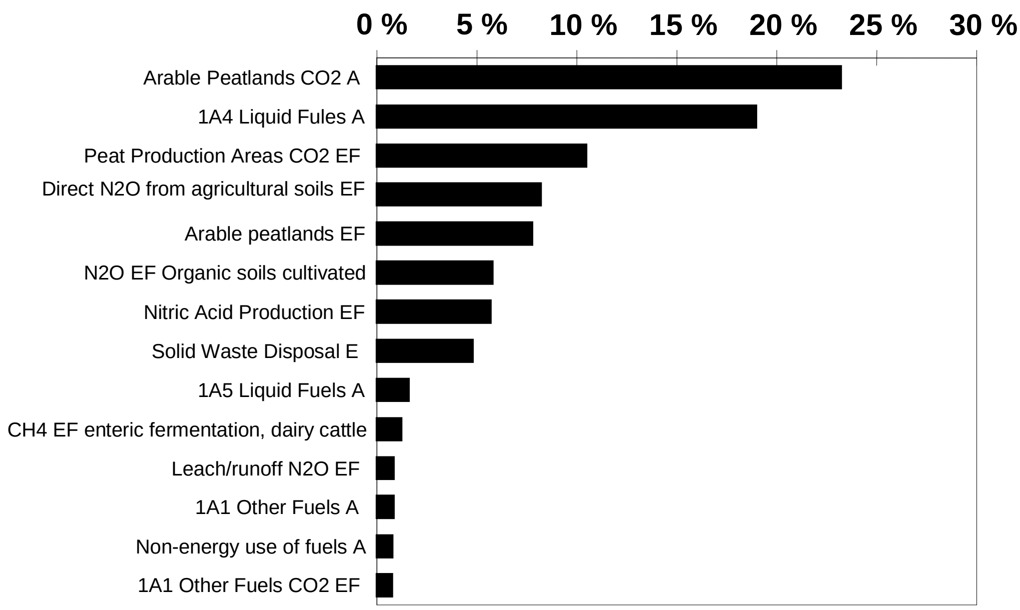

Figure 19. The level key sources in the Finnish 2001 emission inventory using the national method. The key sources are measured by their contribution to variance. EF denotes emission factor, A activity data and E emissions.

10.4 Uncertainty calculated with the Tier 1 method

The results of the Tier 1 calculations are presented in Annex A in Table B. The resulting total uncertainty is ±7%. This uncertainty is slightly larger than the result obtained with the Tier 2 method, mainly due to the use of larger uncertainty in the case of asymmetrical uncertainty distributions. However, when most of the distributions used are normal or nearly normal, Tier 1 is a good method to check whether the Monte Carlo simulation gives reliable results.

Tier 1 and Tier 2 methods give significantly different results for trend uncertainty. The trend uncertainty that is calculated with the Tier 1 method is ±6%. This is discussed in more detail in the following section.

10.5 Uncertainty in trend

Guidelines for the calculation of trend with Tier 2 method given in IPCC Good Practice Guidance (Penman et al. 2000) are not unambiguous. However, the uncertainty in trend of all source categories is calculated simulating the difference between emissions in 2001 and 1990 (Emissions (2001) – Emissions (1990)). The 2.5 and 97.5 percentile values were taken from the resulting distributions, and they were divided by the total emissions of 1990 (a constant value, not a distribution), to obtain the possible change in emissions according to 95% confidence interval. The results of these calculations are presented in the columns I and J of the Table A in Appendix A.

Change in the emissions between 1990 and 2001, which is estimated at 6%, could have values between 2%...11% according to 95% confidence interval. Therefore, the trend uncertainty is ±5% percentage *points* (the lower bound is -5%-points due to rounding, though it seems as if it was -4%-points). However, calculated with the Tier 1 method (Table B in Appendix A), the trend uncertainty was ±6 *percents*. The calculation of trend uncertainty with Tier 2, and the reasons for differences between Tier 1 and Tier 2 should be researched further. Nevertheless, other countries (using the Tier 2) reviewed here have calculated trend uncertainties similar to those in Finland (i.e. ±4-5% percentage points).

10.6 Key Source Identification

Key sources are emission sources, which have a significant effect on emission level, trend or both. In the key source identification there are also two different tiers. In Tier 1, key sources are identified by finding the source categories which, when summed up in descending order of magnitude, add up to over 95% of the total level of emissions or emission trend. In the Tier 2 method, also the uncertainties of each emission source are taken into account. Key sources are the sources, which contain 90% of the level or trend uncertainty (Penman et al. 2000).

In this study, the Tier 2 method was used to identify the key sources. In the level key source identification, a level assessment with uncertainty $LU_{x,t}$ was calculated for each source category in the year 2001 according to equation (4) (Penman et al. 2000):

$$LU_{x,t} = \frac{E_{x,t}}{E_t} U_{x,t} \qquad (4)$$

, where

$E_{x,t}$ is the emission estimate of source category x in year t
E_t is total emissions in year t
$U_{x,t}$ is the source category uncertainty (the larger uncertainty resulting from the Monte Carlo simulation)

The source categories are then ranked according to descending magnitude of $LU_{x,t}$. $LU_{x,t}$ values are then divided by LU_t (sum of all $LU_{x,t}$) and summed up (with the descending order of magnitude) until the sum reaches 0.9. All emission sources above that are key sources. In the Finnish 2001 inventory, 25 level key sources were identified. They are presented in Table 16. It can be seen that the most important key sources are those with large uncertainties, namely CO_2 emissions from peat production and N_2O emissions from agricultural soils.

Table 16. Level key sources of the Finnish 2001 Emission inventory.

A	B	C	D	E
Source category number	**Gas**	**Level key sources**	**Level assessment with uncertainty[1]**	**Cumulative total of column D**
1.B	CO_2	Arable peatlands	0.1702	0.1702
4.D	N_2O	Agricultural soils	0.1316	0.3018
1.B	CO_2	Peat production areas	0.1068	0.4086
1.A.4	CO_2	Other sectors: liquid fuels	0.0881	0.4967
2.B.2	N_2O	Nitric acid production	0.0644	0.5611
6.A	CH_4	Solid waste disposal on land	0.0470	0.6081
1.A.1	CO_2	Energy industries: other fuels	0.0283	0.6364
1.A.5	CO_2	Other: liquid fuels	0.0271	0.6635
1.A.3	N_2O	Road transportation: gasoline (cars with catalytic converters)	0.0269	0.6904
4.A	CH_4	Enteric fermentation	0.0245	0.7149

1.A.4	CH_4	Other sectors: biomass	0.0239	0.7388
1.A.1	CO_2	Energy industries: solid fuels	0.0192	0.7579
2.F.1	HFCs	Refrigeration and air conditioning equipment	0.0183	0.7762
7	CO_2	Other – non-energy use of fuels	0.0178	0.7940
4.B	N_2O	Manure management	0.0166	0.8107
1.A	N_2O	Indirect N_2O from fuel combustion	0.0161	0.8268
1.A.1	N_2O	Energy industries: other fuels	0.0140	0.8408
6.B.2	N_2O	Domestic and commercial wastewater: densely populated areas	0.0135	0.8542
1.A.2	CO_2	Manufacturing industries and construction: solid fuels	0.0101	0.8643
1.A.3	N_2O	Road transportation: diesel	0.0081	0.8724
1.A.4	N_2O	Other sectors: liquid fuels	0.0072	0.8797
1.A.2	N_2O	Manufacturing industries and construction: biomass	0.0070	0.8867
1.A.3	CO_2	Road transportation: diesel	0.0066	0.8933
1.A.2	CO_2	Manufacturing industries and construction: liquid fuels	0.0064	0.8997
6.B.2	CH_4	Domestic and commercial wastewater	0.0062	0.9060

[1] $LU_{x,t}/LU_t$

The sensitivity chart presented in chapter 10.3 is a national method to identify level key sources. The results are almost the same as those presented here. The sensitivity analysis is performed in a more disaggregated level than key source identification (e.g. emission factors and activity data are separated), which is an advantage.

In the key source identification of trend, the following equation (5) is used (Penman et al. 2000):

$$TU_{x,t} = \frac{E_{x,t}}{E_t}\left|\frac{E_{x,t} - E_{x,0}}{E_{x,t}} - \frac{E_t - E_0}{E_t}\right|U_{x,t} \qquad (5)$$

, where subscript 0 denotes the year 1990, and the other factors are the same as in the calculation of level key sources in Equation (4).

However, it is not clear, if the parameter $U_{x,t}$ should denote uncertainty in trend rather than level. Here, in the trend uncertainty assessment, $U_{x,t}$ is understood to be the same as in the calculation of level uncertainty. The trend key sources are identified similarly as the level key sources. The key sources by trend are presented in Table 17.

Table 17. Key sources by trend.

