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Riitta Pipatti

# Greenhouse gas emissions and removals in Finland

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VTT Energy

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# ABSTRACT

This report is part of Finland's National Inventory report to the United Nations' Framework Convention on Climate Change (UNFCCC). The report presents the methodologies, activity data and emission factors used in the compilation of the Finnish inventories for the years 1990–1999, as well as the estimated emissions for those years. A preliminary identification of the key sources in the Finnish inventory for the year 1999 is also given.

The total Finnish anthropogenic greenhouse gas emissions in 1999 were about 76.2 Tg $CO_2$ equivalents, which is about 1 % lower than in 1990. The most important source of the emissions is fuel combustion, which causes about 80 % of the emissions. The emissions from fuel combustion have grown with more than 6 % since 1990. Agriculture is also an important source of greenhouse gas emissions in Finland and contributed about 10 % to the total greenhouse gas emissions in Finland in 1999. The agricultural emissions have declined approximately 25 % since 1990. The importance of the waste sector as a contributor to Finnish greenhouse gas emissions has also declined much during the 1990s (1990: 5 % and 1999: 2 % of the total emissions). The Land-use change and forestry (removals) sector has constituted at net sink during the whole 1990s. In 1999 this sink was estimated to be about 10.8 Tg $CO_2$.

Identification of the so-called key sources of the Finnish inventory is preliminary and will be improved in the coming years. In the improvement of the accuracy of the inventory the key sources should be prioritised. Most of the 26 identified key sources are energy related, but also 5 agricultural, 2 industrial, 1 waste and 1 other key source were identified.

The methodologies used in the compilation of the Finnish inventory are largely consistent with the IPCC Guidelines and good practice guidance. Some needs to improve the methodologies, have, however, been identified. Continuous improvement of the activity and emission factor data is also seen as important.

# PREFACE

This report is part of Finland's annual greenhouse gas inventory submitted to the United Nations' Framework Convention on Climate Change (UNFCCC) in 2001. The report contains a general description of the trends in anthropogenic emissions and removals of greenhouse gases in Finland in 1990–1999 and a detailed description of the methodologies used in the compilation of the inventory. The changes in the methodologies, sources of information and assumptions with respect to the previous submission are also reported here. A preliminary identification of the key sources in the Finnish inventory is also presented.

The annual inventory information for the year 1999 in the common reporting format (CRF) is provided in a separate report. The CRF tables for the year 1999 (CRF99) include also recalculations made for the years 1990 and 1998 for which the CRFs (CRF90 and CRF98) were submitted with the previous inventory. CRFs for the years 1991–1997 are also included in this separate report. The previous inventory submission included only summary information (Trend Tables in the CRF98) for these years. The summary part of Finland's national inventory report describing the organisation of the inventory compilation, methods and the content of the CRFs is also provided separately (for more information see www.vyh.fi/eng/environ/state/air/emis/ghg/ghg.htm).

Riitta Pipatti (Technical Research Centre of Finland, VTT) has compiled this report and an inter-ministerial working group chaired by the Ministry of the Environment (chair Jaakko Ojala) has supervised the work. Statistics Finland (Kari Grönfors), the Finnish Environment Institute (Jouko Petäjä and Kristina Saarinen), the Technical Research Centre of Finland (Kari Mäkelä, Taru Palosuo and Riitta Pipatti), the Agrifood Research Finland (Martti Esala and Merja Myllys), the Finnish Forest Research Institute (Erkki Tomppo) and the Ministry of the Environment (Jaakko Ojala) have made the inventory calculations and compilations, as well as the descriptions of the methodologies and other information. Other governmental institutions, research organisations, universities and private companies have contributed with information and data needed in the detailed emission estimates. Finnish Environment Institute will compile a separate list of all contributors at a later stage.

Finland is in the process of making methodological improvements to the emission calculation system in accordance with the guidance given in the Revised 1996 IPCC Guidelines and the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories -report. Finland is also continuously developing and improving the databases and statistics and the quality of input data. This will result in changes in the now reported figures in the future.

This report will be updated periodically to reflect the changes in the national inventory.

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# LIST OF ABBREVIATIONS

Greenhouse gases:

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

Indirect greenhouse gases:

| | |
|---|---|
| CO | carbon monoxide |
| $NO_x$ | nitrogen oxides |
| NMVOC | non-methane volatile organic compounds |

Other chemical compounds:

| | |
|---|---|
| $SO_2$ | sulphur dioxide |
| $NH_3$ | ammonia |

Other:

CRF Common Reporting Format (standard reporting tables of the UNFCCC for national greenhouse gas inventories)

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 report the GWPs for the time horizon of 100 years have been used.)

$CO_2$ eq Carbon dioxide equivalents (a measure used to compare the emissions of the different greenhouse gases based upon their global warming potential (GWP))

UNFCCC United Nations' Framework Convention of Climate Change

SBSTA Subsidiary Body of Scientific and Technical Advice

IPCC Intergovernmental Panel of Climate Change

# 1 INTRODUCTION

This report presents estimates by Finland of its anthropogenic greenhouse gas emissions and removals by sinks for the years 1990–1999. In addition to the estimated emissions and removals by sinks a general description of the emission sources, the methods, data sources and emission factors used in the compilation of the inventory, are presented.

## 1.1 TRENDS IN FINLAND'S GREENHOUSE GAS EMISSIONS

The total anthropogenic greenhouse gas emissions without land-use change and forestry in Finland in 1999 were 76.2 million metric tons of $CO_2$ eq. (carbon dioxide equivalents)(about 0.8 % under the greenhouse gas emissions for the year 1998 and about 1.1 % under the 1990 baseline level). The land-use change and forestry sector has constituted a net sink during the whole of 1990s. In 1999 the size of this net sink was estimated to be 10.8 million tons of $CO_2$ equivalents. Figures 1.1 through 1.5 illustrate the overall trends in total Finnish emissions by sector and gas, as well as the absolute changes in the emissions since 1990. The same information in numerical form can be found in the CRF-tables (e.g. Summary 2)[1] and in Table 1.1 (trends by gas).

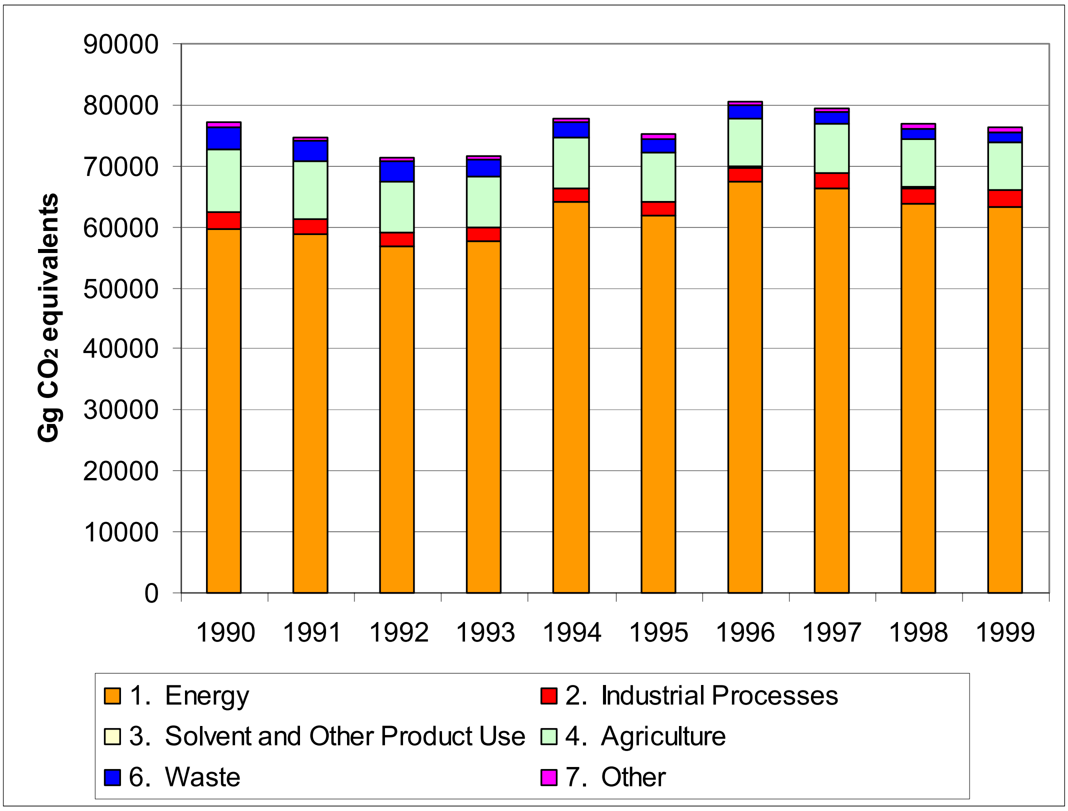


*Figure 1.1. Finnish greenhouse gas emissions (excluding* land-use change and forestry) *by sector in 1990–1999.*

[1] see www.vyh.fi/eng/environ/state/air/emis/ghg/ghg.htm

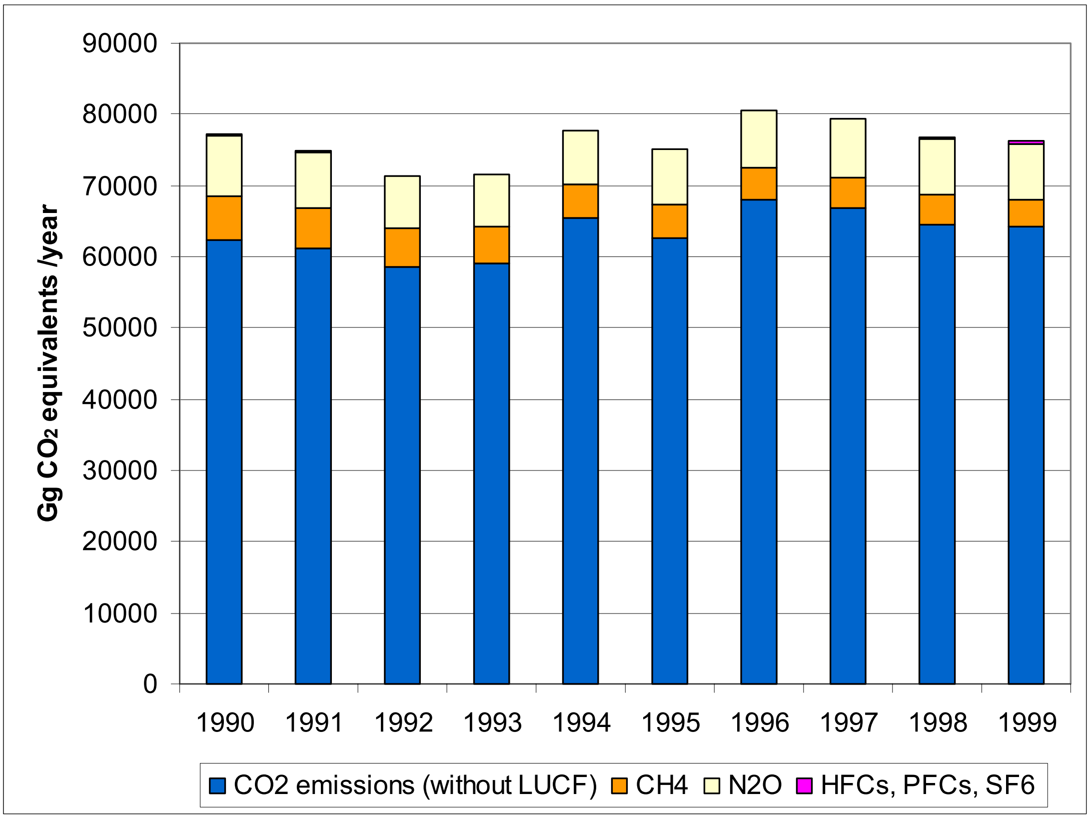


*Figure 1.2. Finnish greenhouse gas emissions (excluding land-use change and forestry) by gas 1990–1999.*