A	B	C	D	E
Source category number	**Gas**	**Trend Key Sources**	**Trend assessment with uncertainty**[1]	**Cumulative total of column D**
4.D	N_2O	Agricultural soils	0.1657	0.1657
1.A.4	CO_2	Other sectors: liquid fuels	0.1120	0.2777
1.A.3	N_2O	Road transportation: gasoline (cars with catalytic converters)	0.0829	0.3606
2.B.2	N_2O	Nitric acid production	0.0775	0.4381
2.F.1	HFCs	Refrigeration and air conditioning equipment	0.0631	0.5013
6.A	CH_4	Solid waste disposal on land	0.0569	0.5582
1.A.1	CO_2	Energy industries: other fuels	0.0439	0.6021
1.B	CO_2	Arable peatlands	0.0381	0.6402
1.A	N_2O	Indirect N_2O from fuel combustion	0.0320	0.6722
4.B	N_2O	Manure management	0.0299	0.7021
1.B	CO_2	Peat production areas	0.0239	0.7260
1.A.5	CO_2	Other: liquid fuels	0.0237	0.7497
4.A	CH_4	Enteric fermentation	0.0229	0.7726
1.A.3	N_2O	Road transportation: gasoline (cars without catalytic converters)	0.0172	0.7898
1.A.1	N_2O	Energy industries: biomass	0.0165	0.8063
1.A.3	N_2O	Civil aviation	0.0147	0.8210
6.B.2	N_2O	Domestic and commercial wastewater (densely populated areas)	0.0144	0.8355
1.A.4	CH_4	Other sectors: biomass	0.0123	0.8478
1.A.4	N_2O	Other sectors: biomass	0.0093	0.8571
1.A.2	N_2O	Manufacturing industries and construction: other fuels	0.0090	0.8661
1.A.2	CO_2	Manufacturing industries and construction: solid fuels	0.0086	0.8747
1.A.2	N_2O	Manufacturing industries and construction: liquid fuels	0.0085	0.8832
1.A.2	N_2O	Manufacturing industries and construction: biomass	0.0081	0.8913
1.A.1	N_2O	Energy industries: other fuels	0.0079	0.8992
1.A.1	CO_2	Energy industries: gaseous fuels	0.0078	0.9070

[1] $TU_{x,t}/TU_t$

Key source category analysis summary is presented in the Table E of Appendix A.

11. Sensitivity analysis

A sensitivity analysis was performed in four different cases. Two of them show the sensitivity of the total inventory uncertainty for two emission sources. The other two sensitivity cases presented the significance of some choices performed in the modelling process. The results are presented in Table 18.

Table 18. Sensitivity studies performed.

Case	Description	Action	Main results
A	Peat Production	Peat production excluded from the inventory calculation	Total inventory uncertainty decreased from -5...+6% to -4...+5%; energy sector uncertainty decreased from -5...+6% to ±3%
B	Other sectors: Activity Data	Activity data uncertainty lowered from ±30% to ±5%	Trend uncertainty decreased from ±5%-points to ±3%-points
C	Correlations	Correlations between emission factors (between different years) turned off	Trend uncertainty increased from ±5%-points to ±9%-points
D	Shape of Distribution	All distributions assumed normal, max uncertainty ±100%	No notable effect

In Case A, the emissions from peat production (i.e. fugitive emissions from solid fuels) were excluded from the inventory total. Emissions from peat production areas and arable peatlands will probably be moved into LULUCF sector in forthcoming inventories. This represents the uncertainty of other sectors than LULUCF in these conditions. As a result of simulations, total inventory uncertainty decreased from -5...+6% to -4...+5%, and the energy sector uncertainty from –5...+6% to ±3%. This shows the great effect of peat production on the total uncertainty in Finland. This change did not, however affect uncertainty in trend, because emissions from peat production are estimated to remain unchanged from year to year and the effect of peat production on the trend is therefore rather insignificant.

In the Finnish inventory, uncertainty in sectoral shares of liquid fuel use is described in the uncertainty analysis as a large uncertainty in activity data (±30%). Uncertainty in oil use is estimated at ±1-5% Austria, Norway, the Netherlands, the UK and the USA (Rypdal & Winiwarter 2001; Rypdal & Zhang 2000). In addition, according to IPCC (Penman et al. 2000), the uncertainty in activity data is ±3-±5%. Therefore, in Case B, the uncertainty in liquid fuels activity data in Other Sectors was reduced from ±30% to ±5%. The changes in total level uncertainty were minor, but the effect on trend uncertainty was significant: it decreased from ±5%-points to ±3%-points. In addition, uncertainty in total fuel combustion CO_2 emissions decreased from ±3% to ±2%.

Currently all emission factors in the Finnish inventory uncertainty estimation are assumed 100% correlated between 1990 and 2001. In Case C, the correlations between emission factors in different years were turned off. The ignorance of this assumption increases the trend uncertainty from ±5%-points to ±9%-points.

In Case D, all input distributions were replaced with normal distributions according to larger uncertainty limit. If the upper value was >100%, an uncertainty of ±100% was used. This assumption did not, however, have notable effect on total level or trend uncertainties. The most important emission sources (CO_2 emissions from fuel combustion) are assumed normally distributed, and this explains at least partly that the change of non-normal distributions into normal did not have a significant effect on total uncertainty.

12. Recommendations for Further Research

In general, uncertainties in inventory input parameters are not likely to vary significantly from year to year, and therefore, the uncertainty estimates presented here can be used as a basis for uncertainty estimates in forthcoming inventories. However, a lot of work is still required to increase the accuracy of emission inventories and uncertainty estimates. In the following chapters, recommendations for further study are given concerning both emission calculation and uncertainty estimates.

Only a few Parties of the UNFCCC have performed a detailed uncertainty analysis, but the number of uncertainty estimates is steadily increasing, and it is therefore necessary to follow the work done in other countries, e.g. by comparing the National Inventory Reports.

12.1 Methodology

- *Calculation of trend uncertainty* in the Tier 2 method is not unambiguous. Trend uncertainty (expressed in percents or percentage points), as well as the explanation for significant differences between Tier 1 and Tier 2 trend uncertainties should be clarified. According to the IPCC Good Practice Guidance (Penman et al. 2000), trend uncertainty is defined as the difference between emissions in the inventory year and the base year. This can be calculated with the Monte Carlo simulation. But if the difference is defined as percents, it must be compared with the base year emissions. It is not clear, if this should be the simulated value of the base year emissions or the mean value (the mean value is used in this study). These methods should be discussed internationally, because results should be comparable between countries.

- *Level key source identification* is another problem: If key sources are identified in accordance with the Good Practice Guidance, the larger uncertainty of the lower and upper bound must be used. This does not, however, take into account the advantages of the Monte Carlo simulation. A useful tool for key source identification with Monte Carlo simulation would be a sensitivity analysis, presented, for example, in Chapter 10.3. A more detailed level of key source identification would give additional information on future research priorities.

- *Trend key source identification* should also be clarified: which uncertainty should be used when using Tier 2 method in uncertainty estimates?

12.2 Stationary Combustion (1A1, 1A2, 1A4, 1A5)

- *The use of statistical differences* (e.g. check-method) as a basis for uncertainty estimates of activity data should be documented

- *Activity data of liquid fuel use in Other sectors (1A4):* CO_2 emissions could be calculated at an upper reporting level, because the problems in allocation of fuel use in subsectors does not affect carbon dioxide emissions. The current uncertainty estimate in activity data might be an overestimate. The problem could probably also be handled with partial correlations, or the uncertainty estimate could be used in fuel statistics level (not together for all liquid fuels).

- *Uncertainties could be calculated at process level,* because especially the N_2O emissions depend strongly on combustion technology. And, also, the uncertainties in emission factors might differ. This approach would also give information on differences between uncertainties in the base year and the inventory year, because the shares of combustion technologies are different.

- *Measurement data of emissions factors* (especially from peat and biomass combustion) in different combustion technologies (N_2O and CH_4) is required to obtain more precise emission factors and their uncertainty ranges.

- *Non-energy use of fuels* will probably be reported in the Industry sector in forthcoming inventories.

12.3 Transport (1A3)

- *N_2O (and CH_4) emission factors in transportation* need to be verified (inconsistencies between emission factors of similar diesel engines).

12.4 Fugitive Emissions (1B)

- *Emission factors of peat fuel production* as well as their uncertainties require further study; the same applies to *arable peatlands.*

- *Fugitive emissions from peat production* will probably be reported under LULUCF sector (IPCC category 5) in forthcoming inventories. This will decrease the total inventory uncertainty without LULUCF, as is presented in the Case A of sensitivity analyses in Chapter 11.

12.5 Industry (2)

- *The uncertainty in the emission factor of nitric acid production* should be checked if new measurement data is available.

12.6 Agriculture (4)

- *Most of the emission factor uncertainty estimates* should be checked in collaboration with the experts from MTT Agrifood Research Finland. Especially the suitability of parameters used, to Finnish conditions should be taken into account in uncertainty estimates.

- *Measurements of N_2O emissions from agricultural soils performed in MTT Agrifood Research Finland* could be taken into account in uncertainty estimates

12.7 Waste (6)

- Uncertainty in activity data of construction and demolition waste should be verified.

- The composition of waste disposed in landfills and the uncertainty associated with it should also be subjected to further study.

- The emissions of CH_4 from domestic wastewaters are rather insignificant. The uncertainty importance of this sector is also minor. However, the sector should be divided into two subcategories, i.e. densely and sparsely populated areas (as is already done in the case of N_2O), because these two subcategories are calculated using different methods.

- The uncertainty in N_2O emissions from wastewaters is extremely high, both in Finland and other countries. Therefore decreasing of uncertainty would require international research.

13. Quality Control (QC) Procedures

According to the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Emission Inventories (Penman et al. 2000), Quality Control (QC) is "a system of routine technical activities, to measure and control the quality of the inventory as it is being developed". The QC system is designed to provide routine and consistent checks to ensure data integrity, correctness and completeness, to identify and address errors and omissions and to document and archive inventory material and record all QC activities (Penman et al. 2000).

In separate guidelines on QC procedures of uncertainty estimates (Paragraph 8.7.3 of Penman et al. 2000) it is said that "It is good practice for QC procedures to be applied to the uncertainty estimations to confirm that calculations are correct and that there is sufficient documentation to duplicate them". Therefore the assumptions, on which the uncertainty estimates were based, as well as expert judgements need to be documented. The calculations of source category and aggregated uncertainties should also be checked.

Expert elicitations are documented with the forms presented in Appendix B of this report. Other sources of uncertainty estimates are documented in Tables C and D in Appendix A. Specific forms for uncertainty estimates of each emission source will be developed when the quality procedures of the total inventory are completed to ensure the compatibility of these two quality systems. Alternatively, the uncertainties can be added to quality forms of all emission sources.

Several verifications of the correctness of uncertainty estimates should be performed if significant changes to previous years' estimates occur. Uncertainties are not likely to vary much from year to year, and therefore all changes and reasons for them should be documented. The new estimates should also be in accordance with the Good Practice Guidance (Penman et al. 2000). All abnormalities should be documented.

The verifications for the aggregated uncertainty include the following:

- Is the emission total in uncertainty analysis the same as in the inventory by gas and by sector?

- Are the total uncertainties nearly equal with uncertainties calculated with the Tier 1 method?

Quality assurance (QA) procedures including review processes is not required for uncertainty estimates by IPCC Good Practice Guidance (Penman et al. 2000).

14. Discussion and Conclusions

The first Finnish Tier 2 uncertainty assessment was performed for the year 2001 and 1990 greenhouse gas emission inventory. According to key source analysis, the most significant sources contributing to the total uncertainty are CO_2 emissions from arable peatlands and peat production areas, and N_2O emissions from agricultural soils. CO_2 emissions from fuel combustion dominate the emission level, thus keeping the total uncertainty rather low.

In greenhouse gases measurement data is often very limited. Uncertainty estimates must therefore be based on literature or expert judgement. The shape of uncertainty distributions is very difficult to estimate. Some rationales for the choices can be found, for example the range of possible values and skewness of the distribution (positively or negatively skewed). Most of the uncertainty distributions used in this study should be seen as “best estimates”, because the shape of the distribution cannot be known exactly. However, the assumptions on non-normal distributions do not affect the total results much (see Case D in Chapter 11).

According to an inventory report by the European Community (Gugele et al. 2003), only a few countries of the European Union (Austria, the Netherlands, the UK and Denmark), and at least Australia, the USA and Norway have performed an uncertainty analysis. Rypdal & Winiwarter (2001) have compared inventory uncertainty estimates of five countries: Austria, Norway, the Netherlands, the UK and the USA. In all these countries, the total level uncertainty was ±4-21%. In addition, Denmark reported a level uncertainty of ±23%. In Finland, the total uncertainty in the 2001 emission inventory was, according to this study, -5...+6%, which is rather low, as the CO_2 emissions from fuel combustion, which are accurately known, dominate the emission level. Uncertainty estimates are always at least to some extent subjective, and differences between the estimates in different countries do not always reflect real differences in inventory uncertainties. For example, the uncertainty in N_2O emissions from Agricultural soils is estimated rather low in Finland (-59...+76%) based on emission factor ranges given by the IPCC (1996a). In some countries, the uncertainty in N_2O emission factor of agricultural soils is estimated at two orders of magnitude and studies performed in other countries show that the total inventory uncertainty is very sensitive to the assumption of this uncertainty. For the above-mentioned reasons, inventory uncertainty should not be referred to as inventory quality.

The total uncertainty in CO_2 emissions from fuel combustion is low in Finland, but the uncertainties in CO_2 emissions from other sources, e.g. peat production, are higher. When compared with other countries (Austria, Norway, the Netherlands, the UK and the USA), uncertainty in Finnish CO_2 emissions is rather high, -4…+6%, when in other countries it is ±2-4% (Rypdal & Winiwarter 2001). Sensitivity analysis (Case A) reveals, however, that the CO_2 uncertainty is at the same level as in other countries, without peat production.

Uncertainties in other gases than CO_2 are high, mainly because of the nature of the emission sources. Uncertainty in CH_4 emissions in other countries varies from ±17% to ±48% (Rypdal & Winiwarter, 2001). In Finland, CH_4 uncertainty is estimated at -19…+20%.

N_2O uncertainty estimates differ significantly between countries. In other countries, the N_2O emission uncertainty varies from ±34% until 230%. The Finnish estimate is -33...+40%. The rather small CH_4 and N_2O uncertainty estimates in Finland occur for two reasons: firstly, the uncertainties in input parameters might be estimated smaller than in reviewed countries. Secondly, a significant amount of these emissions in Finland occur 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 uncertainty in other countries. In addition, negatively skewed uncertainty distributions in fuel combustion sector keep the uncertainty in upper bound low. It is probable that the uncertainties in non-CO_2 gases will increase in the forthcoming uncertainty estimates.

The results of this study indicate that the trend uncertainty in Finland is at the same level as in other countries, i.e. ±5%-points (trend uncertainty is ±4-5%-points in Norway, the UK and Austria). The calculation of trend uncertainty is not as unambiguous as the calculation of level uncertainty when Tier 2 method (as in the IPCC Good Practice Guidance) is used. This can lead to different ways to assess trend uncertainty. These methods should be discussed further, trend uncertainty being even more important than level uncertainty, because climate conventions deal with changes in emissions rather than total emission levels.

The emission sources that affect the total uncertainty most, were identified with key source identification. The most important key sources in Finland in 2001 were CO_2 emissions from peat production areas and arable peatlands, N_2O emissions from agricultural soils, liquid fuel use in Other Sectors (residential, commercial, institutional, agriculture, forestry, fisheries), and N_2O emissions from nitric acid production. In the case of trend, most of the key sources were the same as in year 2001. However, emissions of peat production and arable peatlands were not so important, but N_2O emissions from cars with catalytic converters, as well as HFC emissions from refrigeration and air conditioning equipment were important key sources because of their rapidly increasing emissions.

According to key source identification, the most important areas of inventory improvement in Finland are emissions from peat production and emissions from agricultural soils. However, an accurate calculation of these emissions would require extensive measurement programs, as well as modelling of the phenomena causing emissions in the soil. The suitability of emission factors used for Finnish conditions should be verified in the agriculture sector. However, all these emission sources require further research internationally, because they are poorly understood everywhere.

An important area for improvements in uncertainty assessment is liquid fuel use in Other Sectors, which was discussed in Case B (Chapter 11). Uncertainty in total fuel use is very low. Uncertainty in liquid fuel use in Other sectors, in turn, is substantial, due to problems in allocating total fuel use into sectoral shares. This reflects a common problem in uncertainty estimates: uncertainty analysis should describe inventory uncertainty, but inventory calculations have to be changed or simplified in many cases to calculate the total uncertainty. Therefore, the most appropriate level of disaggregation should be studied further.

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Appendix A: Uncertainty and Key source reporting tables

The Appendix contains uncertainty and key source reporting tables, which were included in the Finnish National Inventory Report (NIR) of the year 2001 (Ministry of the Environment 2003).

Table A presents Tier 2 uncertainty reporting according to Table 6.2 in the IPCC Good Practice Guidance (Penman et al. 2000).

- In columns **E** and **F**, the resulting uncertainties from Monte Carlo simulation for each source category are presented.

- In column **G**, the larger uncertainty of E and F columns is multiplied with 2001 emissions (column D) and divided with the sum of total emissions in the last row of column D. (Example: G7=IF(E7>F7;E7/100;F7/100)*D7/D126). (The number of the row containing sum of emissions is 126)

- In column **H**, the change between year t and base year is calculated (Example: H7=100*(D7-C7)/C7)

- In columns **I** and **J**, the range of likely % change (in column H) is presented. For the column I, the 2.5^{th} percentile of the simulated change between 1990 and 2001 (D-C) is divided with the emissions in 1990 (column C). For column J, the 97.5^{th} percentile of the simulated change between 1990 and 2001 (D-C) is divided with the emissions in 1990 (column C). However, this calculation method should be subject to further consideration (e.g. should also the 1990 value be a result of simulation). IPCC Good Practice Guidance does not give any unambiguous method for the calculation of columns I and J.

Tables B and C present the Tier 1 uncertainty reporting according to Table 6.1 in the IPCC Good Practice Guidance.

- In column **G**, uncertainties presented in columns E and F are combined using a rule for multiplication. (Example: G7=SQRT(E7^2+F7^2))

- In column **H**, uncertainty in column G is multiplied with the fraction of source category emissions of total emissions (Example: H7=D7*G7/D$126) (The number of the row containing sum of emissions is 126)

- In column **I**, type A sensitivity is calculated according to the rules in IPCC Good Practice Guidance (Example: I7=(0,01*D7+D$126-(0,01*C7+C$126))/(0,01*C7+C$126)*100-((D$126-C$126)/C$126)*100)

- In column **J**, type B sensitivity is calculated according to the rules in IPCC Good Practice Guidance (Example: J7= =D8/C$126)

- In column **K**, the uncertainty in trend introduced by emission factor is calculated assuming that uncertainties between emission factors in different years correlate. (Example: K7=I7*F7)

- In column **L**, the uncertainty in trend introduced by activity data is calculated assuming that uncertainties between activity data in different years do not correlate. (Example: L7= J7*E7*SQRT(2)). The only exception is activity data of peat production and arable peatland areas, which are assumed fully correlated (Example: L93=I93*E93).

- In column **M**, uncertainties in trend are combined. (Example: M7=SQRT(K7^2+L7^2))

- In columns **N** and **O**, D, M and R are used depending on the source of uncertainty estimate (default IPCC uncertainty, measurement data or expert judgement).

- In columns **P** and **Q**, sources of uncertainties are denoted.

Table D presents the reference list of Table C, which is essential in quality control. Forms of expert elicitations referred to in Table D are presented in Appendix 2.

Table E presents a summary of key sources according to Table 7.A3 in IPCC Good Practice Guidance.