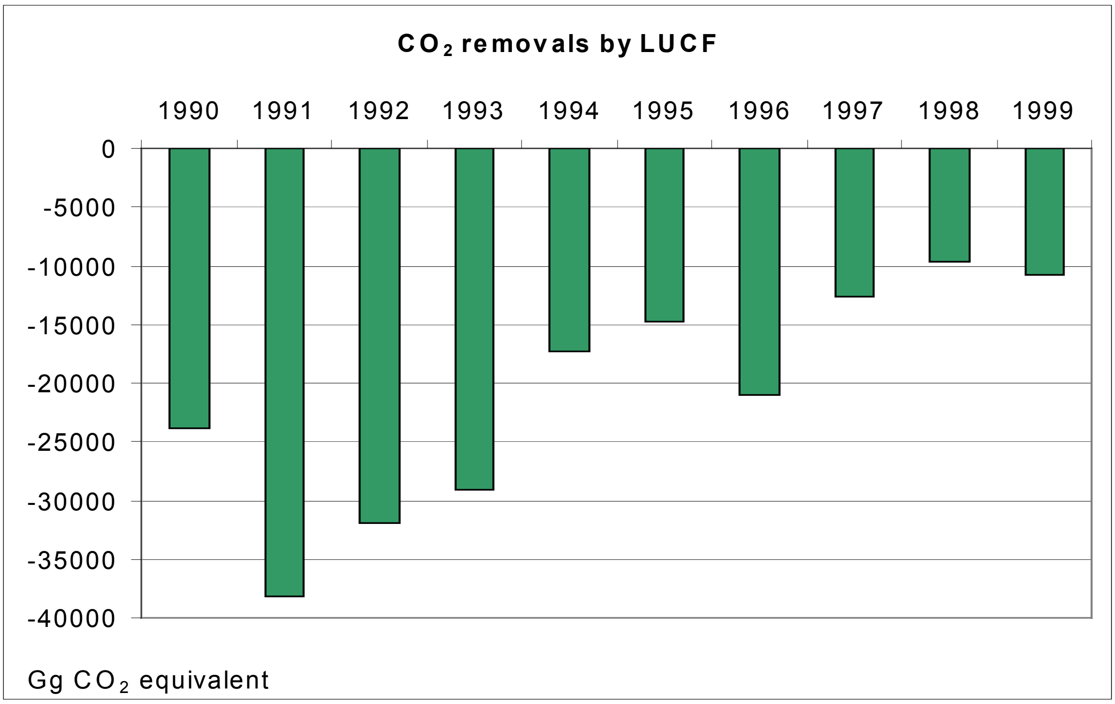


*Figure 1.3. Greenhouse gas removals by sinks in Finland 1990–1999.*

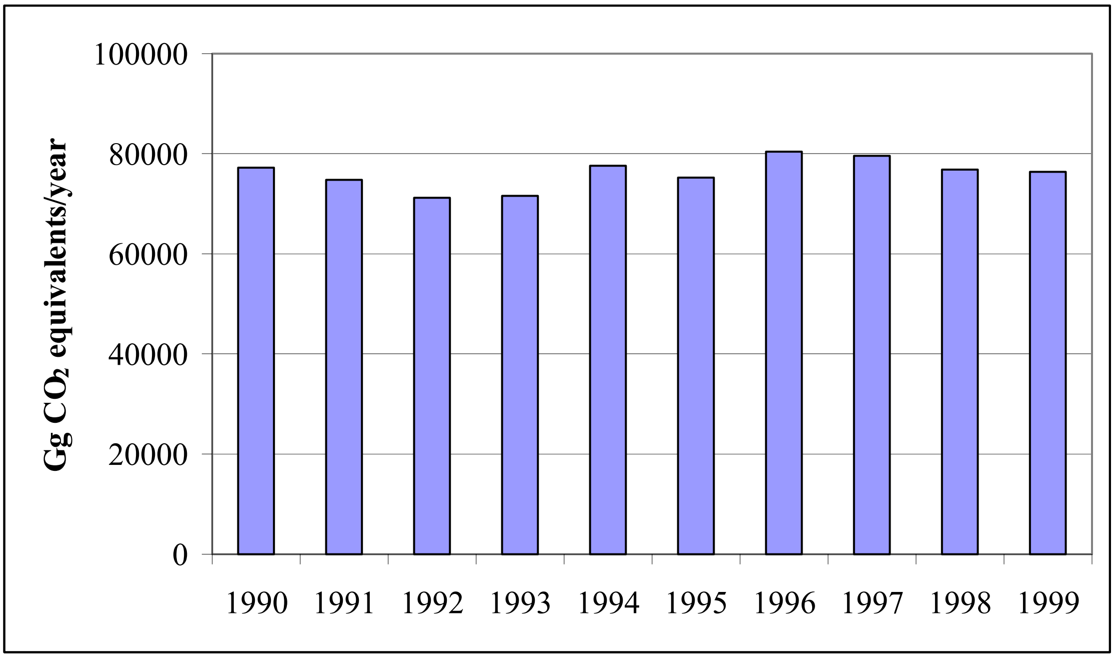


*Figure 1.4. Overall trends in Finnish greenhouse gas emissions (excluding land-use change and forestry) since 1990. The 1999 total emissions are about 1.1 percent lower than the 1990 base level.*

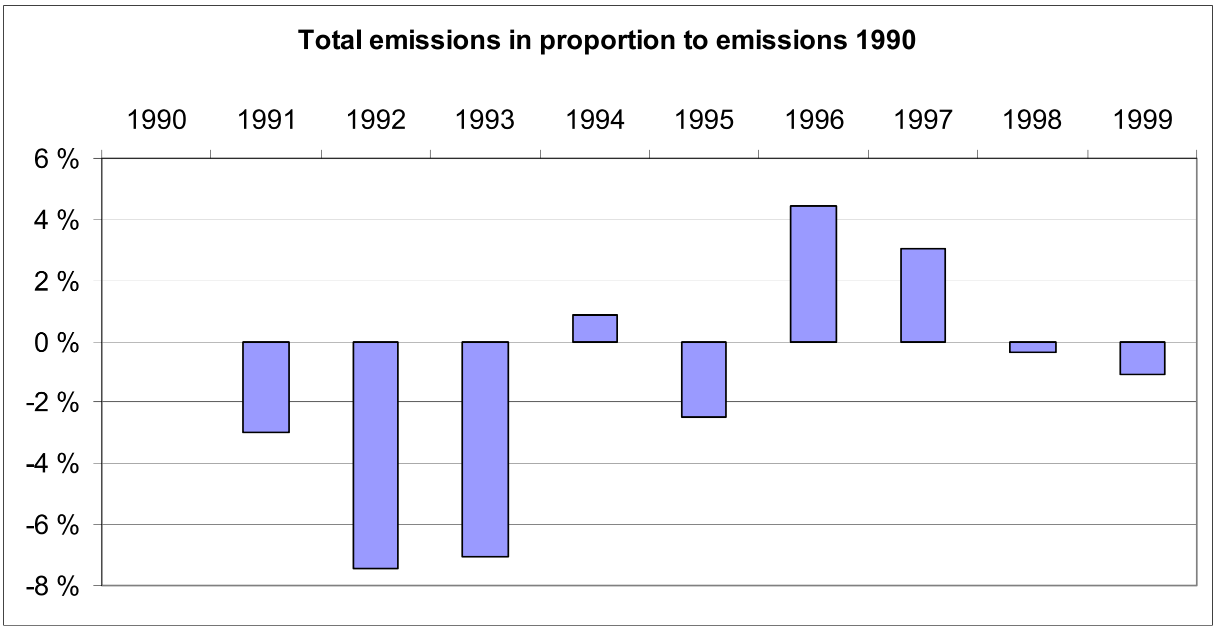


*Figure 1.5. Changes (percentage) in Finnish greenhouse gas emissions (excluding* land-use change and forestry*) since 1990.*

*Table 1.1. Greenhouse gas emissions in Finland in 1990–1999.*

| | 1990 (Base year) | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Tg $CO_2$ equivalents | | | | | | | | | |
| **$CO_2$** | | | | | | | | | | |
| Fuel combustion | 53.9 | 53.1 | 51.3 | 52.0 | 58.3 | 55.9 | 61.2 | 59.8 | 57.4 | 56.8 |
| Fugitive emissions (energy related) | 3.5 | 3.5 | 3.5 | 3.6 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 |
| Industrial processes | 1.2 | 1.0 | 0.9 | 0.8 | 0.8 | 0.8 | 0.9 | 0.9 | 0.9 | 1.1 |
| Agricultural soils | 3.2 | 2.8 | 2.3 | 2.2 | 2.1 | 1.7 | 1.8 | 2.1 | 2.0 | 2.0 |
| Other sources | 0.6 | 0.6 | 0.6 | 0.6 | 0.7 | 0.7 | 0.7 | 0.6 | 0.7 | 0.8 |
| **$CH_4$** | 6.1 | 5.8 | 5.4 | 5.0 | 4.7 | 4.6 | 4.5 | 4.3 | 4.1 | 3.9 |
| **$N_2O$** | 8.4 | 7.9 | 7.3 | 7.5 | 7.6 | 7.8 | 7.8 | 8.1 | 7.9 | 7.7 |
| **$SF_6$, HFCs, PFCs** | 0.07 | 0.05 | 0.03 | 0.03 | 0.03 | 0.04 | 0.09 | 0.2 | 0.3 | 0.4 |
| **Total** | **77.1** | **74.8** | **71.4** | **71.7** | **77.8** | **75.2** | **80.5** | **79.4** | **76.8** | **76.2** |
| Land-use change and forestry (removals) | -23.8 | -38.2 | -31.9 | -29.1 | -17.3 | -14.7 | -21.0 | -12.6 | -9.7 | -10.8 |

The annual change in Finland's greenhouse gas emissions per capita has varied somewhat during the 1990s (see Figure 1.6). The emissions per capita were lowest during 1991 to 1993 when Finland's economy was struggling with a severe recession that started around the turn of the decade. Current per capita emissions are slightly lower than in 1990. The emissions are approximately the same, but the population has grown. Emissions per gross domestic product (GDP) have decreased with approximately 16 % since 1990.

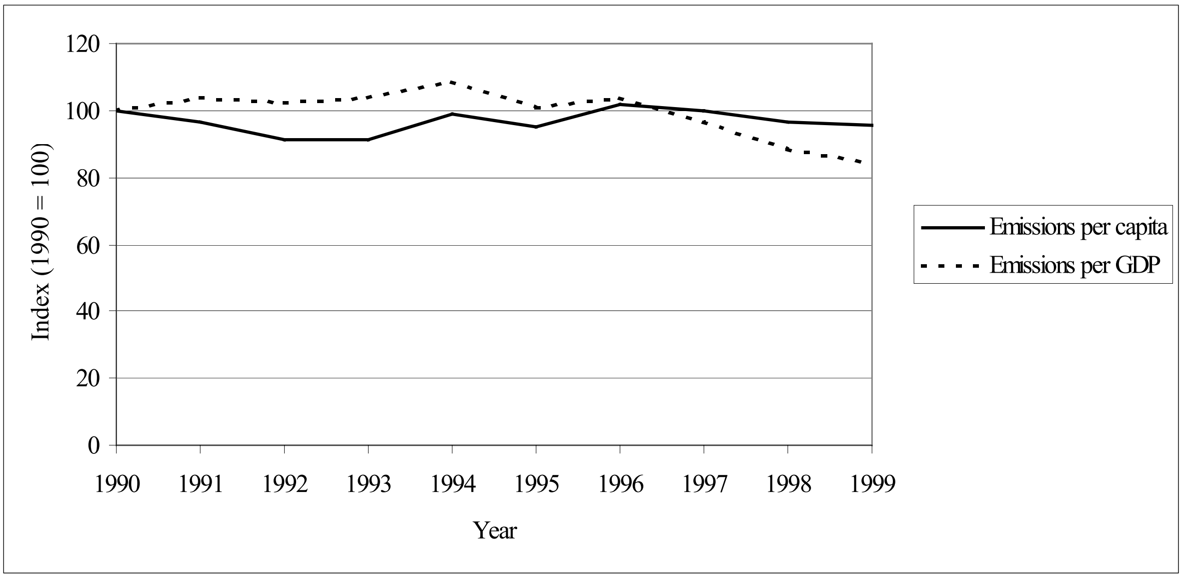


Figure 1.6 Finland's greenhouse gas emissions (excluding land-use change and forestry) per capita and per gross domestic product.[2]

## 1.2 METHODOLOGY AND DATA SOURCES

Finland's greenhouse gas inventory is compiled in accordance with UNFCCC reporting guidelines on annual inventories (FCCC/CP/1999/7), to the extent possible. Emissions and removals by sinks of greenhouse gases from various sources have been estimated using methodologies that are consistent with the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Houghton et al. 1997, hereafter referred to as the IPCC Guidelines).

The inventory estimates (1990–1999) and a summary of the methodologies and data sources are given in the following six sector-specific chapters:

1 Energy (including specific information on international bunkers)
2 Industrial Processes
3 Solvent Use
4 Agriculture
5 Land-use Change and Forestry
6 Waste

A more specific description of the specific methodologies and assumptions used in each sector is provided in the Annexes. This includes information on the level of complexity (IPCC tiers) and on national methods used. Calculation sheets or other equivalent information on the inventory calculations, including disaggregated emission factors and activity data, are also provided in the Annexes. The information includes also references

[2] GDP in 1995 prices

and sources of data related to the methodologies, emission factors and activity data, as well as the rationale for their selection where needed (when they differ from IPCC default). Specific information on feedstocks and bunkers is given in the Energy sector (see also Annex B).

## 1.3 UNCERTAINTY ESTIMATES AND KEY SOURCE DETERMINATION

The IPCC report on Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (Penman et al. 2000, hereafter referred to as the good practice report) was finalised in spring 2000. Its use in the compilation of national inventories is encouraged by SBSTA (FCCC/SBSTA/2000/5)) already in the submission of the 1999 inventory in 2001. Finland has started incorporating the use of the good practice report into the compilation of its annual inventories. All aspects of the report have, however, not yet been implemented.

Chapter 6 in the good practice report describes good practice in estimating and reporting uncertainties associated with both annual estimates of emissions, and emission trends over time. The approach to estimate the uncertainties of the Finnish inventory is up to date very simple and pragmatic, and based entirely on expert judgement. The total uncertainty of the inventory for the year 1999 has in this preliminary assessment been estimated to be around 7 %. In the future more resources will be allocated to the development of better quantitative uncertainty estimates.

Chapter 7 in the good practice report gives guidance on identification of key source categories in the inventory. Finland has made a preliminary identification of its key sources using the Tier 2 methodology given in the good practice report. The key source identification is described in Annex A, where also the estimation of the uncertainties and the results of the key source identification are recorded. The key source identification will be improved together with better assessment of the associated uncertainty estimates in future inventories.

In the preliminary analysis altogether 26 key sources were identified with the Tier 2 method, either based on the level or trend analysis. The majority of the identified key sources are energy related (17 key sources), in addition 5 agricultural, 2 industrial, 1 waste and 1 other key source were identified in the analysis. The list of the key sources and basis for their identification is given in Annex A.

The results of the key source identification will be used to assess the need for improving the methodologies, emission factors and activity data collection procedures of the specific emission sectors, and especially in setting priorities and allocating resources to this work. Some anticipated future improvements are discussed in more detail for each sector in chapters 2 to 7.

## 1.4 CHANGES IN METHODOLOGIES, ACTIVITY DATA, EMISSION FACTORS OR REPORTING SINCE LAST INVENTORY SUBMISSION

Each year Finland attempts to improve the inventory estimates through the use of better methods and data, taking into account the development in the IPCC methodologies and UNFCCC reporting requirements. The required changes and improvements mean that recalculations and revised estimates on historical inventory data are needed in order to maintain the consistency in the time series.

The principle of using the same method for all inventory years is followed in the Finnish inventory as a rule, but due to finite resources all the recalculations cannot be done at once. Therefore, some of the changes may have been incorporated in the inventory for the year 1999, but not yet in the calculation of all previous inventory years. In the Energy sector changes affect mostly the allocation of the emissions, the total amount changes less. The principle in doing the updates, which are often very resource consuming, is that at first the improvements are made in the inventory calculation of the current year, then to the base year inventory and last to the years in between.

Since the 1998 inventory submission following changes in methodologies, historical data or reporting have been made. Unless otherwise stated, all changes have been made in the way that the consistency of the time series is maintained. The recalculated emissions for the year 1990 were approximately 2.5 % and for the year 1998 0.7 % higher than the previously submitted values for the total inventories without Land-use Change and Forestry. The quantified impact of the changes in methodologies and other data on the emission estimates in 1990 and 1998 are reported by sector in the Common Reporting Tables (CRF99: Table 8(a) Recalculation – Recalculated data). [3]

Energy sector

The most important changes in the Energy sector relate to the incorporation of more detailed information on emissions from the transportation sector. For instance, a new calculation model (TYKO) for emissions from off-road machinery was finalised in 2000 and the results have been incorporated in the 1999 inventory. Other minor changes relating to improved activity data and related changes in emission factors have also been made. The changes in the Energy sector will affect the total $CO_2$ emission amounts very little. The allocation of the emissions to subcategories will change more. The other greenhouse gas emissions ($CH_4$ and $N_2O$) as well as NMVOC, CO and $NO_x$ emissions may also change more significantly as their emissions are more technology dependent than those of $CO_2$. The changes and the new model (TYKO) are described in more detail in the energy chapter and in Annex B.

[3] see: http://www.vyh.fi/eng/environ/state/air/emis/ghg/ghg.htm

Industrial Processes sector

The estimate for $CO_2$ emissions from mineral products has changed due to improved activity data (4 % higher emissions for 1990; no changes for 1998). The $CH_4$ emissions from pig iron and sinter production have been omitted from the inventory. The former emission estimates for $CH_4$ emissions from these sources were based on default methodology given in the IPCC 1995 Guidelines. The IPCC Revised 1996 Guidelines do not any more give this default methodology. Measurements in Finnish plants also indicate that these emissions are negligible and incorporated in the emission factor given for coke production (Hemminki 2000).

The actual HFC emissions from other stationary refrigeration and air conditioning in 1999 were estimated using the Tier 2 Top-Down methodology described in the IPCC Good Practice guidance. The methodology applied for the years 1993–1998 is based on the IPCC 1996 Revised Guidelines. For this particular source sub-category the difference in the emissions calculated with these two methodologies is approximately 5% for the year 1999. Before applying the new method to the entire time series, data for the year 2000 will be collected to gain more confidence in the proportional differences of the estimates of the two methodologies.

Agriculture sector

In the good practice report the methodology for estimating the gross energy input from cattle has changed due the incorporation of a scaling factor (mature animal weight) to the calculations. This change is taken into account in the Finnish inventory and therefore all estimates on methane from enteric fermentation and manure emissions have changed. Also the time series of some activity data (animal weights, daily weight gain and nitrogen content in manure) have been improved.

More accurate data on the areas of cultivated organic soils and the estimation of the $CO_2$ emissions from mineral soils for the first time have changed the $CO_2$ emission estimates from agricultural soils considerably.

More details on the changes can be found in Chapter 5 and Annex D.

Waste sector

The activity data and estimates on the DOC content for sludges have been improved and the estimates for solid waste disposal and wastewater handling in 1998 have been reduced somewhat (-6.5 %). No changes in methods have been made.

## 1.5 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC) PROCEDURES

The quality assurance and quality control procedures for the Finnish inventory are currently under development.

## 1.6 RECORD KEEPING

The 1999 inventory submission is archived at the Finnish Environment Institute. Information on activity data collection systems, emission factors and other detailed information needed in the calculation of the emissions and removals, and in the compilation of the inventory can be found at the various institutes taking part in the work, as well as in the literature cited in reference list. A comprehensive and more easily accessible archiving system is currently under development as a part of the QA/QC system.

# 2 ENERGY

## 2.1 ENERGY-RELATED EMISSIONS IN FINLAND IN 1999

Energy-related activities are the primary source of anthropogenic greenhouse gas emissions in Finland. In 1999 the greenhouse gas emissions from the Energy sector were 63.3 million tons $CO_2$-eq., which accounted for about 83 % of the total national emissions (excluding emissions and removals from land-use change and forestry)[4].

The greenhouse gas emissions in the Energy sector come from a variety of sources. The largest source, $CO_2$ from fossil fuel combustion (56.8 Tg in 1999) accounted for 75 % of the total national greenhouse gas emissions. Fugitive $CO_2$ emissions from fuels, mainly associated with peat production, are also significant in Finland. The estimated emissions for 1999 are 3.5 million tons $CO_2$-eq. or about 4.5 % of total greenhouse gas emissions. The estimated $N_2O$ emissions from the Energy sector account for 3.2 % of the total emissions in 1999. These emissions come mainly from fluidized bed combustion and transportation. Energy-related $CH_4$ emissions are mainly due to incomplete combustion and accounted for only 0.7 % of the total national greenhouse gas emissions in 1999 (see Fig. 2.1).

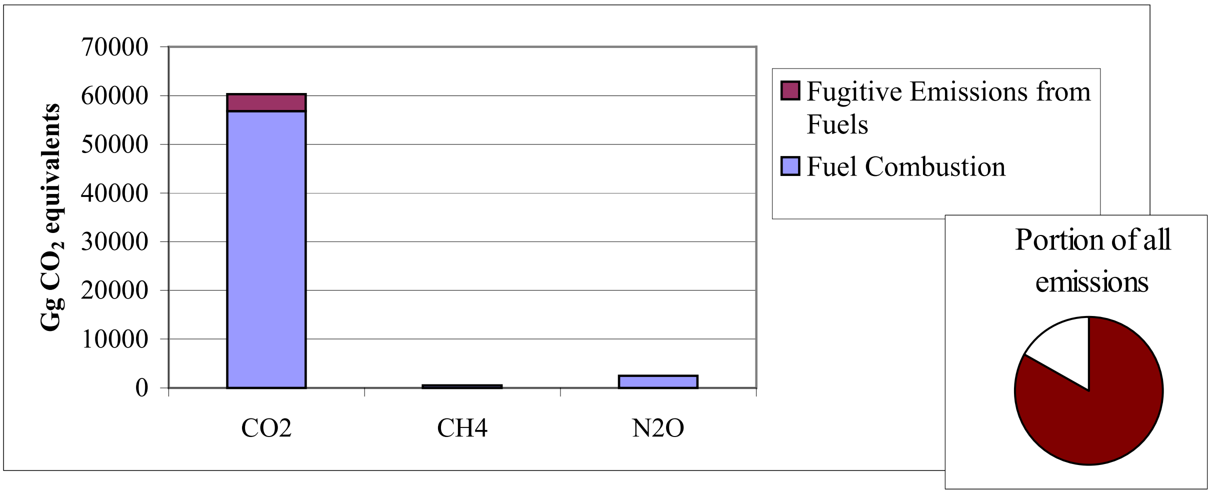


*Figure 2.1 Finnish energy related greenhouse gas emission by gas and main sources in 1999. The energy related emissions (63.3 Tg $CO_2$ eq) account for over 80 % of the greenhouse gas emissions in Finland.*

Energy Industries caused most of the emissions in the Energy sector in 1999. Manufacturing Industries and Construction produce much energy themselves, and their

[4] Herafter, when refferring to total anthropogenic greenhouse gas emissions in Finland the removals and emissions from the land-use change and forestry sector are excluded, unless otherwise stated.

share of the emissions was also significant. Transportation accounted for about one fifth of the energy related emissions in 1999 (see Fig. 2.2).

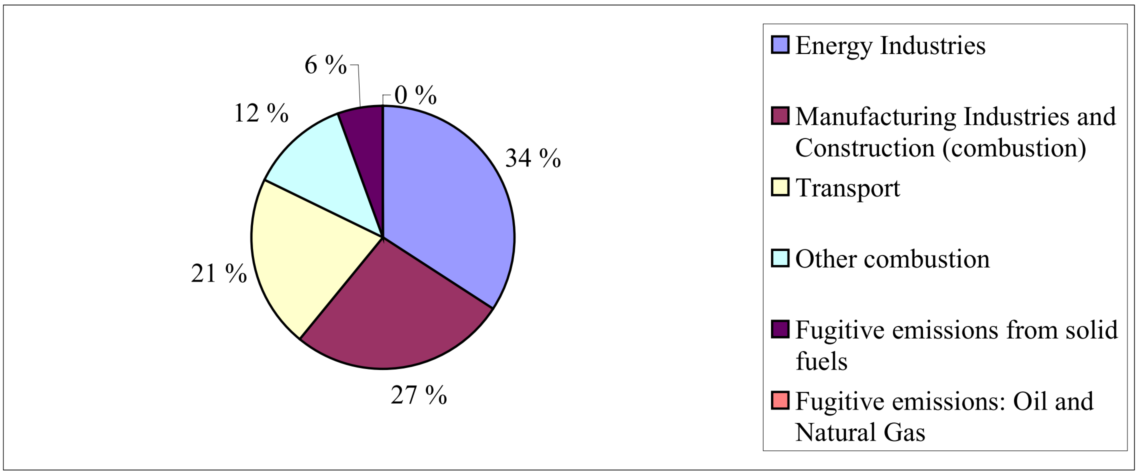


*Figure 2.2. Main source categories of the greenhouse gas emissions in the Energy sector in Finland in 1999.*

Liquid fuels (heating oils, gasoline etc.) accounted for about 47 %, solid fuels (coal and peat) almost 39 % and gaseous fuels about 14 % of the energy related $CO_2$ emissions in 1999. $CO_2$ emissions calculated with the national method and the reference approach given in the IPCC guidelines differed in 1999 by only 0.1 percent (see Table 2.1). This difference is smaller than usual, as the difference has varied from -8.3 % to +9.3 % during the 1990s.

In the reference approach data on fuel import is taken from the customs statistics. All imported fuels are, however, not combusted the same year they are imported. The fuel reserves can be large and explain much of the difference. In the longer run the differences are evened out. Errors in the use of custom codes have sometimes also caused part of the difference. In general, the fuels statistics based on sales are considered to provide more reliable estimates on annual fuel use than custom statistics.

*Table 2.1 Comparison of $CO_2$ emission estimates from fuel combustion calculated with the IPCC Reference approach and national approach for the year 1999.*

| FUEL TYPES | Reference approach | | National approach | | Difference | |
|---|---|---|---|---|---|---|
| | Energy consumption | $CO_2$ emissions | Energy consumption | $CO_2$ emissions | Energy consumption | $CO_2$ emissions |
| | (PJ) | (Gg) | (PJ) | (Gg) | (%) | (%) |
| Liquid Fuels (excluding international bunkers) | 395.1 | 27 388.5 | 366.4 | 26 837.2 | 7.9 | 2.1 |
| Solid Fuels | 220.6 | 21 618.2 | 228.5 | 22 015.5 | -3.4 | -1.8 |
| Gaseous Fuels | 140.1 | 7 838.6 | 141.7 | 7 928.7 | -1.1 | -1.1 |
| Other | | | 0.0 | 0.0 | 0.0 | 0.0 |
| Total | 755.8 | 56 845.4 | 736.5 | 56 781.4 | 2.6 | 0.1 |

## 2.2 TRENDS IN EMISSIONS 1990–1999

Table 2.2 presents the estimated greenhouse gas emissions from the Energy sector in Finland 1990–1999. The emissions have grown by approximately 6 % since 1990.

*Table 2.2. Trends in greenhouse gas emissions (Tg $CO_2$ eq.) in the Energy sector.*

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| **$CO_2$** | | | | | | | | | | |
| A. Fuel Combustion | 53.9 | 53.1 | 51.3 | 52.0 | 58.3 | 55.9 | 61.2 | 59.8 | 57.4 | 56.8 |
| 1. Energy Industries | 18.5 | 19.1 | 17.5 | 19.9 | 24.6 | 22.5 | 27.5 | 24.7 | 21.4 | 21.0 |
| 2. Manufacturing Industries and Construction | 14.4 | 13.8 | 13.5 | 13.2 | 14.0 | 13.9 | 13.5 | 15.2 | 15.3 | 15.8 |
| 3. Transport | 12.5 | 11.6 | 11.6 | 11.0 | 11.4 | 11.1 | 11.0 | 11.5 | 12.3 | 12.7 |
| 4. Other Sectors | 7.6 | 7.2 | 7.4 | 6.6 | 6.9 | 6.7 | 6.5 | 6.6 | 6.7 | 6.4 |
| 5. Other | 1.0 | 1.3 | 1.3 | 1.3 | 1.5 | 1.8 | 2.7 | 1.8 | 1.8 | 0.9 |
| B. Fugitive Emissions | 3.5 | 3.5 | 3.5 | 3.6 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 |
| 1. Solid Fuels | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 |
| 2. Oil and Natural Gas | 0.04 | 0.03 | 0.05 | 0.06 | 0.04 | 0.04 | 0.02 | 0.03 | 0.02 | 0.02 |
| ***Total $CO_2$*** | ***57.4*** | ***56.6*** | ***54.8*** | ***55.6*** | ***61.9*** | ***59.4*** | ***64.7*** | ***63.3*** | ***60.9*** | ***60.4*** |
| **$CH_4$** | | | | | | | | | | |
| A. Fuel Combustion | 0.4 | 0.4 | 0.3 | 0.3 | 0.3 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| 1. Energy Industries | 0.03 | 0.03 | 0.03 | 0.03 | 0.04 | 0.03 | 0.04 | 0.04 | 0.03 | 0.03 |
| 2. Manufacturing Industries and Construction | 0.04 | 0.04 | 0.04 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| 3. Transport | 0.07 | 0.07 | 0.07 | 0.07 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.07 |
| 4. Other Sectors | 0.3 | 0.3 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| 5. Other | 0.003 | 0.003 | 0.003 | 0.002 | 0.002 | 0.003 | 0.007 | 0.004 | 0.006 | 0.003 |
| B. Fugitive Emissions | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| 1. Solid Fuels | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| 2. Oil and Natural Gas | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.01 | 0.009 | 0.008 | 0.007 |
| ***Total $CH_4$*** | ***0.4*** | ***0.4*** | ***0.4*** | ***0.3*** | ***0.4*** | ***0.5*** | ***0.5*** | ***0.5*** | ***0.5*** | ***0.5*** |
| **$N_2O$** | | | | | | | | | | |
| A. Fuel Combustion | 1.7 | 1.8 | 1.7 | 1.7 | 1.8 | 2.0 | 2.1 | 2.5 | 2.5 | 2.5 |
| 1. Energy Industries | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.5 | 0.6 | 0.6 | 0.6 | 0.6 |
| 2. Manufacturing Industries and Construction | 0.4 | 0.5 | 0.4 | 0.4 | 0.4 | 0.6 | 0.5 | 0.9 | 0.9 | 0.9 |
| 3. Transport | 0.6 | 0.5 | 0.5 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.8 | 0.7 |
| 4. Other Sectors | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| 5. Other | 0.01 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.02 | 0.01 |
| ***Total $N_2O$*** | ***1.7*** | ***1.8*** | ***1.7*** | ***1.7*** | ***1.8*** | ***2.0*** | ***2.1*** | ***2.5*** | ***2.5*** | ***2.5*** |
| **Total all gases** | **59.6** | **58.8** | **56.8** | **57.7** | **64.1** | **61.9** | **67.4** | **66.3** | **63.9** | **63.3** |

The numbers in Table 2.2 are given with one decimal or at least with one meaningful digit. This does not reflect the accuracy of the figures, but simply allows the reader to see how the emissions have changed in time. The sums of the columns may not be the sums of the numbers given in the table due to rounding.

### 2.2.1 $CO_2$ emissions

The $CO_2$ emissions from the Energy sector are the most important greenhouse gas emissions in Finland. The emissions come mainly from combustion of fossil fuels, although fugitive $CO_2$ emissions from peat production are also estimated to be important (see Fig. 2.3).