Table A. Tier 2 uncertainty reporting

A	B	C	D	E	F	G	H	I	J
Greenhouse gas source and sink categories	**Gas**	**Base year (1990) emissions**	**Year t (2001) emissions**	**Uncertainty in year 2001 emissions as % of emissions in the category**		**Uncertainty introduced on national total in year 2001**	**% change in emissions between year t and base year**	**Range of likely % change between year t and base year**	
		Gg CO2 equivalent	**Gg CO2 equivalent**	**% below (2.5 percentile)**	**% above (97.5 percentile)**	**%**	**%**	**Lower % (2.5 percentile)**	**Upper % (97.5 percentile)**
1.A. Fuel combustion activities									
1.A.1 Energy industries									
Liquid fuels	CO2	2 607	2 881	3	3	0.104	11	8	14
	CH4	6	6	75	12	0.006	10	0	16
	N2O	26	30	76	12	0.029	17	0	22
Solid fuels	CO2	9 279	10 211	4	4	0.472	10	7	13
	CH4	9	10	75	12	0.010	16	0	22
	N2O	85	105	50	50	0.067	24	11	38
Gaseous fuels	CO2	2 659	5 882	1	1	0.107	121	118	124
	CH4	4	8	76	11	0.007	118	27	132
	N2O	18	42	49	50	0.027	137	69	207
Biomass	CH4	2	11	52	57	0.008	448	211	717
	N2O	10	73	71	149	0.137	655	188	1 638
Other fuels	CO2	3 972	7 679	7	7	0.696	93	82	105
	CH4	5	6	50	51	0.004	8	0	19

	N2O	141	180	70	151	0.344	27	7	75
1.A.2 Manufacturing industries and construction									
Liquid fuels	CO2	4 294	4 374	3	3	0.158	2	-1	5
	CH4	8	40	75	12	0.038	430	31	549
	N2O	83	152	75	12	0.145	83	-57	169
Solid fuels	CO2	6 410	5 476	4	4	0.249	-15	-17	-12
	CH4	4	3	74	12	0.003	-32	-38	-7
	N2O	108	97	50	50	0.062	-10	-17	-3
Gaseous fuels	CO2	2 094	2 294	1	1	0.042	10	8	11
	CH4	5	6	74	11	0.006	32	7	38
	N2O	17	19	50	50	0.012	13	5	21
Biomass	CH4	20	23	51	54	0.016	14	-9	41
	N2O	111	89	70	154	0.173	-20	-65	0
Other fuels	CO2	1 561	1 656	7	7	0.149	6	-1	13
	CH4	4	4	50	51	0.002	-2	-12	6
	N2O	56	25	70	148	0.048	-54	-135	-16
1.A.3 Transport									
a. Civil aviation	CO2	403	360	5	5	0.025	-11	-17	-4
	CH4	11	0	57	98	0.000	-97	-193	-41
	N2O	57	5	70	149	0.009	-92	-230	-27
b. Road transportation									
Gasoline	CO2	6 202	5 202	2	2	0.001	-16	-17	-15
	CH4	44	45	49	50	0.029	4	-2	11
Cars with catalytic converters	N2O	35	348	70	150	0.663	882	266	2 207
Cars without catalytic converters	N2O	67	21	81	189	0.049	-69	-191	-12
Diesel	CO2	4 909	5 705	2	2	0.163	16	15	18

	CH4	15	6	50	50	0.004	-60	-91	-30
	N2O	78	77	80	205	0.199	-2	-27	17
Natural gas	CO2	0	3	2	2	0.000	*	*	*
	CH4	0	1	50	51	0.000	*	*	*
	N2O	0	0	70	146	0.000	*	*	*
c. Railways	CO2	192	136	5	5	0.009	-29	-35	-23
	CH4	0	0	60	109	0.000	40	14	89
	N2O	25	17	70	147	0.032	-31	-81	-8
d. Navigation									
Residual oil & gas/Diesel oil	CO2	227	311	10	10	0.040	37	20	54
	CH4	0	0	57	99	0.001	233	98	471
	N2O	29	24	70	147	0.044	-18	-59	-1
Gasoline	CO2	0	153	20	20	0.039	*	*	*
	CH4	0	9	58	103	0.012	*	*	*
	N2O	0	1	71	150	0.002	*	*	*
e. Other transportation (other off-road-machinery)									
Gasoline	CO2	74	97	30	30	0.037	30	-19	79
	CH4	0	1	54	64	0.001	2 187	1 004	3 595
	N2O	1	1	72	154	0.002	-17	-79	22
Diesel	CO2	469	609	5	5	0.040	30	22	38
	CH4	0	6	49	50	0.004	2 187	1 111	3 283
	N2O	74	61	91	55	0.070	-17	-32	4
1.A.4 Other sectors									
Liquid fuels	CO2	7 274	5 662	30	30	2.168	-22	-60	16
	CH4	19	16	75	40	0.015	-18	-60	21
	N2O	201	183	77	40	0.178	-9	-53	33

Solid fuels	CO2	57	8	11	11	0.001	-85	-96	-75
	CH4	0	1	75	20	0.001	440	107	540
	N2O	0	0				-100	-152	-50
Gaseous fuels	CO2	99	274	5	5	0.018	178	164	193
	CH4	0	0	76	15	0.000	150	35	178
	N2O	1	2	50	50	0.001	150	75	228
Biomass	CH4	245	306	70	151	0.588	25	-2	81
	N2O	24	60	71	152	0.116	149	42	380
Other fuels	CO2	141	121	30	33	0.051	-14	-48	19
	CH4	5	1	52	60	0.001	-76	-126	-34
	N2O	1	2	71	155	0.003	25	-16	96
1.A.5 Other									
Liquid fuels	CO2	736	1 050	50	50	0.666	43	-44	130
	CH4	2	2	79	61	0.002	6	-69	82
	N2O	6	12	78	61	0.012	90	-17	209
Gaseous fuels	CO2	236	305	25	25	0.096	29	-12	70
	CH4	0	0	75	35	0.000	14	-25	55
	N2O	1	2	53	59	0.001	25	-15	73
Indirect N2O from fuel combustion	N2O	462	312	79	100	0.396	-32	-147	71
1.B Fugitive emissions from fuels									
1.B.1 Solid fuels									
Arable peatlands	CO2	2 500	2 500	68	132	4.189	0	-14	14
Peat production areas	CO2	1 000	1 000	80	207	2.630	0	-22	20
	CH4	21	21	80	202	0.054	0	-24	22
1.B.2 Oil and natural gas	CO2	42	25	22	23	0.007	-41	-57	-28
	CH4	4	19	22	23	0.006	434	335	540
2. Industrial processes									
2.A.1 Cement production	CO2	777	625	7	7	0.056	-20	-26	-13
2.A.2 Lime production	CO2	398	417	11	11	0.060	5	-10	20
2.B.2 Nitric acid production	N2O	1 598	1 262	57	99	1.585	-21	-48	-7
2.B.5 Other	CH4	4	5	21	21	0.001	39	27	51

2.C Iron and steel production	CH4	5	10	20	20	0.002	87	68	105
2.F.1 Refrigeration and air conditioning equipment	HFCs	0	486	73	44	0.450	*	*	*
2.F.2 Foam blowing	HFCs	0	52	26	25	0.017	*	*	*
2.F.4 Aerosols	HFCs	0	74	4	4	0.004	*	*	*
2.F.7 Electrical equipment	SF6	87	36	7	12	0.006	-59	-109	-8
2.F Other (grouped data)	HFCs, PFCs, SF6	8	20	39	39	0.010	157	46	267
3. Total solvent and other product use	N2O	62	62	34	38	0.030	0	-43	43
4. Agriculture									
4.A Enteric fermentation	CH4	1 868	1 565	30	30	0.602	-16	-23	-10
4.B Manure management	CH4	200	202	17	16	0.042	1	-3	5
4.B Manure management	N2O	562	393	82	35	0.409	-30	-56	-2
4.D Agricultural soils	N2O	4 291	3 349	59	76	3.240	-22	-57	-1
6. Waste									
6.A Solid waste disposal on land	CH4	3 679	2 901	29	31	1.157	-21	-62	17
6.B.1 Industrial wastewater	CH4	22	19	56	108	0.026	-13	-45	6
6.B.2 Domestic and commercial wastewater	CH4	132	111	55	109	0.153	-16	-40	-4
6.B.2 Domestic and commercial wastewater									
sparsely pop. areas	N2O	21	17	92	370	0.081	-19	-106	10
densely pop. areas	N2O	85	69	92	378	0.332	-19	-102	6
6.B.3 N input from fish farming	N2O	8	5	92	397	0.023	-44	-221	-3
6.B.3 N input from ind. wastewater	N2O	27	18	92	396	0.091	-32	-176	-1
7. Other – non-energy use of fuels	CO2	640	690	50	50	0.439	8	-66	81
TOTAL		**74 058**	**78 853**	**5**	**6**	**6.383**	**6**	**2**	**11**

*Trend not calculated, when base year emissions ≈ 0

Table B. Tier 1 uncertainty reporting, columns A-M.