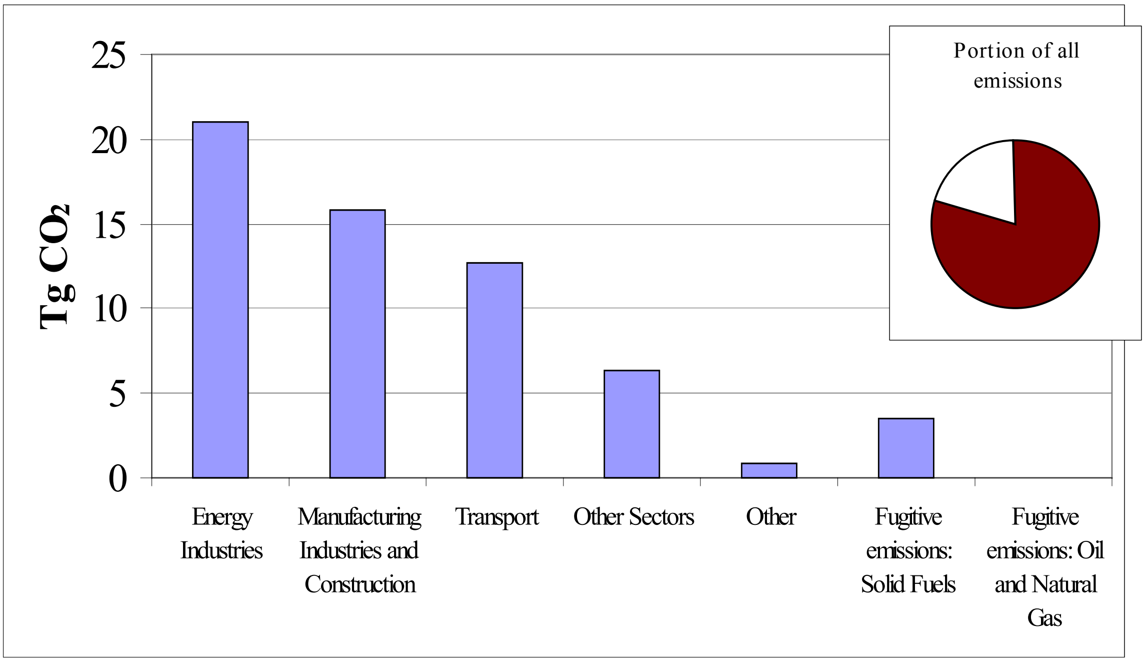


*Figure 2.3. $CO_2$ emissions (60.4 Tg) in the Energy sector by main source categories and their portion of all anthropogenic emission in Finland in 1999.*

Emissions trends

The energy consumption has grown steadily in Finland since the energy crisis in mid and late 1970s. This growth has continued in the 1990's with exception of the first few years of the decade when Finland experienced a severe recession. The growth in energy consumption has only partly been reflected in the $CO_2$ emissions from fuel combustion as the share of renewable energy has increased. A shift from coal and peat to natural gas, upgrading of the existing nuclear power plants, improved energy efficiency and the good availability of hydropower in the Nordic markets (electricity import) have also contributed to this development. The $CO_2$ emission trends from fossil fuel combustion are given in Figure 2.4. The $CO_2$ emissions from fossil fuel combustion in 1999 were about 5 % higher than in 1990.

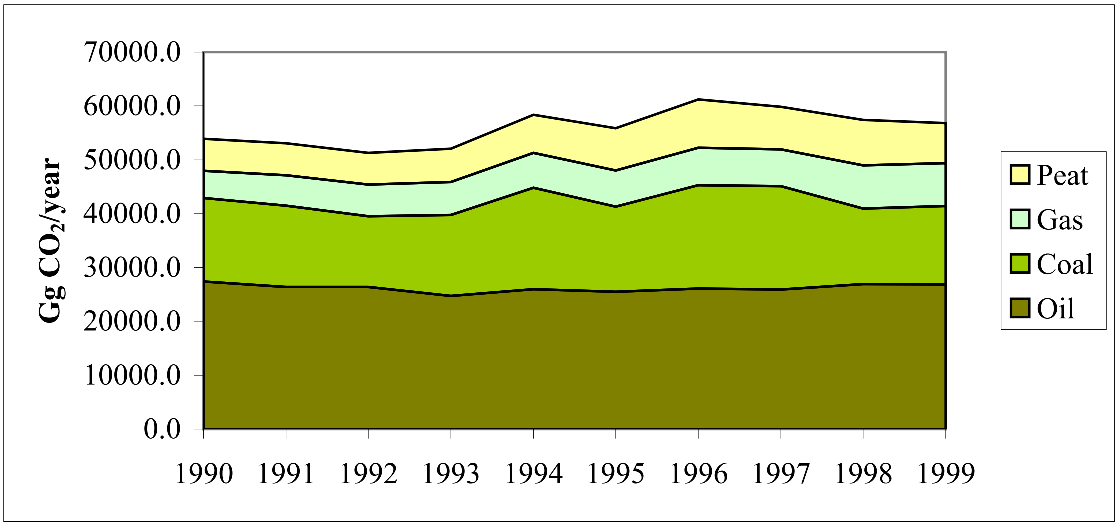


*Figure 2.4 $CO_2$ emissions by fuel combustion in 1990–1999.*

The energy-related fugitive $CO_2$ emissions arise particularly from peat production (preparation and profiling of peat soils and stockpiling of peat and arable land reserved for peat production). These emissions have been estimated to be constant during 1990–1999 due to lack of time dependent activity data.

<u>Methodology</u>

The $CO_2$ emissions from fuel combustion are calculated with the ILMARI calculation system of Statistics Finland. ILMARI is a calculation system for the Finnish energy sector and the methodology is for most parts consistent with the Tier 2 method in the IPCC Guidelines. The methods used are also largely consistent with those given in the IPCC Good Practice report.

The ILMARI calculation system combines three types of source data

1. Detailed bottom up data for point sources collected by the Regional Environment Centres' VAHTI data system, Electricity Statistics, District Heating Statistics and Manufacturing Industry Statistics. The total fuel consumption data, as well as some aggregate sectoral or sub-sectoral fuel data, are from the national Energy Statistics.
2. Aggregate transport and off-road machinery data calculated by the detailed calculation models LIPASTO and TYKO of the Technical Research Centre of Finland (VTT).
3. Aggregate sectoral (sub-sectoral) data for other sources (small combustion, residential, etc.) based mainly on separate research projects, studies or surveys.

ILMARI has been in use for national emission calculations since 1992. The emissions for the year 1990 have also been calculated by ILMARI. The estimate for the year 1991 is the result of an interpolation. In addition, the results of the interpolation have been adjusted to figures obtained from the Energy Statistics.

The ILMARI calculation system, the VAHTI database, the LIPASTO and TYKO models are described in more detail in Annex B.

The IPCC Guidelines and good practice report do not give a method for estimation of fugitive emissions from peat production. The Finnish estimate is based national research (Ahlholm & Silvola 1990; Nykänen et al. 1995 and 1996; Mälkki & Frilander 1997, Minkkinen & Laine 1998, Laine et al. 1998, Crill et al. 2000 and others; see Annex B for further information). Further research is needed to improve the methodology, the accuracy of the estimated emissions and the time series for the emissions.

Change with respect to previous years

The system for calculation of emissions from transportation (including off-road vehicle emissions) has been improved and complemented during the last years. The new model (TYKO) for calculation of emissions from off-road machinery was finalised in 2000 and the results have been incorporated in the 1999 inventory. The updates for the other years are underway.

Recalculations in the emissions reported in the previous submission are small. The recalculations are due to improved activity data and small revisions in emission factors (e.g. better incorporation of the results of the LIISA 99 model to ILMARI). The impact of the recalculations compared with the previous submission is small: the estimated emissions for the year 1990 have increased by 0.01 % (no changes for the 1998 emissions).

Uncertainties

According to the preliminary quantified estimates (based entirely on expert opinions) the uncertainties for $CO_2$ emissions from fuel combustion are small. Uncertainties in sectoral activity data are generally in the range of 1–5 % and uncertainties in emission factors are even smaller. For some specific source categories, e.g. off-road machinery, higher uncertainties are reported. In general, uncertainties in the total $CO_2$ emissions from fuel combustion are considered to be even smaller than the uncertainties of the different subsectors. It might therefore be advisable to base the uncertainty of the total inventory, and also the key source identification, on the uncertainties of the total $CO_2$ emissions. This will be explored further in future inventories.

On the contrary, the fugitive $CO_2$ emissions related to peat production are estimated to be uncertain. Especially the emissions from the arable peatland reservoirs are very uncertain: the emission factors are poorly known and a dynamic model for land areas will be required.

Key source identification and implications

Because of their large volume, many of the identified $CO_2$ key sources are in the Energy sector, even if the uncertainties in these emissions are usually small. Altogether nine

$CO_2$ fuel combustion sources were identified as key sources, and in addition also the fugitive $CO_2$ emissions from peat production are identified as a key source (Table 2.3).

Solid fuel combustion in the Energy Industries and Manufacturing Industries and Construction –sectors, road vehicles in the Transportation sector and liquid fuels in the Other Sector are all significant sources in the Finnish inventory. These sources have been identified as key sources because of their contribution to the total emissions. The uncertainties associated with these emission estimates are small. The emissions have also been estimated with methods consistent with the IPCC good practice instructions. No specific changes in methods to improve these estimates are therefore needed. The continuing improvement of the quality of the emissions will naturally continue.

*Table 2.3. Key sources: $CO_2$ from energy.*

| IPCC Greenhouse Gas Source Category | Criteria for identification |
|---|---|
| **Fuel Combustion** | |
| 1. Energy Industries | |
| Solid fuels | level |
| Other fuels | level, trend |
| 2. Manufacturing Industries | |
| Solid fuels | level |
| Other fuels | level, trend |
| 3. Transport | |
| Mobile combustion: road vehicles | level |
| Mobile combustion: waterborne navigation | level, trend |
| Mobile combustion: off-road machinery | level |
| 4. Other Sectors | |
| Liquid fuels | level, trend |
| 5. Other | |
| Liquid fuels | level |
| | |
| **Fugitive Emissions from Fuels** | |
| 1. Solid fuels | level |

The key source categories relating to Other fuels in the Energy Industries and Manufacturing Industries and Construction sectors are also significant in quantity. The associated uncertainties are higher (combined uncertainty in the order of 7 %). The other fuels (mainly peat) have more uncertain calorific values, and the fuel consumption data is also to some extent less certain than for most other fuels due to e.g. varying moisture content. The parameters that affect the uncertainties have been identified before and efforts to improve them are made continuously.

Waterborne navigation was also identified as a key source. The emissions from this source are rather small, and the key source identification relates more to the relatively large uncertainties in the activity data (mainly due to poor data on fuel use of small ships and leisure boats).

The $CO_2$ emissions from off-road vehicles are also a key source. The uncertainty associated with this category is largely related to uncertainties in the allocation of the use of liquid fuels (mainly light fuel oil, but also gasoline to some extent) to the various subcategories. The total consumption of liquid fuels is well known, and the total uncertainties within the transportation sector are less uncertain than the uncertainties of the subcategories. Efforts to improve the data have already been made. A calculation model (TYKO) with improved data for calculation of emissions from off-road vehicles has been completed in the summer 2000. The results have up-to-date been included in the ILMARI model for the year 1999 only. The emissions from off-road machinery will, however, always be more uncertain than most other energy related $CO_2$ emissions due to the nature of the source.

The fugitive emissions from peat production are also a key source category for which the need for improvement has been recognised before. Improving these emissions is resource consuming as both new systems for activity data collection and research and measurements concerning the emission factors may be needed. International co-operation in determining the emission factors is also needed.

Future improvement in methodology and input data

The key source identification implicated areas for improvement in input data that have been identified also before. The data collection system in the Energy sector is improved continuously. Especially data on how the liquid fuels (light and heavy fuel oils and gasoline) are distributed between the subcategories within the Energy sector needs improving. The development of the LIPASTO and TYKO models has been a step forward in this direction. Further, the LIPASTO model will be updated within the coming years. Also other changes relating to the structure and allocation of emission calculation are foreseen. The activity data and emission factors used in the TYKO model will also improved when better data is available.

To avoid inconsistencies in time series some improvements require recalculations of previously submitted data. These recalculations are often very time consuming due to the complexity of the calculation system. The recalculations that are foreseen concern a more detailed categorisation of the activity data.

Already in previous submissions the value for carbon oxidation for peat was changed to the value (0.99) given in the IPCC Guidelines and good practise report from the value (0.98) formerly used (Boström 1994). This change has not yet been done for the inventories for the years 1992–1994. The value will be updated also for these years in spring 2001.

### 2.2.2 $CH_4$ and $N_2O$ emissions

The $CH_4$ emissions from the Energy sector are relatively a small part of the total greenhouse gas emissions in Finland (Fig. 2.5). $CH_4$ is released to the atmosphere in combustion mainly as a result of incomplete burning. The main part of the $CH_4$ emissions from energy production comes from small scale burning of wood, even though the share of energy produced by small scale burning is small. Transportation causes less than a fifth of the $CH_4$ emissions of the Energy sector. The role of fugitive emissions from natural gas distribution is much smaller.

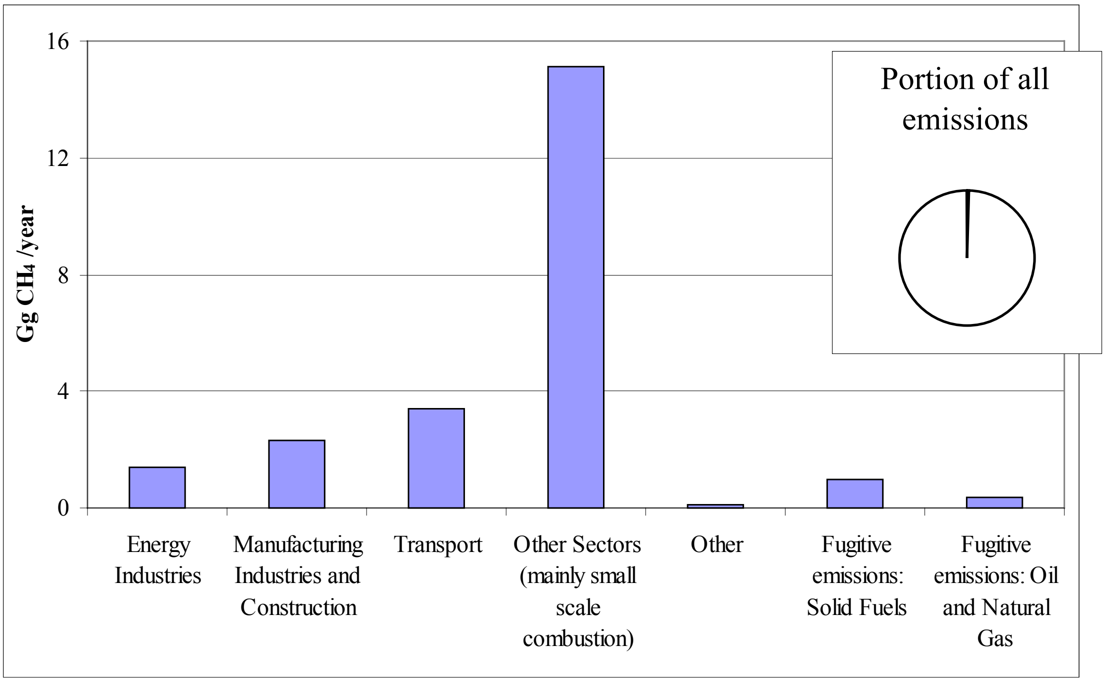


*Figure 2.5. $CH_4$ emissions from fuel combustion and natural gas distribution (0.5 Tg $CO_2$ eq) and their portion of all anthropogenic emissions in Finland in 1999.*

$N_2O$ emissions from the Energy sector are, contrary to $CH_4$ emissions, significant in Finland (Fig. 2.6). Most combustion processes produce only small amounts of $N_2O$. Fluidized bed combustion is an exception and the $N_2O$ emissions are important. The fuel and combustion conditions like temperature and air coefficient influence the emissions from fluidized bed combustion decisively.

$NO_x$ reduction techniques, like ammonia or urea addition, can also increase the $N_2O$ emissions from energy production. These emissions have not been included in the inventory, as quantitative data on the increase to emissions is lacking (the emission factors are not known).

Catalytic converters in cars increase the amount of $N_2O$ emitted compared to cars without them. In 1990 only 5 per cent of personal cars in Finland were equipped with catalytic converters, in 1999 the share has increased already to 47 %. $N_2O$ emissions from road transport are becoming more important as the share of cars with catalytic converters is increasing, although it is expected that the technological measures to mitigate $NO_x$ emissions from cars will also reduce the $N_2O$ emissions.

Nitrogen deposition due to $NO_x$ emissions increases the nitrogen load of soils. In the Finnish inventory these emissions are calculated also for energy-related and industrial $NO_x$ emissions. The share of indirect emissions is approximately 20–25 % of the total $N_2O$ emissions of fuel combustion. These indirect emissions are included in the total emissions of the relevant source categories.

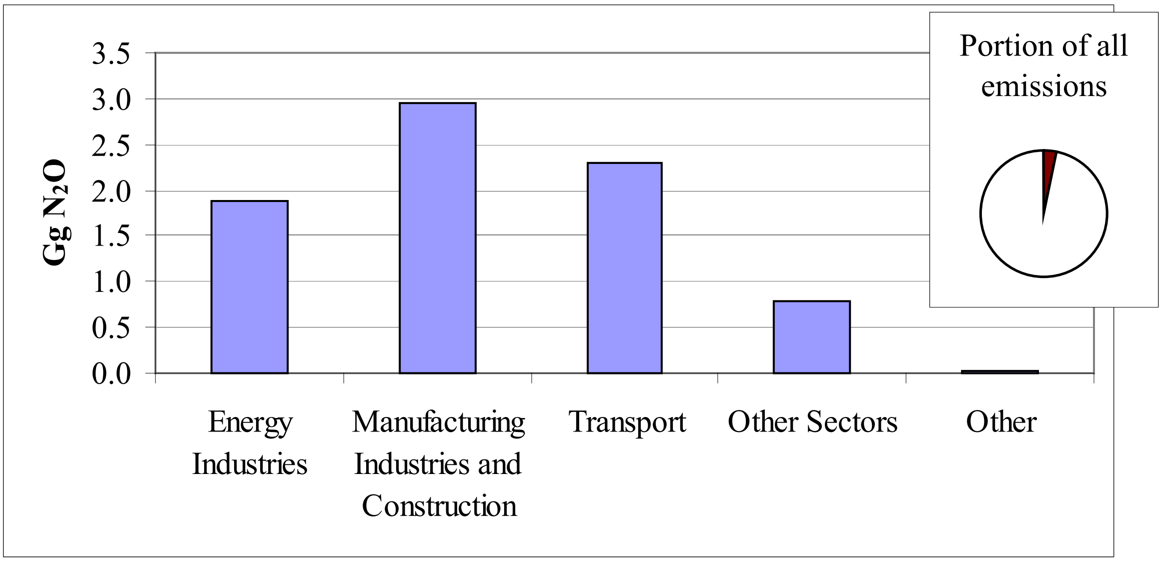


*Figure 2.6. $N_2O$ emissions (2.5 Tg $CO_2$ eq) in the Energy sector and their portion of all anthropogenic emissions in Finland in 1999.*

<u>Emissions trends</u>

The $CH_4$ emissions in the Energy sector have grown by about 14 % during the 1990s (see Table 2.2). The main reason for growth is the increased use of biomass in the Energy sector. Due to the small emissions, this growth has contributed very little to the total change in the anthropogenic greenhouse gas emissions in Finland.

The energy related $N_2O$ emissions have also grown in Finland during the 1990s. The 1999 emissions are more than 40 % higher than those in 1990. This increase is mainly due to increased use of fluidized bed combustion in the energy and manufacturing industries, increased use of catalytic converters in cars contribute much less to this increase. This estimated increase in $N_2O$ emissions from fuel combustion (excluding transportation) may, however, not reflect the actual situation. The whole time series 1990–1999 has been calculated using emission factors that were based on measurements done at the beginning of the 1990s. Since then fuel mixes have changed and combustion conditions have been altered and optimised to decrease the emissions. Recently done measurements in Finland by both industry and research organisations indicate, that current emission factors could be much lower.

Methodology

The calculation for $CH_4$ and $N_2O$ emissions is consistent with the Tier 2 method in the IPCC Guidelines. The emissions are calculated from detailed data on fuel consumption and national emission factors specified by fuel and burning equipment. The methodology is also consistent with the IPCC good practice guidance.

IPCC Guidelines give in the Agriculture sector a methodology and emission factor for estimation of indirect $N_2O$ emissions due to atmospheric deposition of $NO_x$ and $NH_3$ emissions. The methodology is by most countries used only to calculate indirect $N_2O$ emissions due to agricultural $NH_3$ emissions. In the Finnish inventory these emissions have been calculated also for energy related and industrial $NO_x$ and $NH_3$ emissions using the methodology and default emission factor given in the IPCC Guidelines.

A more detailed description of the calculation method, including activity data and emission factors, is presented in Annex B.

Change with respect to previous years

The changes in the $CH_4$ and $N_2O$ emission estimates are related to the incorporation of the results of the improvements in LIPASTO and the new TYKO model to the calculation system. A better allocation of the fuel consumption within the subcategories in the Energy sector improves the accuracy of the $CH_4$ and $N_2O$ emissions, as these emissions are much dependent on the technologies used.

The recalculations in the $CH_4$ and $N_2O$ emissions compared to the previous submission are due to improved activity data and small revisions in emission factors. The impact of the changes in the calculated emissions are very small, compared to the previous submission the estimated emissions for the year 1990 the $CH_4$ emissions have increased by 0.2 % and the $N_2O$ emissions decreased by 0.3 %. The changes for the year 1998 are: $CH_4$ +1.7 % and $N_2O$ -0.02 %.

Uncertainties

The uncertainties in the $CH_4$ and $N_2O$ emissions in the Energy sector are much larger than in the $CO_2$ emissions from fuel combustion. This is due to the fact that $CH_4$ and $N_2O$ are very dependent on the fuel type and combustion conditions. The uncertainties in the emission factors have therefore been estimated to be in the order of 30–100 %. Uncertainties for $CH_4$ emissions are deemed to be somewhat smaller than for $N_2O$. The uncertainties concerning the activity data are small, as for the Energy sector on whole.

Key source identification and implications

One $CH_4$ key source in the Energy sector was identified, namely $CH_4$ emissions from biomass burning (mainly small scale burning of wood) in the source category "Other Sectors". This source produces the bulk part of the $CH_4$ emissions in the Energy sector and both the activity data and emission factors are poorly known. The emission factor for small scale burning (< 1 MW) of wood is based on VOC measurement assuming the share of $CH_4$ to be 10 %. The uncertainty in the VOC emission factors based on these measurements is considerable; the estimation of methane's share of the total hydrocarbons increases the uncertainties. The emission factors are based on research in the turn of the 1990s'. The introduction of new stoves and other small scale burning equipment has probably changed the mean emission factor, and research in the area is needed for updating of the emission factors. Due to the small importance of these emissions, this has however not been prioritised in the improvement of the inventory.

Six $N_2O$ emission sources in the Energy sector were identified: biomass burning in the four main Energy sectors, and other fuel combustion in Energy Industries and Manufacturing Industries and Construction -sectors, and $N_2O$ emissions from road vehicles. The methods and activity data are considered reliable, but emissions factors need updating (see text on emission trends and future improvement in methodology and input data).

Future improvement in methodology and input data

The Finnish calculation system for the $CH_4$ and $N_2O$ emissions from fuel combustion is advanced compared with the systems of most other countries. The emission factors for $CH_4$ and $N_2O$ are based on research data from the beginning of the 1990's and appropriate for the emission calculations for that period. Since then, however, the combustion conditions and fuel mixes have changed, and an update of the emission factors based on research and measurements under current conditions is needed. This is especially needed for $N_2O$ emissions from fluidized bed combustion due to their great and growing importance in the Finnish inventory. Distinct emission factors for circulating fluidized bed combustion (CFBC) and bubbling fluidized bed combustion (BFBC) are needed, as the $N_2O$ emission from the former are probably higher than from the latter. In the ILMARI calculation system equivalent $N_2O$ emission factors are sometimes used for wood and peat as emission factors for wood from fluidized bed combustion are lacking. According to Kilpinen (1995) the $N_2O$ emissions factor for wood is less than for peat and the emissions for wood may therefore be overestimated.

Some measurements of $N_2O$ emissions have already been done in Finland both by industry and research organisations, and they indicate lower emission factors than those used in the inventory calculations, especially for $N_2O$ from wood combustion in fluidized bed combustion.

Some $NO_x$ reduction technologies have been identified to increase $N_2O$ emissions. The ILMARI model contains already some data on these technologies but no emission factors are available. An improvement of the data on the use of these technologies in Finland and determination of emission factors could be considered.

The $CH_4$ emission factors are largely based on VOC measurements. Updating of the emission factors for VOC emissions may also change emission factors for $CH_4$.

In addition to measurements, the IPCC default emission factors and international research carried out after 1990 on the $CH_4$ and $N_2O$ emissions from combustion should be evaluated and used when updating the emission factors. The $N_2O$ and $CH_4$ emissions are very much dependent on both fuel type and burning conditions, and this should be taken into consideration when deciding if and how new data should applied.

## 2.3 INTERNATIONAL BUNKERS

Emissions from international bunkers amounted to about 4 % of total anthropogenic greenhouse gas emissions in Finland in 1999. About 2/3 of the emission come from marine bunkers and about 1/3 from aviation. The total emissions from international bunkers have fluctuated somewhat during the 1990s, but no fast growing trend has been noticed (Fig. 2.7).

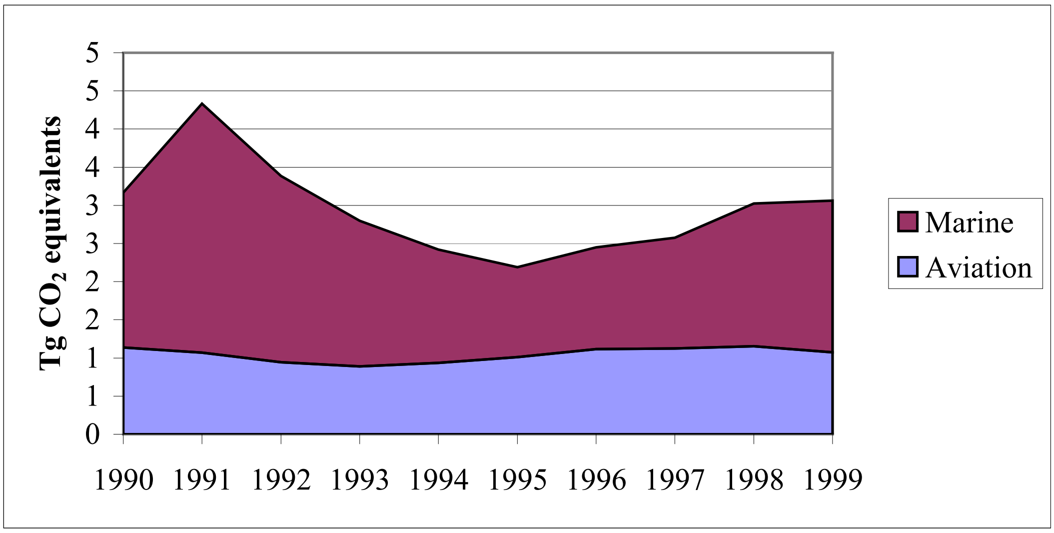


*Figure 2.7. Trend in greenhouse gas emissions from international bunkers in 1990–1999.*

Methodology

Finnish emissions from international bunkers are calculated with the ILMARI calculation system. The calculation is based on energy statistics on fuels sold to ships and aircraft with a destination abroad in accordance with the IPCC methodology.

The LIPASTO submodels MEERI and ILMI (for further information, see Annex B) calculate emissions from marine and air transportation based on actual traffic flows and emission factors specified by aircraft, ship or engine type. The emissions are calculated for traffic within the Finnish economic zone for aircraft and ships entering or leaving Finland. Due to the differences in the calculation specifications these results cannot be used as such in the Finnish inventory. The ILMARI calculation system, however, uses the results to improve its data on sectoral fuel consumption to better correspond to the actual situation.

Change with respect to previous years

No change in methods with respect to the previous submission has been made. The accuracy with which the results of ILMI and MEERI are used is improved.

Uncertainties

No quantitative uncertainty estimates have been made for the greenhouse gas emissions from international bunkers. Qualitative estimates are presented in the CRF tables (Table 7)[5]. The quality of the $CO_2$ estimates is considered high, whereas the estimates for the other greenhouse gases are considered low due to more uncertain, and sometimes even lacking, emission factors.

Key source identification

International bunkers have not been included in the key source identification in accordance with the IPCC good practice report.

Future improvement in methodology and input data

The current calculation is consistent with the IPCC methodology and no larger changes in the calculation system are foreseen. Better emission factor data on non-$CO_2$ emissions will be incorporated in the calculation system, when available.

[5] see http://www.vyh.fi/eng/environ/state/air/emis/ghg/ghg.htm

# 3 INDUSTRIAL PROCESSES

## 3.1 EMISSIONS IN 1999

Industrial greenhouse gas emissions contribute less than 4 % to the total anthropogenic greenhouse gas emissions in Finland (Fig. 3.1). The most important industrial greenhouse gas emissions are the $N_2O$ emissions from nitric acid production, $CO_2$ emissions from cement and lime production amount to almost as much together. HFCs, PFCs and. SF6 are together only about 0.5 % of the total anthropogenic greenhouse gas emissions in Finland. $CH_4$ emissions come from coke and ethylene production and they are even smaller.