A	B	C	D	E	F	G	H	I	J	K	L	M
IPCC greenhouse gas source and sink categories	**Direct greenhouse gas**	**Base year emissions, 1990**	**Current year emissions, 2001**	**Activity data uncertainty**	**Emission factor uncertainty[1]**	**Combined uncertainty**	**Combined uc as part of total national emissions in 2001**	**Type A sensitivity**	**Type B sensitivity**	**Uncertainty in trend in national emissions introduced by emission factor uncertainty**	**Uncertainty in trend in national emissions introduced by activity data uncertainty**	**Uncertainty introduced into the trend in total national emissions**
1.A Fuel combustion activities												
1.A.1 Energy industries												
Liquid fuels	CO2	2 607	2 881	2%	2%	3%	0.00103	0.00143	0.03891	0.00003	0.00110	0.00110
	CH4	6	6	2%	75%	75%	0.00006	0.00000	0.00008	0.00000	0.00000	0.00000
	N2O	26	30	2%	75%	75%	0.00029	0.00004	0.00041	0.00003	0.00001	0.00003
Solid fuels	CO2	9 279	10 211	2%	3%	4%	0.00467	0.00446	0.13788	0.00013	0.00390	0.00390
	CH4	9	10	2%	75%	75%	0.00009	0.00001	0.00013	0.00001	0.00000	0.00001
	N2O	85	105	2%	50%	50%	0.00067	0.00020	0.00142	0.00010	0.00004	0.00011
Gaseous fuels	CO2	2 659	5 882	1%	1%	1%	0.00105	0.04118	0.07943	0.00041	0.00112	0.00120
	CH4	4	8	1%	75%	75%	0.00007	0.00005	0.00010	0.00004	0.00000	0.00004
	N2O	18	42	1%	50%	50%	0.00027	0.00031	0.00057	0.00016	0.00001	0.00016
Biomass	CH4	2	11	20%	50%	54%	0.00008	0.00012	0.00015	0.00006	0.00004	0.00008
	N2O	10	73	20%	150%	151%	0.00140	0.00084	0.00098	0.00127	0.00028	0.00130
Other fuels	CO2	3 972	7 679	5%	5%	7%	0.00689	0.04656	0.10369	0.00233	0.00733	0.00769
	CH4	5	6	5%	50%	50%	0.00004	0.00000	0.00008	0.00000	0.00001	0.00001
	N2O	141	180	5%	150%	150%	0.00342	0.00040	0.00243	0.00060	0.00017	0.00062

1.A.2 Manufacturing industries and construction												
Liquid fuels	CO2	4 294	4 374	2%	2%	3%	0.00157	-0.00266	0.05907	-0.00005	0.00167	0.00167
	CH4	8	40	2%	75%	75%	0.00038	0.00044	0.00054	0.00033	0.00002	0.00033
	N2O	83	152	2%	75%	75%	0.00144	0.00086	0.00205	0.00064	0.00006	0.00065
Solid fuels	CO2	6 410	5 476	2%	3%	4%	0.00250	-0.01820	0.07394	-0.00055	0.00209	0.00216
	CH4	4	3	2%	75%	75%	0.00003	-0.00002	0.00004	-0.00002	0.00000	0.00002
	N2O	108	97	2%	50%	50%	0.00062	-0.00023	0.00131	-0.00012	0.00004	0.00012
Gaseous fuels	CO2	2 094	2 294	1%	1%	1%	0.00041	0.00087	0.03097	0.00001	0.00044	0.00044
	CH4	5	6	1%	75%	75%	0.00006	0.00002	0.00008	0.00001	0.00000	0.00001
	N2O	17	19	1%	50%	50%	0.00012	0.00001	0.00026	0.00001	0.00000	0.00001
Biomass	CH4	20	23	15%	50%	52%	0.00015	0.00002	0.00031	0.00001	0.00007	0.00007
	N2O	111	89	15%	150%	151%	0.00170	-0.00040	0.00120	-0.00060	0.00025	0.00065
Other fuels	CO2	1 561	1 656	5%	5%	7%	0.00149	-0.00008	0.02237	0.00000	0.00158	0.00158
	CH4	4	4	5%	50%	50%	0.00002	0.00000	0.00005	0.00000	0.00000	0.00000
	N2O	56	25	5%	150%	150%	0.00049	-0.00046	0.00034	-0.00069	0.00002	0.00069
1.A.3 Transport												
a. Civil aviation	CO2	403	360	5%	2%	5%	0.00025	-0.00093	0.00486	-0.00002	0.00034	0.00034
	CH4	11	0	5%	100%	100%	0.00000	-0.00015	0.00000	-0.00015	0.00000	0.00015
	N2O	57	5	5%	150%	150%	0.00009	-0.00075	0.00006	-0.00113	0.00000	0.00113
b. Road transportation												
Gasoline	CO2	6 202	5 202	1%	2%	2%	0.00148	-0.01890	0.07025	-0.00038	0.00099	0.00106
	CH4	44	45	1%	50%	50%	0.00029	-0.00002	0.00061	-0.00001	0.00001	0.00001
Cars with catalytic converters	N2O	35	348	1%	150%	150%	0.00663	0.00419	0.00470	0.00629	0.00007	0.00629

Cars without catalytic converters	N2O	67	21	1%	179%	179%	0.00047	-0.00069	0.00028	-0.00123	0.00000	0.00123
Diesel	CO2	4 909	5 705	1%	2%	2%	0.00162	0.00645	0.07703	0.00013	0.00109	0.00110
	CH4	15	6	1%	50%	50%	0.00004	-0.00014	0.00008	-0.00007	0.00000	0.00007
	N2O	78	77	1%	200%	200%	0.00194	-0.00009	0.00103	-0.00018	0.00001	0.00018
Natural gas	CO2	0	3	1%	2%	2%	0.00000	0.00004	0.00004	0.00000	0.00000	0.00000
	CH4	0	1	1%	50%	50%	0.00000	0.00001	0.00001	0.00001	0.00000	0.00001
	N2O	0	0	1%	150%	150%	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
c. Railways	CO2	192	136	5%	2%	5%	0.00009	-0.00093	0.00183	-0.00002	0.00013	0.00013
	CH4	0	0	5%	110%	110%	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	N2O	25	17	5%	150%	150%	0.00033	-0.00013	0.00023	-0.00019	0.00002	0.00019
d. Navigation												
Residual oil & gas/Diesel oil	CO2	227	311	10%	2%	10%	0.00040	0.00094	0.00420	0.00002	0.00059	0.00059
	CH4	0	0	10%	100%	100%	0.00001	0.00000	0.00001	0.00000	0.00000	0.00000
	N2O	29	24	10%	150%	150%	0.00045	-0.00010	0.00032	-0.00014	0.00005	0.00015
Gasoline	CO2	0	153	20%	2%	20%	0.00039	0.00206	0.00206	0.00004	0.00058	0.00058
	CH4	0	9	20%	100%	102%	0.00011	0.00012	0.00012	0.00012	0.00003	0.00012
	N2O	0	1	20%	150%	151%	0.00002	0.00002	0.00002	0.00003	0.00000	0.00003
e. Other transportation (other off-road-machinery)												
Gasoline	CO2	74	97	30%	2%	30%	0.00037	0.00024	0.00130	0.00000	0.00055	0.00055
	CH4	0	1	30%	50%	58%	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
	N2O	1	1	30%	150%	153%	0.00002	0.00000	0.00001	0.00000	0.00000	0.00001
Diesel	CO2	469	609	30%	2%	30%	0.00232	0.00148	0.00822	0.00003	0.00349	0.00349
	CH4	0	6	30%	50%	58%	0.00005	0.00008	0.00008	0.00004	0.00004	0.00005

	N2O	74	61	30%	90%	95%	0.00073	-0.00023	0.00082	-0.00021	0.00035	0.00041
1.A.4 Other sectors												
Liquid fuels	CO2	7 274	5 662	30%	2%	30%	0.02159	-0.02811	0.07645	-0.00056	0.03243	0.03244
	CH4	19	16	30%	75%	81%	0.00016	-0.00006	0.00021	-0.00005	0.00009	0.00010
	N2O	201	183	30%	75%	81%	0.00187	-0.00042	0.00247	-0.00031	0.00105	0.00109
Solid fuels	CO2	57	8	10%	5%	11%	0.00001	-0.00070	0.00011	-0.00004	0.00002	0.00004
	CH4	0	1	10%	75%	76%	0.00001	0.00001	0.00001	0.00000	0.00000	0.00000
	N2O	0	0	10%	0%	10%	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Gaseous fuels	CO2	99	274	5%	1%	5%	0.00018	0.00229	0.00370	0.00002	0.00026	0.00026
	CH4	0	0	5%	75%	75%	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	N2O	1	2	5%	50%	50%	0.00001	0.00001	0.00002	0.00001	0.00000	0.00001
Biomass	CH4	245	306	15%	150%	151%	0.00586	0.00062	0.00414	0.00092	0.00088	0.00127
	N2O	24	60	15%	150%	151%	0.00115	0.00047	0.00081	0.00070	0.00017	0.00072
Other fuels	CO2	141	121	25%	20%	32%	0.00049	-0.00039	0.00164	-0.00008	0.00058	0.00058
	CH4	5	1	25%	50%	56%	0.00001	-0.00005	0.00002	-0.00003	0.00001	0.00003
	N2O	1	2	25%	150%	152%	0.00003	0.00000	0.00002	0.00000	0.00001	0.00001
1.A.5 Other												
Liquid fuels	CO2	736	1 050	50%	2%	50%	0.00666	0.00359	0.01418	0.00007	0.01002	0.01002
	CH4	2	2	50%	75%	90%	0.00003	0.00000	0.00003	0.00000	0.00002	0.00002
	N2O	6	12	50%	75%	90%	0.00013	0.00007	0.00016	0.00005	0.00011	0.00012
Gaseous fuels	CO2	236	305	25%	1%	25%	0.00097	0.00072	0.00412	0.00001	0.00146	0.00146
	CH4	0	0	25%	75%	79%	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	N2O	1	2	25%	50%	56%	0.00001	0.00000	0.00002	0.00000	0.00001	0.00001
Indirect N2O from fuel combustion	N2O	462	312	100%	0%	100%	0.00396	-0.00242	0.00422	0.00000	0.00596	0.00596
1.B Fugitive emissions from fuels												
1.B.1 Solid fuels												
arable peatlands	CO2	2 500	2 500	109%	50%	120%	0.03808	-0.00218	0.03376	-0.00109	-0.00239	0.00262