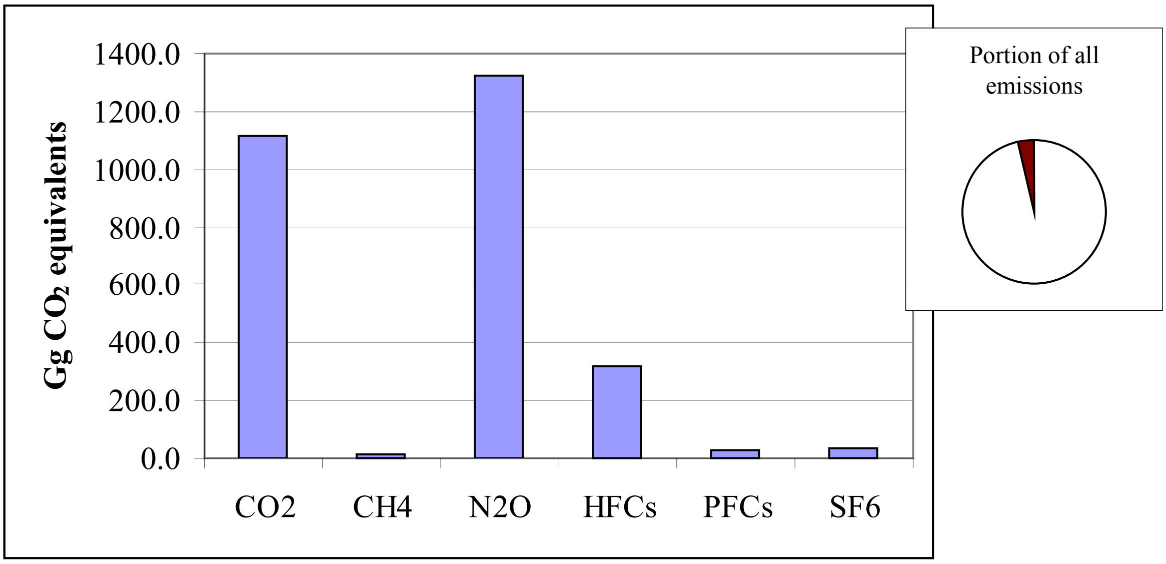


*Figure 3.1. Greenhouse gas emissions from industrial processes (totally 2.8 Tg $CO_2$ eq) and their portion of the total anthropogenic emissions in Finland in 1999.*

## 3.2 TREND IN INDUSTRIAL EMISSIONS 1990–1999

The total industrial greenhouse gas emissions have fluctuated somewhat during the 1990s, but the 1999 emissions are almost the same as the emissions in the base year 1990 (see Table 3.1). The most significant change is the increase in the emissions of the so-called new gases (HFCs, PFCs and $SF_6$) which are now more than five-fold compared to 1990 emissions. The $N_2O$ emissions from nitric acid have decreased by almost 20 %, which almost equals in amount the increase of the new gases. The $CH_4$ emissions have increased much (more 30 %), but their contribution to the total industrial emissions is very small. Industrial $CO_2$ emissions decreased much in the beginning of the 1990s. In 1993 they were more than 30 % lower than in 1990, but have now almost reached the level of the 1990 emissions.

*Table 3.1 Industrial greenhouse gas emissions in Finland in 1990–1999.*

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Tg $CO_2$ equivalents | | | | | | | | | |
| **$CO_2$** | | | | | | | | | | |
| Cement and lime production | 1.2 | 1.0 | 0.9 | 0.8 | 0.8 | 0.8 | 0.9 | 0.9 | 0.9 | 1.1 |
| **$CH_4$** | | | | | | | | | | |
| Coke and ethylene production | 0.009 | 0.010 | 0.010 | 0.013 | 0.013 | 0.014 | 0.014 | 0.013 | 0.015 | 0.015 |
| **$N_2O$** | | | | | | | | | | |
| Nitric acid production | 1.6 | 1.4 | 1.3 | 1.3 | 1.3 | 1.4 | 1.4 | 1.4 | 1.3 | 1.3 |
| **HFCs** | 0.0003 | 0.0003 | 0.0004 | 0.0004 | 0.01 | 0.03 | 0.1 | 0.2 | 0.2 | 0.3 |
| **PFCs** | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.03 |
| **$SF_6$** | 0.07 | 0.05 | 0.03 | 0.03 | 0.03 | 0.01 | 0.01 | 0.02 | 0.01 | 0.03 |
| | | | | | | | | | | |
| **Total** | **2.9** | **2.5** | **2.2** | **2.1** | **2.2** | **2.3** | **2.4** | **2.5** | **2.5** | **2.8** |

### 3.2.1 Industrial $CO_2$ emissions

Industrial $CO_2$ emissions have only been estimated for cement and lime production. Agricultural limestone and dolomite use is reported in the Agriculture sector, other use has not been estimated. No estimates have either been made for soda ash production, asphalt roofing and road paving with asphalt. The emissions from these sectors are anticipated to be small, but efforts will be made to obtain estimates also for these categories into future inventories.

Emission trends

In 1999 the $CO_2$ emissions from cement production were somewhat lower than in 1990, whereas the $CO_2$ emissions from lime production were almost the same amount higher. In the first few years of 1990s the emissions from cement production were much lower due to the recession in Finland, during which especially the volume of the construction industry declined much. In the recent years the construction industry has revived, but the $CO_2$ emissions from cement production are still some 25 % lower than in 1990. Totally the industrial $CO_2$ emissions are some 5 % below the 1990 level.

Methodology

The $CO_2$ emissions from cement production have been estimated with the method given in IPCC Guidelines. This method has been used consistently for all years of the Finnish inventory. The method, activity data and emission factors are addressed in more detail in the Annex C.

The $CO_2$ emissions from coke used in the blast furnaces in the Iron and Steel Industry have been reported in the Energy Sector (CRF Table 1A2: Fuel Consumption in the Manufacturing Industry[6]). There are two reasons for this. Firstly, coke has usually been treated as an energy producing material in the Finnish Energy Statistics. Secondly, the calculation of the emissions can be done more accurately from the total coke consumption than from partly coke and partly blast furnace gases (see also Annex C).

Change with respect to previous years

The activity data for limestone use in Finland is based on Industrial Statistics. The value for the year 1990 in the last submission was, however, based on a preliminary estimate. This value has now been updated to the value given in the Industrial Statistics. The Industrial Statistics for the year 1999 are not available yet, wherefore also the estimate for 1999 (now based on the Environmental Report of the main user) may be modified later on. No other changes in methods, activity data collection or emission factors have been made since the last submission.

Uncertainties

The uncertainties in activity data and emission factor for $CO_2$ emissions from cement industry are estimated to be small (around 5 %). This is the case also for $CO_2$ emissions from lime production, although the activity data is estimated to be more uncertain (10 %).

Key source identification

Industrial $CO_2$ emissions were not identified as key sources.

Future improvement in methods and input data

The estimation of the emission from the missing sources is seen as the most urgent task in the improvement of inventory.

### 3.2.2 Industrial $CH_4$ emissions

Emission trends

The $CH_4$ emissions from coke and ethylene production have increased much during the 1990s. Coke production has almost doubled during this time, and the increases in ethylene production have also been significant. Due to the small emissions the contribution to the total emissions has, however, been small.

[6] see http://www.vyh.fi/eng/environ/state/air/emis/ghg/ghg.htm

Methodology

The methodology used in the estimation of industrial $CH_4$ emissions is the IPCC default methodology (see activity data and emission factors in Annex C).

Change with respect to previous years

In previous Finnish inventories the industrial $CH_4$ emissions included also estimates for emissions from pig iron and sinter production in accordance with the IPCC Guidelines (1995). The Revised 1996 IPCC Guidelines do no longer give default emission factors for sinter and pig iron production. The reason why these emission factors have been omitted from the revised guidelines is not given in the guidelines. Measurement done by Finnish industry (Hemminki 2000) indicated that the emissions from pig iron and sinter production were negligible. Also the emission factor for coke was lower than the IPCC default value. The estimates from pig iron and sinter production are therefore no longer included in the inventory. This change has been made consistently for the whole time series. The IPCC default emission factor is still used for estimation of emissions from coke production, although the Finnish measurements indicated that this might overestimate the emissions by a factor of 5.

Uncertainties

The uncertainties related to the activity data are considered small (3 % for emission from coke and 5 % for emissions from ethylene production). The emissions factors are estimated to be more uncertain.

Key source identification

Industrial $CH_4$ emissions were not identified as key sources in the Finnish inventory.

Future improvement in methods and input data

Due the small importance of the industrial $CH_4$ emissions in Finland no changes in methodologies, activity data collection or emission factors are under consideration.

### 3.2.3 Industrial $N_2O$ emissions

$N_2O$ emissions from the production of nitric acid and adipic acid can be significant. In Finland only nitric acid is produced. So far other industrial processes that produce $N_2O$ in Finland have not been identified. IPCC guidelines give examples of processes that could produce $N_2O$: production of caprolactam, acrylonitrile and catalytic cracking of oil. The two first mentioned chemicals are not produced in Finland, cracking of oil is done at the refineries. The IPCC guidelines give, however, no methodology or emission factors for the estimation of the $N_2O$ emissions from catalytic cracking of oil. Only emissions from nitric acid production are therefore included in the Finnish inventory.

Emission trends

Nitric acid production and consequently also the $N_2O$ emissions have decreased by almost 20 % during the 1990s. Nitric acid is used for nitrogen fertiliser production and the decrease in production can partly be attributed to declining nitrogen fertiliser use in Finland. The decrease nitrogen fertiliser use in Finnish agriculture has been even larger than the decline in nitric acid production. Much of the Finnish fertiliser production is, however, exported and the production of the existing plants has not changed much in the recent years. The closing of an older plant in Oulu in 1992 has caused the decline in the production and emissions.

Methodology

The $N_2O$ emissions are estimated with the method given in the IPCC Guidelines, but using national data on emission factors (see Annex C for details).

Change with respect to previous years

No changes in methods, activity data collection or emission factors have been made since the last submission.

Uncertainties

The nitric acid production data is considered reliable (uncertainty 5 %), whereas the emission factors are still considered uncertain (uncertainty 20 %) due the small number of measurements that have been done. The uncertainties in actual measurements done are smaller. According to DEKATI Measurement Oy (Penttilä 1999) the relative accumulation error of the gas analyses, on which the emission factor determination is based upon, is approximately ±10 % of the measured value.

Key source identification and implications

$N_2O$ emissions from nitric acid production are identified as a key source in the Finnish inventory. The methodology used in the estimation of the emissions is consistent with the IPCC good practice.

Future improvement in methods and input data

The emission factors are based on measurements at the plants. The measurements have been done to define the correct emission level and to test how different catalysts and process conditions affect the emissions. The continuation of the measurements is uncertain. The need for future emission measurements should be assessed, especially if some mitigation measures are introduced.

The Good practice guidelines encourage the use of measurements in improving the accuracy of the inventories. It is, however, uncertain if the number of measurements done fulfil the criteria of good practice. The principles of conversion of measured data to emission factors should also be documented in more detail; likewise the basis for determining the emissions factor for the plant that was closed in 1992.

### 3.2.4 HFC, PFC and $SF_6$ emissions

HFCs, PFCs and $SF_6$ are not produced in Finland; all consumption is based on imports. Identified emission sources are refrigeration and air conditioning systems, aerosols, foam blowing, electrical equipment, fixed fire fighting systems and electronics manufacturing. Two major global sources of these gases are also absent in Finland: HFC-23 emissions from HCFC-22 manufacturing and PFC emissions from primary aluminium production (Oinonen 2000).

Emission trends

The emissions of HFCs, PFCs and $SF_6$ are about 0.5 % of the total anthropogenic emissions in Finland. The most important of these emissions (in $CO_2$ equivalent tonnes) are HFC emissions (about 84 %), the importance of PFCs (8 %) and $SF_6$ (9 %) in 1999 was almost equal. The relative growth in the HFC emissions is large; the 1999 emissions are about thousand times larger than the 1990 emissions. PFC emissions have increased with a factor of about 50. $SF_6$ emissions have, on the contrary, decreased by a factor of 2 (see Table 3.1).

Methodology

Both potential (Tier 1b) and actual emissions (Tier 2) have been estimated using the methods in the IPCC Guidelines. Some refinement in accordance with methods given in the IPCC good practice report has also been implemented. The activity data used in the estimation of the emissions is based on annual surveys to the importers and users of the gases in question. The emission factors are mainly IPCC default values, for some sources national values have been used (for details see Annex C).

Changes with respect to previous years

The actual emissions from other stationary refrigeration and air conditioning in the 1999 inventory are estimated using the Tier 2 Top-Down methodology as described in the IPCC Good practice report. For the other years (1993–1998) a national method is used. An estimate of the 1999 emissions was made also using this method. For this source category the difference in the 1999 emissions estimated with the two methodologies is approximately 5 percent. The data for the year 2000 will also be estimated using both methods. The decision on recalculation and updating of the entire time series will be done after that, when more confidence on the proportional difference in the estimates produced by the two methodologies is gained.

Uncertainties

The estimated uncertainties (10 %) related to the activity data collection for HFCs, PFCs and $SF_6$ are considered small. Uncertainties arise as some users may import these chemicals directly from chemical producers. Such imports are difficult to track because statistics on imports from other EU countries are not available. Moreover, no statistics are generally available on imports and exports of HFC/PFC/$SF_6$ containing products.

The emission factors are considered more uncertain (the uncertainty is estimated to be about 40 %) than the activity data. The emissions come from a variety of sources and the applications and technologies within the sources are many. The use of mean emission factors to cover this variety contributes to the uncertainty, as well as the fact the most of the emission factors are based on expert judgement rather than direct measurements.

Key source identification and implications

When the HFC, PFC and $SF_6$ emissions are grouped to together they are identified as a key source in the Finnish inventory based on trend analysis. The importance of these emissions as a growing source of greenhouse gas emissions in Finland has been recognised also before.

Future improvements in methods and input data

Efforts to improve the inventories have been done continuously. Due to the many sources and their small share of the total emissions in the Finnish inventory, no measurements to improve emission factors are anticipated. Improvements in the activity data collection and method development are, however, expected.

# 4 SOLVENT USE

The sector ”Solvent and other product” use deals mainly with the NMVOC (non-methane volatile organic compounds) emission estimates.

The only direct greenhouse gas source identified in this sector is the use of $N_2O$ in industrial, medical and other applications. In Finland $N_2O$ is used in hospitals and by dentist to relive pain and fear, and for detoxification. In addition to the medical use, $N_2O$ is used also for other purposes, but no specific data is available on this. In the inventory it is assumed that all used $N_2O$ is released into the atmosphere. AGA Oy, Woikoski Oy and Messer Suomi Oy deliver $N_2O$ for medical and other purposes in Finland. All delivery is currently based on import of the gas to Finland.

These $N_2O$ emissions have been fairly constant during the whole of the 1990s, around 0.2 Gg per year (less than 0.1 % of the total anthropogenic greenhouse gas emissions in Finland). The emission estimate is based on information on sales of $N_2O$ in Finland in 1990–1999. The company specific information is confidential.