peat production areas	CO2	1 000	1 000	10%	208%	208%	0.02634	-0.00087	0.01350	-0.00181	-0.00009	0.00182
	CH4	21	21	10%	208%	208%	0.00055	-0.00002	0.00028	-0.00004	0.00000	0.00004
1.B.2 Oil and natural gas	CO2	42	25	10%	20%	22%	0.00007	-0.00027	0.00033	-0.00005	0.00005	0.00007
	CH4	4	19	10%	20%	22%	0.00005	0.00021	0.00026	0.00004	0.00004	0.00006
2. Industrial processes												
2.A.1 Cement production	CO2	777	625	5%	5%	7%	0.00056	-0.00275	0.00843	-0.00014	0.00060	0.00061
2.A.2 Lime production	CO2	398	417	10%	5%	11%	0.00059	-0.00009	0.00564	0.00000	0.00080	0.00080
2.B.2 Nitric acid production	N2O	1 598	1 262	5%	100%	100%	0.01602	-0.00593	0.01703	-0.00593	0.00120	0.00606
2.B.5 Other	CH4	4	5	5%	20%	21%	0.00001	0.00002	0.00007	0.00000	0.00001	0.00001
2.C Iron and steel production	CH4	5	10	3%	20%	20%	0.00002	0.00006	0.00013	0.00001	0.00001	0.00001
2.F.1 Refrigeration and air conditioning equipment	HFCs	0	486	73%	0%	73%	0.00449	0.00656	0.00656	0.00000	0.00676	0.00676
2.F.2 Foam blowing	HFCs	0	52	26%	0%	26%	0.00017	0.00071	0.00071	0.00000	0.00026	0.00026
2.F.4 Aerosols	HFCs	0	74	4%	0%	4%	0.00004	0.00100	0.00100	0.00000	0.00005	0.00005
2.F.7 Electrical equipment	SF6	87	36	12%	0%	12%	0.00005	-0.00076	0.00048	0.00000	0.00008	0.00008
2.F Other (grouped data)	HFCs, PFCs, SF6	8	20	39%	0%	39%	0.00010	0.00016	0.00028	0.00000	0.00015	0.00015
3. Total Solvent and other product use	N2O	62	62	30%	20%	36%	0.00028	-0.00005	0.00084	-0.00001	0.00036	0.00036
4. Agriculture												
4.A Enteric fermentation	CH4	1 868	1 565	30%	0%	30%	0.00588	-0.00573	0.02113	0.00000	0.00885	0.00885
4.B Manure management	CH4	200	202	16%	0%	16%	0.00042	-0.00014	0.00273	0.00000	0.00064	0.00064
4.B Manure management	N2O	562	393	83%	0%	83%	0.00412	-0.00276	0.00531	0.00000	0.00620	0.00620

4.D Agricultural soils	N2O	4 291	3 349	75%	0%	75%	0.03190	-0.01646	0.04522	0.00000	0.04804	0.04804
6. Waste												
6.A Solid waste disposal on land	CH4	3 679	2 901	32%	0%	32%	0.01159	-0.01372	0.03917	0.00000	0.01745	0.01745
6.B.1 Industrial wastewater	CH4	22	19	10%	104%	105%	0.00026	-0.00006	0.00026	-0.00006	0.00004	0.00007
6.B.2 Domestic and commercial wastewater	CH4	132	111	5%	104%	105%	0.00147	-0.00041	0.00150	-0.00043	0.00011	0.00044
6.B.2 Domestic and commercial wastewater												
sparsely pop. areas	N2O	21	17	10%	380%	380%	0.00083	-0.00007	0.00023	-0.00028	0.00003	0.00028
densely pop. areas	N2O	85	69	5%	380%	380%	0.00333	-0.00029	0.00093	-0.00110	0.00007	0.00110
6.B.3 N input from fish farming	N2O	8	5	10%	380%	380%	0.00022	-0.00005	0.00006	-0.00021	0.00001	0.00021
6.B.3 N input from ind. wastewater	N2O	27	18	5%	380%	380%	0.00087	-0.00014	0.00024	-0.00054	0.00002	0.00054
7.Other – non-energy use of fuels	CO2	640	690	50%	5%	50%	0.00440	0.00011	0.00932	0.00001	0.00659	0.00659
TOTAL		**74 058**	**78 853**				**0.06624**					**0.06490**

[1]When uncertainties are calculated with a separate model, resulting uncertainty in emissions is reported in column E, thus resulting in 0% in column F.

Table C. Tier 1 uncertainty reporting, columns A-B and N-Q.

A	B	N	O	P	Q
IPCC Greenhouse Gas Source and Sink Categories	**Direct Greenhouse Gas**	**Emission factor quality indicator**	**Activity data quality indicator**	**Expert judgement reference numbers[1]**	**Footnote Reference numbers[1]**
1.A. Fuel combustion activities					
1.A.1 Energy industries					
Liquid fuels	CO2	R	R	E1	
	CH4	R	R	E1	M2
	N2O	R	R	E1	M2
Solid fuels	CO2	R	R	E1	
	CH4	R	R	E1	M2
	N2O	R	R	E1	
Gaseous fuels	CO2	R	R	E1	
	CH4	R	R	E1	M2
	N2O	R	R	E1	
Biomass	CH4	R	R	E1	
	N2O	R	R	E1	
Other fuels	CO2	R	R	E1	
	CH4	R	R	E1	
	N2O	R	R	E1	
1.A.2 Manufacturing industries and construction					
Liquid fuels	CO2	R	R	E1	
	CH4	R	R	E1	M2
	N2O	R	R	E1	M2
Solid fuels	CO2	R	R	E1	
	CH4	R	R	E1	M2
	N2O	R	R	E1	
Gaseous fuels	CO2	R	R	E1	
	CH4	R	R	E1	
	N2O	R	R	E1	
Biomass	CH4	R	R	E1	
	N2O	R	R	E1	
Other fuels	CO2	R	R	E1	
	CH4	R	R	E1	
	N2O	R	R	E1	
1.A.3 Transport					
a. Civil aviation	CO2	R	R		
	CH4	D	R		L4

	N2O	R	R		
b. Road transportation					
Gasoline	CO2	R	R		
	CH4	M	R		L5
Cars with catalytic converters	N2O	M	R		L6, L7, L8, L9, L10
Cars without cat. converters	N2O	M	R		L6, L9, L10
Diesel	CO2	R	R		
	CH4	M	R		L5
	N2O	M	R		L6, L8, L11
Natural gas	CO2	R	R		
	CH4	M	R		L5
	N2O	R	R		
c. Railways	CO2	M	R		
	CH4	M	R		M3
	N2O	R	R		M3
d. Navigation					
Residual oil & gas/Diesel oil	CO2	R	R		
	CH4	D	R		L4
	N2O	R	R		
Gasoline	CO2	R	R		
	CH4	D	R		L4
	N2O	R	R		
e. Other transportation (other off-road-machinery)					
Gasoline	CO2	R	R		
	CH4	R	R		
	N2O	R	R		
Diesel	CO2	R	R		
	CH4	R	R		
	N2O	R	R		
1.A.4 Other sectors					
Liquid fuels	CO2	R	R	E1	
	CH4	R	R	E1	M2
	N2O	R	R	E1	M2
Solid fuels	CO2	R	R	E1	
	CH4	R	R	E1	M2
	N2O	R	R	E1	
Gaseous fuels	CO2	R	R	E1	
	CH4	R	R	E1	M2
	N2O	R	R	E1	
Biomass	CH4	R	R	E1	

	N2O	R	R	E1	
Other fuels	CO2	R	R	E1	
	CH4	R	R	E1	
	N2O	R	R	E1	
1.A.5 Other					
Liquid fuels	CO2	R	R	E1	
	CH4	R	R	E1	M2
	N2O	R	R	E1	M2
Gaseous fuels	CO2	R	R	E1	
	CH4	R	R	E1	M2
	N2O	R	R	E1	
Indirect N2O from fuel combustion	N2O	R	R		L1, M3, L2
1.B Fugitive emissions from fuels					
1.B.1 Solid fuels					
arable peatlands	CO2	R	R		L3
peat production areas	CO2	R	R		
	CH4	R	R		
1.B.2 Oil and natural gas	CO2	R	R	E1	
	CH4	R	R	E1	
2. Industrial processes					
2.A.1 Cement production	CO2	R	R	E1	
2.A.2 Lime production	CO2	R	R	E1	
2.B.2 Nitric acid production	N2O	R	R		M1
2.B.5 Other	CH4	R	R	E1	
2.C Iron and steel production	CH4	R	R	E1	
2.F.1 Refrigeration and air conditioning equipment	HFCs	R	R	E2	
2.F.2 Foam blowing	HFCs	R	R	E2	
2.F.4 Aerosols	HFCs	R	R	E2	
2.F.7 Electrical equipment	SF6	R	R	E2	
2.F Other (grouped data)	HFCs, PFCs, SF6	R	R	E2	
3. Total solvent and other product use	N2O	R	R	E1	
4. Agriculture					
4.A Enteric fermentation	CH4	D/R	R		L4, L13
4.B Manure management	CH4	R	R		
4.B Manure management	N2O	R	R		L12, L14, L15, L16, L17, L4
4.D Agricultural soils	N2O	D/R	R		L2, L18
6. Waste					
6.A Solid waste disposal on land	CH4	D/R	R	E3	L4, M4
6.B.1 Industrial wastewater	CH4	R	R	E3	L4

6.B.2 Domestic and commercial wastewater	CH4	R	R	E3	L4
6.B.2 Domestic and commercial wastewater					
sparsely pop. areas	N2O	R	R	E3	L2
densely pop. areas	N2O	R	R	E3	L2
6.B.3 N input from fish farming	N2O	R	R	E3	L2
6.B.3 N input from ind. wastewater	N2O	R	R	E3	L2
7. Other – non-energy use of fuels	CO2	R	R	E1	

[1] See Table D.

Table D. References of table C.

Expert Elicitations	
E1	Grönfors, Kari and Äikäs, Mikko (Statistics Finland) 27 August 2002
E2	Teemu Oinonen (Finnish Environment Institute) 21 November 2002
E3	Jouko Petäjä (Finnish Environment Institute) 21 November 2002
Measurement data	
M1	Confidential measurement data from nitric acid production plants
M2	Korhonen, S., Fabritius, M and Hoffren, H. (2001). Methane and nitrous oxide emissions in the Finnish energy production. Fortum Power and Heat Oy. TECH-4615. Helsinki.
M3	Korhonen, R. and Määttänen, M. (1999). To solve the specific emissions of locomotive diesel engines, Final Report. MOBILE 237T-1. Kymenlaakso Polytechnic, Kotka. 15 pp.
M4	Leinonen, S. and Kuittinen, V. (2001). Suomen biokaasulaitosrekisteri. Tiedot vuodelta 2000. Joensuun yliopisto. Karjalan tutkimuslaitoksen monisteita 4/2001.
Literature	
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L10	Egebäck, K. E. and Bertilsson, B. M. (1983). Chemical and biological characterization of exhaust emissions from vehicles fuelled with gasoline, alcohol, LPG and diesel. SNV pm 1635.
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L12	Finnish Grassland Society. http://www.agronet.fi/nurmiyhdistys/
L13	Nieminen, M., Maijala, V. and Soveri, T. (1998). Reindeer feeding (Poron ruokinta). Finnish Game and Fisheries Research Institute. (In Finnish).
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Table E. Key Source Category Analysis summary.

Quantitative method used: Tier 2			
A	B	C	D
IPCC source categories	**Direct greenhouse gas**	**Key source categoty flag (Yes or No)**	**If C is Yes, criteria for identification**
1.A. Fuel combustion activities			
1.A.1 Energy industries			
Liquid fuels	CO_2	No	
	CH_4	No	
	N_2O	No	
Solid fuels	CO_2	Yes	Level
	CH_4	No	
	N_2O	No	
Gaseous fuels	CO_2	Yes	Trend
	CH_4	No	
	N_2O	No	
Biomass	CH_4	No	
	N_2O	Yes	Trend
Other fuels	CO_2	Yes	Level, Trend
	CH_4	No	
	N_2O	Yes	Level, Trend
1.A.2 Manufacturing industries and construction			
Liquid fuels	CO_2	Yes	Level
	CH_4	No	
	N_2O	Yes	Trend
Solid fuels	CO_2	Yes	Level, Trend
	CH_4	No	
	N_2O	No	
Gaseous fuels	CO_2	No	
	CH_4	No	
	N_2O	No	
Biomass	CH_4	No	
	N_2O	Yes	Level, Trend
Other fuels	CO_2	No	
	CH_4	No	
	N_2O	Yes	Trend
1.A.3 Transport			
a. Civil aviation	CO_2	No	
	CH_4	No	

	N2O	Yes	Trend
b. Road transportation			
Gasoline	CO2	No	
	CH4	No	
Cars with catalytic converters	N2O	Yes	Level, Trend
Cars without catalytic converters	N2O	Yes	Trend
Diesel	CO2	Yes	Level
	CH4	No	
	N2O	Yes	Level
Natural gas	CO2	No	
	CH4	No	
	N2O	No	
c. Railways	CO2	No	
	CH4	No	
	N2O	No	
d. Navigation			
Residual oil & gas/Diesel oil	CO2	No	
	CH4	No	
	N2O	No	
Gasoline	CO2	No	
	CH4	No	
	N2O	No	
e. Other transportation (other off-road-machinery)			
Gasoline	CO2	No	
	CH4	No	
	N2O	No	
Diesel	CO2	No	
	CH4	No	
	N2O	No	
1.A.4 Other sectors			
Liquid fuels	CO2	Yes	Level, Trend
	CH4	No	
	N2O	Yes	Level
Solid fuels	CO2	No	
	CH4	No	
	N2O	No	
Gaseous fuels	CO2	No	
	CH4	No	
	N2O	No	
Biomass	CH4	Yes	Level, Trend
	N2O	Yes	Trend

Other fuels	CO2	No	
	CH4	No	
	N2O	No	
1.A.5 Other			
Liquid fuels	CO2	Yes	Level, Trend
	CH4	No	
	N2O	No	
Gaseous fuels	CO2	No	
	CH4	No	
	N2O	No	
Indirect N2O from fuel combustion	N2O	Yes	Level, Trend
1.B Fugitive emissions from fuels			
1.B.1 Solid fuels			
Arable peatlands	CO2	Yes	Level, Trend
Peat production areas	CO2	Yes	Level, Trend
	CH4	No	
1.B.2 Oil and natural gas	CO2	No	
	CH4	No	
2. Industrial Processes			
2.A.1 Cement production	CO2	No	
2.A.2 Lime production	CO2	No	
2.B.2 Nitric acid production	N2O	Yes	Level, Trend
2.B.5 Other	CH4	No	
2.C Iron and steel production	CH4	No	
2.F.1 Refrigeration and air conditioning equipment	HFCs	Yes	Level, Trend
2.F.2 Foam blowing	HFCs	No	
2.F.4 Aerosols	HFCs	No	
2.F.7 Electrical equipment	SF6	No	
2.F Other (grouped data)	HFCs, PFCs, SF6	No	
3. Total solvent and other product use	N2O	No	
4. Agriculture			
4.A Enteric fermentation	CH4	Yes	Level, Trend
4.B Manure management	CH4	No	
4.B Manure management	N2O	Yes	Level, Trend
4.D Agricultural soils	N2O	Yes	Level, Trend
6. Waste			
6.A Solid waste disposal on land	CH4	Yes	Level, Trend
6.B.1 Industrial wastewater	CH4	No	
6.B.2 Domestic and commercial wastewater	CH4	Yes	Level

6.B.2 Domestic and commercial wastewater			
sparsely pop. areas	N2O	No	
densely pop. areas	N2O	Yes	Level, Trend
6.B.3 N input from fish farming	N2O	No	
6.B.3 N input from ind. wastewater	N2O	No	
7. Other – non-energy use of fuels	CO2	Yes	Level

Appendix B: Forms of expert elicitations

Expert Elicitation	
Reference number	E1
Date	27 August 2002
Experts involved	Kari Grönfors (Statistics Finland) kari.gronfors@stat.fi Mikko Äikäs (Statistics Finland) mikko.aikas@stat.fi
Elicitors	Suvi Monni (Technical Research Centre of Finland) suvi.monni@vtt.fi Sanna Syri (Technical Research Centre of Finland) sanna.syri@vtt.fi Ilkka Savolainen (Technical Research Centre of Finland) ilkka.savolainen@vtt.fi
The quantities being judged (IPCC source category number)	Fuel combustion: Energy Industries (1.A.1) Manufacturing Industries and Construction (1.A.2) Other Sectors (1.A.4) Other (1.A.5) Fugitive emissions from fuels Oil and Natural gas 2.B.2 Industrial processes: Mineral Products (2.A) Chemical Industry (2.B) Metal Production (2.C) Solvent and Other Product Use (3) Other (non-energy use of fuels) (7)
Year being estimated	1990, 2000,2001
Logical basis for judgement, including any data taken into consideration	reassessment of estimates for the year 1999 inventory, mostly no changes
Identification of any external reviewers	
Results of external review	
Approval by inventory agency, specifying date and person	
Other notices	uncertainties for all years assumed to be indentical

Uncertainty estimates (years 1990, 2000, 2001)				
IPCC source category	**activity data uc**	**distribution**	**emission factor UC**	**distribution**
1. Energy				
1.A. Fuel Combustion				
1.A.1 Energy Industries				
Liquid fuels CO2	±2 %	normal	±2 %	normal
Liquid fues CH4	±2 %	normal	±30 %	normal
Liquid fuels N2O	±2 %	normal	±50 %	normal
Solid fuels CO2	±2 %	normal	±3 %	normal
Solid fuels CH4	±2 %	normal	±30 %	normal
Solid Fuels N2O	±2 %	normal	±50 %	normal
Gaseous Fuels CO2	±1 %	normal	±1 %	normal
Gaseous fuels CH4	±1 %	normal	±30 %	normal
Gaseous fuels N2O	±1 %	normal	±50 %	normal
Biomass CH4	±20 %	normal	±50 %	normal
Biomass N2O	±20 %	normal	-70...+150	lognormal