# 5 AGRICULTURE

Agricultural greenhouse gas emissions come from a variety of sources. This chapter includes greenhouse gas emissions from enteric fermentation in domestic livestock ($CH_4$), livestock manure management ($CH_4$ and $N_2O$) and agricultural soils ($CO_2$, $N_2O$). Emissions from other agricultural activities described in the IPCC Guidelines do not occur at all (rice cultivation, prescribed burning of savannahs) or occur only in negligible amounts (field burning of agricultural residues) in Finland.

## 5.1 AGRICULTURAL EMISSIONS IN FINLAND IN 1999

In 1999 Finnish agricultural greenhouse gas emission were totally 7.6 Tg $CO_2$ equivalents, which is around 10 % of the total Finnish anthropogenic greenhouse gas emissions. The agricultural emissions in 1999 by main sources and gas are illustrated in Figure 5.1.

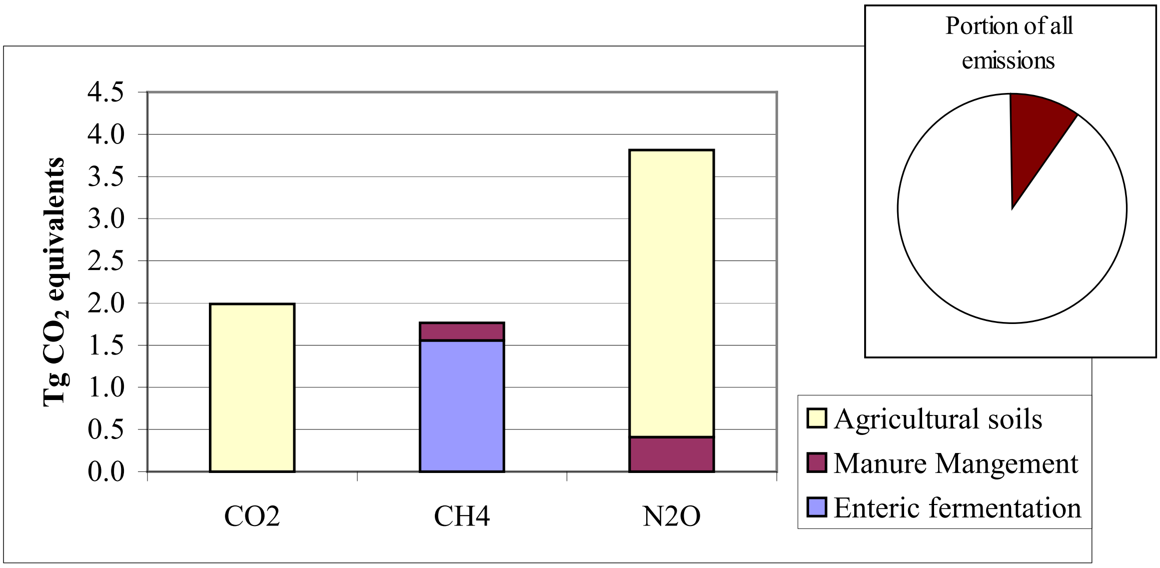


*Figure 5.1 Agricultural greenhouse gas emissions (totally 7.6 Tg $CO_2$ eq) in Finland in 1999 by main source category and gas.*

The most important agricultural greenhouse gas emissions are the nitrous oxide ($N_2O$) emissions from agricultural soils; smaller amounts of $N_2O$ are emitted from manure management. The $N_2O$ emissions from agricultural soils come mainly from fertilisation (direct and indirect) and cultivation of organic soils.

The $CO_2$ emissions from cultivation and liming of agricultural soils are also important. The $CO_2$ emissions from cultivation and liming of agricultural soils are estimated for three subcategories: cultivation of mineral soils, cultivation of organic soils and liming (all soil types). Cultivation of organic soils causes most of the reported agricultural $CO_2$ emissions (about 65 % in 1999).

According to the IPCC Guidelines (Volume 3. Reference Manual, pp. 4.2, 4.87) $CO_2$ emissions from agricultural soils are to be included under Land-Use Change and Forestry (LUCF). At the same time, the Summary Report 7A (Volume 1. Reporting Instructions, Tables.27) allows for reporting of $CO_2$ emissions or removals from agricultural soils, either in the Agriculture sector or in the Land-Use Change and Forestry sector. Finland reports $CO_2$ emissions from agricultural soils under the Agriculture sector as the emissions are caused by agricultural activities, not by land use change. The $CO_2$ emissions are also very analogous to the $N_2O$ emissions from agricultural soils, and also some activity data used in the calculations are common to both gases.

Enteric fermentation and manure management are the main sources of agricultural methane ($CH_4$) emissions in Finland. Agricultural soils can also act as sources or sinks of methane. Quantitative information on methane emissions or removals from agricultural soils is scarce, and estimates of these have therefore not been included in this inventory. Most of the reported agricultural (about 88 % in 1999) methane emissions come from enteric fermentation.

## 5.2 TREND IN AGRICULTURAL EMISSIONS 1990–1999

Tables 5.1 present the estimates for the agricultural greenhouse gas emissions in Finland in 1990–1999.

*Table 5.1. Agricultural greenhouse gas emissions (in Tg $CO_2$ equivalents) in Finland in 1990–1999.*

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| **$CO_2$** | | | | | | | | | | |
| Agricultural soils | 3.2 | 2.8 | 2.3 | 2.2 | 2.0 | 1.7 | 1.8 | 2.1 | 2.0 | 2.0 |
| **$CH_4$** | | | | | | | | | | |
| Enteric Fermentation | 1.8 | 1.7 | 1.7 | 1.7 | 1.7 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 |
| Manure Management | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| **$N_20$** | | | | | | | | | | |
| Manure Management | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.4 | 0.4 |
| Agricultural Soils | 4.4 | 4.1 | 3.7 | 3.7 | 3.7 | 3.8 | 3.7 | 3.6 | 3.5 | 3.4 |
| **Total** | **10.2** | **9.3** | **8.4** | **8.4** | **8.2** | **7.8** | **7.8** | **8.0** | **7.8** | **7.6** |

The trend in the agricultural emissions has been declining throughout the period. Finland’s agriculture has gone through many changes in 1990’s. The membership in the European Union since 1995 has changed the economy of agriculture. The farm size in Finland has grown as many smaller farms have stopped production. This has enabled improved production efficiencies, and led to decreases in the number of livestock number. At the same time more weight has been put to environmental issues in developing the agricultural practices. This can be seen e.g. in declining nitrogen (and phosphorus) fertilisation figures.

The interaction between various environmental agricultural greenhouse gas emissions is complex. Measures that reduce one type of emissions can lead to an increase in another type (Kulmala & Esala 2000; Pipatti et al. 2000). The measures that have been undertaken in Finland have decreased the total agricultural greenhouse gas emissions, although some specific agricultural emissions (methane emissions from manure management) have also increased. In the following subchapters the trends in specific agricultural emissions are given. The methods for estimating the emissions are also given, as well as the uncertainties associated with the estimates. Changes since the last inventory submission are also highlighted and clarified.

The detailed description of the estimation of the agricultural emissions including activity data and disaggregated emission factors is given in Annex D.

### 5.2.1 $CO_2$ emissions from agricultural soils and liming

Emission trends

Agricultural $CO_2$ emissions have been estimated for 1) net changes in carbon stocks in mineral soils due to changes in land-use and management, 2) cultivation of organic soils and 3) liming. The most important agricultural $CO_2$ emissions come from cultivation of organic soils. The total estimated emissions have decreased in the 1990s with about one third (see Fig. 5.2).

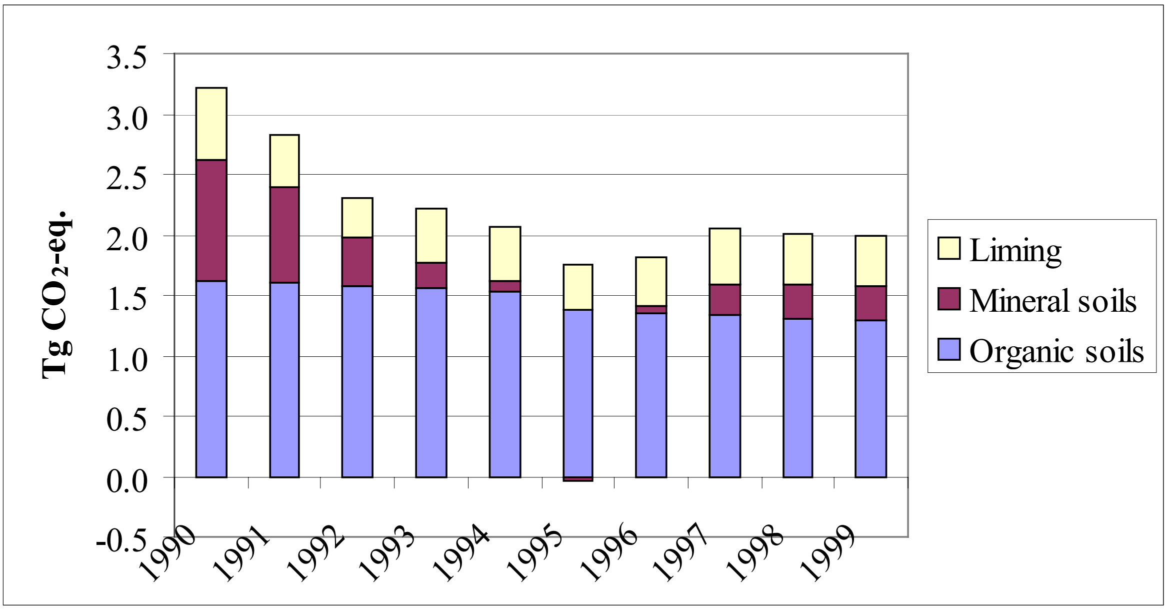


*Figure 5.2. $CO_2$ emissions from agricultural soils in 1990–1999.*

Methodology

The agricultural $CO_2$ emissions have been calculated using the methods given in the IPCC guidelines and national emission factors (with the exception of liming for which IPCC default emission factors have been used).

Changes to previous years

The emission estimates for changes in carbon stocks in mineral soils are included in the Finnish inventory for the first time. The emissions have been calculated for the whole time series 1990–1999 using the same method (see Annex D).

The land-area data of organic soils have been improved and a time series for the changes since 1990 has been developed. Agrifood Research Finland has calculated the land-areas and emissions based on information from unpublished statistics of the Finnish Soil Analysis Service and the references (Nykänen et al. 1995; Berglund 1989).

Uncertainties

The uncertainties in the emissions from mineral and organic soils are considerable. The uncertainties in emission factors contribute most to the total uncertainty. The uncertainties in the land areas have been greatly decreased by the estimates done by Agrifood Research Finland.

Key source identification and implications

Agricultural $CO_2$ emissions have been identified as a key source in Finland. The importance of these emissions was recognised even before, and the improvements done in the current inventory are considerable. Further improvements are, however, still needed. Especially the emission factors used in the calculation of the emissions from mineral and organic soils need more research. In the Finnish Global Research Programme (FIGARE) an agricultural research project aims at improving this data by doing actual measurements on the emissions from different soils types under varying management practices. The results will be used to improve the emissions factors, when available.

Future improvement of methods and input data

The improvement of the methods and input data to obtain more accurate estimates of the agricultural $CO_2$ emissions is a continuous task. The emissions are considered to be very uncertain and both national and international research is needed in improving them. The emission methodology for the calculation of the carbon changes in mineral soils is applied for the first time in the Finnish inventory. The IPCC method is applied, but the suitability of method for annual estimates is questioned and need to be explored further. All the activity data and emissions factors need also improving.

## 5.2.2 Methane emissions from enteric fermentation

Emission trends

Methane is produced as part of normal digestive processes in animals. The amount of emissions produced depends primarily on the animal's digestive system, and the amount and type of feed it consumes. Ruminant animals (e.g. cattle, sheep and goats) are the major emitters because of their unique digestive system. Emissions caused by non-ruminant animals (e.g. pigs and horses) are smaller. Cattle, and of those dairy cattle, produce the bulk part of these emissions in Finland.

The estimated Finnish emissions from enteric fermentation for 1990 to 1999 are given in Table 5.2.

*Table 5.2. Estimated $CH_4$ emissions (Gg/a) from enteric fermentation by animal category in Finland 1990–1999.*

| **Animal category** | **1990** | **1991** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** |
|---|---|---|---|---|---|---|---|---|---|---|
| dairy cows | 47.6 | 43.7 | 42.1 | 42.3 | 42.3 | 41.0 | 40.5 | 41.2 | 40.5 | 40.1 |
| mother cows | 0.9 | 1.4 | 1.8 | 2.2 | 2.2 | 1.9 | 2.1 | 2.1 | 2.0 | 2.0 |
| bull > one year | 9.0 | 8.7 | 8.6 | 8.4 | 8.6 | 6.6 | 6.9 | 7.2 | 6.9 | 7.1 |
| heifers | 13.4 | 13.1 | 12.9 | 13.3 | 13.2 | 11.6 | 12.3 | 12.1 | 11.7 | 11.5 |
| calves < one year | 12.2 | 12.2 | 11.6 | 11.0 | 10.7 | 10.6 | 10.2 | 10.1 | 10.0 | 9.5 |
| pigs | 2.1 | 2.0 | 1.9 | 1.9 | 1.9 | 2.1 | 2.1 | 2.2 | 2.1 | 2.0 |
| sheep | 0.8 | 0.9 | 0.9 | 1.0 | 1.0 | 1.3 | 1.2 | 1.2 | 1.0 | 0.9 |
| goats | 0.03 | 0.03 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 | 0.04 | 0.04 | 0.04 |
| horses | 0.8 | 0.8 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 1.0 | 1.0 | 1.0 |
| | | | | | | | | | | |
| ***Total, Gg $CH_4$*** | ***86.9*** | ***82.7*** | ***80.8*** | ***80.9*** | ***80.7*** | ***75.9*** | ***76.2*** | ***77.1*** | ***75.3*** | ***74.0*** |
| **Total, Tg $CO_2$-eq.** | **1.8** | **1.7** | **1.7** | **1.7** | **1.7** | **1.6** | **1.6** | **1.6** | **1.6** | **1.6** |

Methodology

The Finnish emissions from enteric fermentation for cattle are calculated using the Tier 2 methodology of the IPCC Guidelines as elaborated by the good practice report. The input data needed in the calculations have been obtained from the national statistics (animal numbers, milk production for dairy cows) and Finnish agricultural experts (animal weights, weight gain, DE%, milk production for mother cows). The IPCC default value has been used for methane conversion rate ($Y_m$). The emissions for the other animal categories are based on the Tier 1 method in the IPCC Guidelines. The compilation of the emission estimates, activity data and parameters used in the calculations are presented in more detail in Annex D.