Other fuels CO_2	±5 %	normal	±5 %	normal
Other fuels CH_4	±5 %	normal	±50 %	normal
Other fuels N_2O	±5 %	normal	-70...+150	lognormal
1.A.2. Manufacturing Industry and Construction				
Liquid fuels CO_2	± 2 %	normal	± 2 %	normal
Liquid fues CH_4	± 2 %	normal	± 30 %	normal
Liquid fuels N_2O	± 2 %	normal	± 50 %	normal
Solid fuels CO_2	± 2 %	normal	± 3 %	normal
Solid fuels CH_4	± 2 %	normal	± 30 %	normal
Solid Fuels N_2O	± 2 %	normal	± 50 %	normal
Gaseous Fuels CO_2	± 1 %	normal	± 1 %	normal
Gaseous fuels CH_4	± 1 %	normal	± 30 %	normal
Gaseous fuels N_2O	± 1 %	normal	± 50 %	normal
Biomass CH_4	± 15 %	normal	±50 %	normal
Biomass N_2O	± 15 %	normal	-70...+150	lognormal
Other fuels CO_2	± 5 %	normal	± 5 %	normal
Other fuels CH_4	± 5 %	normal	±50 %	normal
Other fuels N_2O	± 5 %	normal	-70...+150	lognormal
1.A.4. Other Sectors				
Liquid fuels CO_2	± 30 %	normal	± 2 %	normal
Liquid fues CH_4	± 30 %	normal	± 30 %	normal
Liquid fuels N_2O	± 30 %	normal	± 50 %	normal
Solid fuels CO_2	± 10 %	normal	± 5 %	normal
Solid fuels CH_4	± 10 %	normal	± 30 %	normal
Solid Fuels N_2O	± 10 %	normal	± 50 %	normal
Gaseous Fuels CO_2	± 5 %	normal	± 1 %	normal
Gaseous fuels CH_4	± 5 %	normal	± 30 %	normal
Gaseous fuels N_2O	± 5 %	normal	± 50 %	normal
Biomass CH_4	± 15 %	normal	-70...+150	lognormal
Biomass N_2O	± 15 %	normal	-70...+150	lognormal
Other fuels CO_2	± 25 %	normal	± 20 %	normal
Other fuels CH_4	± 25 %	normal	±50 %	normal
Other fuels N_2O	± 25 %	normal	-70...+150	lognormal
1.A.5 Other				
Liquid fuels CO_2	± 50 %	normal	± 2 %	normal
Liquid fues CH_4	± 50 %	normal	± 30 %	normal
Liquid fuels N_2O	± 50 %	normal	± 50 %	normal
Gaseous Fuels CO_2	± 20 %	normal	± 1 %	normal
Gaseous fuels CH_4	± 20 %	normal	± 30 %	normal
Gaseous fuels N_2O	± 20 %	normal	± 50 %	normal
Biomass CH_4	± 25 %	normal	-70...+150	lognormal
Biomass N_2O	± 25 %	normal	-70...+150	lognormal
1.B. Fugitive emissions from fuels				
2.B.2. Oil and Natural gas	±10%	normal	± 20 %	normal
2. Industrial Processes				
2.A. Mineral Products				
2.A.1. Cement Production CO_2	± 5 %	normal	± 5 %	normal
2.A.2. Lime Production CO_2	± 10 %	normal	± 5 %	normal
2.B Chemical Industry				
2.B.2 Nitric Acid Prod. N_2O	± 5 %	normal	± 20 %	normal
2.B.5 Other (Ethylene) CH_4	± 5 %	normal	± 20 %	normal

2.C. Metal Production				
2.C.1 Iron and Steel Production - Coke CH4	± 3 %	normal	± 20 %	normal
3. Total Solvent and other product use N2O	± 30 %	normal	± 20 %	normal
7. Other (non-energy use of fuels) CO2	± 50 %	normal	± 5 %	normal

Expert Elicitation	
Reference number	E2
Date	21.11.2002
Experts involved	Teemu Oinonen (Finnish Environment Institute) Teemu.Oinonen@ymparisto.fi
Elicitors	Suvi Monni (Technical Research Centre of Finland) suvi.monni@vtt.fi Sanna Syri (Technical Research Centre of Finland) sanna.syri@vtt.fi Sampo Soimakallio (Technical Research Centre of Finland) sampo.soimakallio@vtt.fi
The quantities being judged (IPCC source category number)	Industrial processes: Consumption of Halocarbons and SF_6 (2F) Metal Production (SF_6 from Magnesium) (2C)
Years being estimated	2001, 1990
Logical basis for judgement, including any data taken into consideration	Empirical data Oinonen, 2003 Expert judgement IPCC Good Practice Guidance
Identification of any external reviewers	
Results of external review	
Approval by inventory agency, specifying date and person	
Other notices	Uncertainty analysis was entirely performed by Teemu Oinonen. In Expert Elicitation the basis of uncertainty estimates as well as the assumptions made were discussed.

Uncertainty estimates			
IPCC source category	**uncertainty 2001**	**distribution 2001**	**uncertainty 1990**
2. Industrial Processes			
2.F. Consumption of Halocarbons and SF_6			
2.F.1 Refrigeration and Air Conditioning	-73 %...+44 %	neg. skew. Gumbel	NA[1]
2.F.2 Foam blowing	± 26 %	normal	NA
2.F.4 Aerosols and OCF	± 4 %	normal	NA
2.F.7 Electrical equipment	-7 %...+12 %	pos. skew Gumbel	normal ±50%
Other	± 39 %	normal	normal ±50%

[1] NA = not applicable. Emissions from categories 2F2 and 2F3 did not occur in 1990. Emissions from 2F1 were also practically zero in 1990.

Expert Elicitation	
Reference number	E3
Date	21.11.2002
Experts involved	Jouko Petäjä (Finnish Environment Institute) jouko.petaja@ymparisto.fi
Elicitors	Suvi Monni (Technical Research Centre of Finland) suvi.monni@vtt.fi Sanna Syri (Technical Research Centre of Finland) sanna.syri@vtt.fi Sampo Soimakallio (Technical Research Centre of Finland) sampo.soimakallio@vtt.fi
The quantities being judged (IPCC source category number)	Waste (6)
Years being estimated	2001, 1990
Logical basis for judgement, including any data taken into consideration	Measurement data IPCC Good Practice Guidance
Identification of any external reviewers	
Results of external review	
Approval by inventory agency, specifying date and person	
Other notices	

Uncertainty estimates		
IPCC source category	**UC 2001**	**UC 1990**
6. Waste		
6.A. Solid Waste Disposal on Land		
6.A.1 Managed Waste Disposal on Land		
Activity data	± 10-25 %	± 20-30 %
Historical activity data	± 50 %	
k	=0.05: -40 ...+300 % =0.2: -75...+10 %	=0.05: -40 ...+300 % =0.2: -75...+10 %
MCF	± 5 %	-5...+2%
DOC	± 20 %	± 20 %
DOC_F	± 10 %	± 10 %
R	± 5 %	± 5 %
F	± 5 %	± 5 %
OX	-50...+10 %	-50...+10 %
6.A.3 Other		
k		
MCF	± 5 %	± 5 %
DOC	± 15 %	± 15 %
DOC_F	± 10 %	± 10 %
R	± 5 %	± 5 %
F	± 5 %	± 5 %
OX	-50...+10 %	-50...+10 %
Activity data		
Municipal Sludge	-50...+100%	-50 ...+100%
Industrial Sludge	± 30-50 %	± 30-50 %
Industrial Solid Waste	± 10-25 %	± 20-30 %
Constr. and Demolition Waste	± 10-25 %	± 20-30 %
6.B Wastewater handling		
6.B.1 Industrial Wastewater		
COD	± 10 %	± 15 %

MCF	-50...+100%	-50...+100%
B_0	± 20 %	± 20 %
6.B.2 Domestic Wastewater		
BOD	± 5 %	± 5 %
MCF	-50...+100%	-50...+100%
B_0	± 10 %	± 10 %
6.B.3 Other (activity data)		
N-input from human sewage (sparcely pop.areas)	± 10 %	± 10 %
N-input from human sewage (densely pop. areas)	± 5 %	± 5 %
N-input (industry)	± 5 %	± 5 %
N-input (Fish Farming)	± 10 %	± 10 %

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Uncertainties in the Finnish 2001 Greenhouse Gas Emission Inventory

Abstract

This study is a part of Finland's Greenhouse Gas Emission Inventory work to the United Nations Framework Convention on Climate Change (UNFCCC). Reliable uncertainty estimates are required by the UNFCCC, and they also function as a tool for increasing the quality of national emission inventories. Uncertainty in emission estimates can arise from inaccuracy in emission monitoring, lack of knowledge involving the emission factor and activity data estimates, or, for example, biased 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, and the other greenhouse gases of the Kyoto Protocol, CH_4, N_2O, HFCs, PFCs and SF_6, are usually rather poorly known. This is the first time Tier 2 uncertainty assessment is used for the Finnish Greenhouse Gas Emission Inventory. For the purpose of this report it was performed concerning the years 1990 and 2001. This report presents the basis of each input parameter uncertainty estimate which were mainly 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 were combined using Monte Carlo simulation, which allows the use of asymmetrical distributions and flexible handling of correlations. The resulting total uncertainty in the 2001 emissions was -5...+6%. The asymmetry results from highly uncertain emission sources that have asymmetrical distributions. The trend uncertainty (change between 1990 and 2001) was assessed to ±5%-points. The most significant sources contributing to the total uncertainty were identified with sensitivity analysis and key source identification. The most important emission sources affecting the total uncertainty are CO_2 emissions from arable peatlands and peat production areas, and N_2O emissions from agricultural soils.

Keywords
greenhouse gases, emissions, Finland, uncertainly, Monte Carlo simulation, Kyoto protocol, UNFCCC, energy production, manufacturing industry, fuels

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This report is a part of Finland's greenhouse gas emission inventory work to the United Nations Framework Convention on Climate Change (UNFCCC). In the report, the uncertainty estimates for the year 2001 and the trend (change in emissions between 1990 and 2001) are presented. Uncertainties in all calculation parameters of greenhouse gas emission inventory are presented, as well as the methods used to combine uncertainties (Monte Carlo simulation). The most important sources affecting the uncertainty, i.e. the key sources, are also identified.

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