Changes with respect to the previous years

The elaboration of the IPCC methodology in the good practice report has somewhat changed it. The Finnish emission estimates have been changed accordingly. A new concept called the mature weight (MW) has been included in the methodology as a scaling factor. Finnish values for mature weight (MW) were determined for mature dairy cows (570 kg) and bulls and mother cows (750 kg). The values were based on information received from the Finnish Rural Advisory Centres (Juho Kyntäjä, 11.10.2000).

In earlier inventory submissions constant values for animal weights and weight gain were used for the whole period. Now these values have been revised based on data from farm recordings in Finland (Juho Kyntäjä, 11.10.2000) and changes in these values during the calculation period are taken into account.

The changes influence the calculation of the gross energy intake of cattle and have an effect also on the estimates on methane emissions from manure management.

The changes described here have been made consistently to emission estimates throughout the period from 1990 to1999.

Uncertainties

The agricultural input data needed in the Tier 2 methodology of the IPCC Guidelines is estimated to be of good quality in Finland for the time period in question and most of the uncertainties in the emission estimate are due to the methodology and the varying nature of the source. The uncertainties in activity data are estimated to be 10%. Uncertainties associated with emission factors (parameters used in the calculation) are estimated to be around 30%. Overall, the estimated emissions are regarded to be of medium quality (uncertainties of the order of ±30 %).

Key source identification and implications

Methane emissions from enteric fermentation in livestock are identified as a key source category in the Finnish inventory. However, only one animal category (cattle) contributes significantly (more than 90 %) to the emissions. The current calculation follows the good practice guidance (decision tree in Fig. 4.2, page 22 in Chapter 4 of the good practice report). The emissions for cattle have been estimated with the Tier 2 methodology in the IPCC Guidelines and the emission for the other animal categories using the IPCC default emission factors (IPCC Tier 1).

Future improvement in methodology and input data

Finnish agricultural experts have put forward the option to base the emission calculation on average information on feed intake by cattle, instead of calculating it indirectly from average values on weight, weight gain and production related input parameters. This option will be explored in more detail.

Some of the input data used in the calculation are based on expert opinions. Checking of the data by wider range of experts is underway. The development of ways to get this data from yearly statistics or by means other periodic data collection procedures are explored.

### 5.2.3 Methane emissions from manure management

Emission trends

Methane emissions from manure management are caused by the microbial decomposition of the organic matter in manure under anaerobic conditions. The manure management system influences the emission much, as does temperature and also the way the animals are fed. The emissions from liquid manure are tenfold to the emissions from solid manure in Finnish climate conditions. In warmer countries the difference is even larger. The type of feed the animals receive affects the organic matter content in their manure, and hence the emissions. Corn-based animal diets cause in general more emissions than forage-based diets. The diets in Finland are typically forage-based.

The Finnish $CH_4$ emissions from manure management are rather small due to the cold climate and the large share of solid manure management. The emissions have, however, grown somewhat in Finland during the 1990s (see Table. 5.3) due to increased utilisation of liquid manure treatment methods. This has outweighed the impact on declining animal numbers on the emissions.

*Table 5.3. $CH_4$ emissions from manure management in Finland in 1999.*

| **Animal category** | **1990** | **1991** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** |
|---|---|---|---|---|---|---|---|---|---|---|
| dairy cows | 3.1 | 2.9 | 2.8 | 2.8 | 2.8 | 3.0 | 2.9 | 3.0 | 3.0 | 2.8 |
| mother cows | 0.02 | 0.03 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.05 | 0.04 | 0.04 |
| bulls > one year | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| heifers | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| calves < one year | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 |
| pigs | 3.9 | 3.7 | 3.6 | 3.5 | 3.6 | 4.7 | 4.7 | 4.9 | 4.7 | 4.6 |
| sheep | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 | 0.02 | 0.02 |
| goats | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| horses | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| poultry | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.9 | 0.9 | 0.9 | 1.0 | 0.9 |
| | | | | | | | | | | |
| ***Total, Gg $CH_4$*** | ***9.5*** | ***9.0*** | ***8.8*** | ***8.7*** | ***8.8*** | ***10.3*** | ***10.3*** | ***10.7*** | ***10.4*** | ***10.0*** |
| **Total, Tg $CO_2$-eq.** | **0.2** | **0.2** | **0.2** | **0.2** | **0.2** | **0.2** | **0.2** | **0.2** | **0.2** | **0.2** |

Methodology

The $CH_4$ emissions from manure management have been estimated with the Tier 2 methodology given in the IPCC Guidelines. Both IPCC default and national parameters have been used in the calculation of the emission factors.

Changes to previous years

No actual changes have been made to the methodology, but the methodological change in the calculation of the gross energy intake of cattle discussed in the enteric fermentation chapter changes also the emissions from manure management. The improved activity data (discussed also in the chapter on enteric fermentation) changes the emissions also somewhat.

Uncertainties

The agricultural input data needed in the Tier 2 methodology of the IPCC Guidelines is estimated to be of good quality in Finland for the time period in question and most of the uncertainties in the emission estimate are due to the methodology and the varying nature of the source. The uncertainties in activity data are estimated to be 10 %. Uncertainties associated with emission factors (parameters used in the calculation) are estimated to be around 30 %. Overall, the estimated emissions are regarded to be of medium quality (uncertainties of the order of ±30 %).

Key source identification and implications

$CH_4$ emissions from manure management were not identified as a key source in the Finnish inventory.

Future improvement of methods and input data

No major changes in the use of methods or collection of activity is foreseen for the estimation of the $CH_4$ emissions from manure management. If the methods for estimating the $CH_4$ emissions from enteric fermentation are changed, these changes would affect also the estimation the emissions from manure management.

The IPCC good practice report gives new default factors for liquid/slurry manure management systems that are considerably higher than the ones given in the IPCC Guidelines and which are used in the Finnish inventory. The new default values have not been used in the Finnish inventory as it is not known if they apply for Finnish conditions (e.g. the climate in Finland is much colder than what is defined as “cold climate” by the IPCC).

### 5.2.4 Nitrous oxide

<u>Emission trends</u>

In the Finnish inventory concerning direct $N_2O$ emissions from agricultural soils following sources have been considered:

- synthetic fertilisers
- animal excreta used as fertiliser
- biological nitrogen fixation
- crop residue and sewage sludge application
- cultivation of soils with high organic content.

Agricultural $NH_3$ emissions and nitrogen leaching to waterways have been considered in the estimation of the indirect $N_2O$ emissions. The estimated $N_2O$ emissions are given in Figure 5.3.

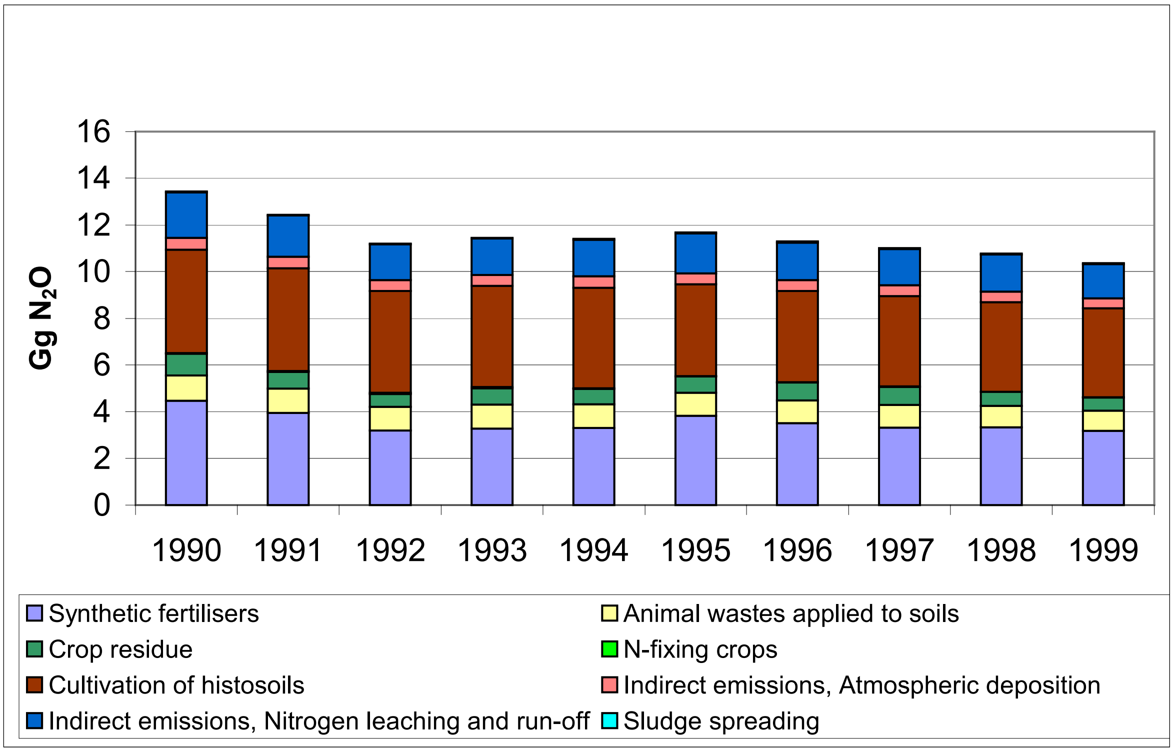


*Figure 5.3 $N_2O$ emissions from agricultural soils in Finland in 1990–1999.*

In addition to $N_2O$ emissions from agricultural soils, also emissions from manure management are estimated (see Fig. 5.4). Contrary to $CH_4$ emissions, the $N_2O$ emissions from manure management are larger from solid manure than from liquid manure. The trend in the emissions has been declining; both the decreases in the animal numbers and increasing use of liquid manure treatment has favoured this trend.

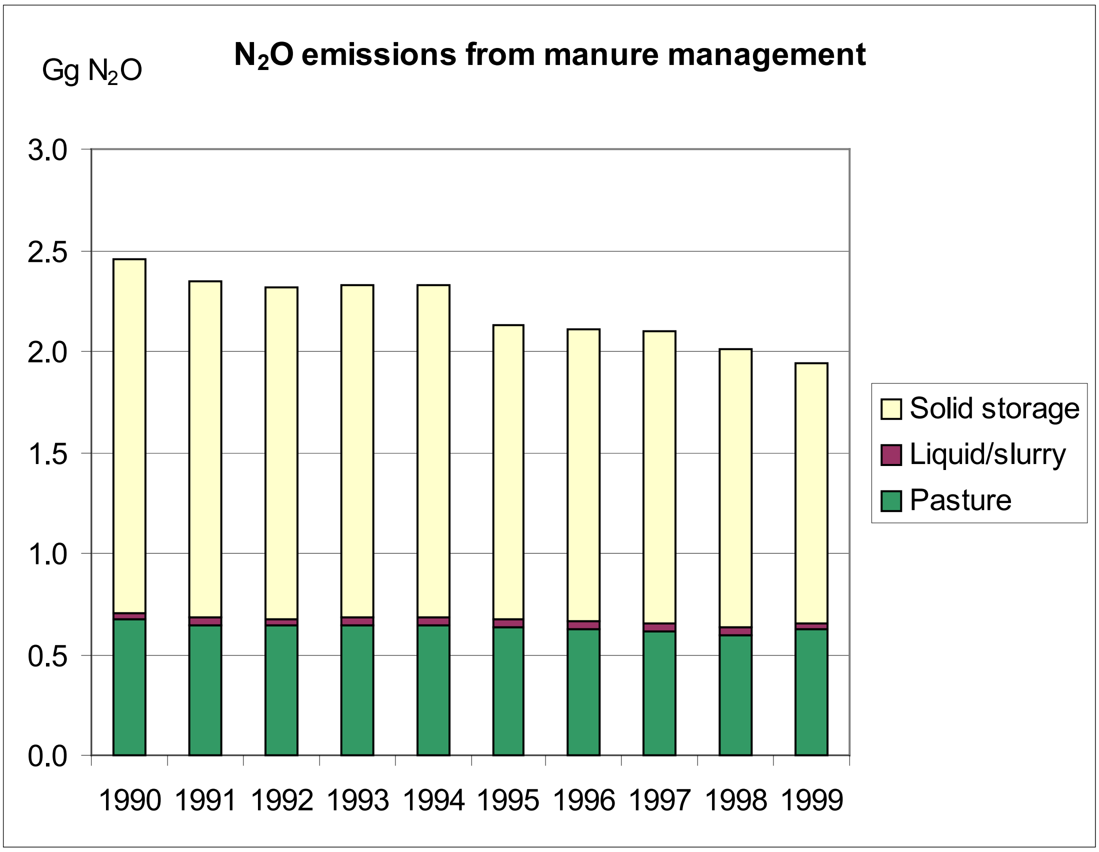


*Figure 5.4 $N_2O$ emissions from manure management in Finland in 1990–1999.*

Methodology

The methodology in the IPCC guidelines and the default emission factors used in the calculation the $N_2O$ emissions from agricultural soils and manure management with two exceptions. The nitrogen content in animal manure and the amount of nitrogen leached from agricultural soil to waterways is based on national data (see Annex D).

Changes to previous years

No changes in methodologies have been made, but activity data has been improved. A time series for the nitrogen content in manure has been developed (earlier the same values were used for all years).

Uncertainties

The uncertainties in the agricultural $N_2O$ emissions are considerable. The emission factors contribute most to the uncertainties, but also some activity data needs improvement.

Key source identification and implications

All main agricultural $N_2O$ emission sources, the direct and indirect $N_2O$ emissions from agricultural soils and the $N_2O$ emissions from manure management, have been defined as key sources in the Finnish inventory. This in mainly due to the large uncertainties in the emission factors.

Future improvement of methods and input data

Efforts to improve the knowledge on the $N_2O$ emission factors are made in the ongoing research program of the Finnish Global Research Program (FIGARE) (see above text on $CO_2$ emissions from agricultural soils).

# 6 LAND USE CHANGE AND FORESTRY

## 6.1 REMOVALS IN 1999

Tree harvesting and cutting cause $CO_2$ emissions, tree growth $CO_2$ uptakes in the Land-Use Change and Forestry Sector. Tree growth clearly overweighs the harvesting and cuttings, and the sector is a net sink for carbon in Finland. In 1999 the removals were approximately 15 % of the total greenhouse gas emissions in Finland.

## 6.2 TRENDS IN REMOVALS DURING 1990–1999

The tree growth has been rather steady in Finland during the 1990s and increment in the stem volume has varied between 73.4 and 78.0 million $m^3$. The annual changes in tree harvesting and cutting have been larger and the drain has varied from 44.6 to 69.4 million $m^3$. Hence also the annual net removal of $CO_2$ from the atmosphere have varied much during this period (9.7–38.2 Tg $CO_2$/year, see Table 6.1).

*Table 6.1. Stem volume increment and drain, as well as carbon (C) and $CO_2$ uptake and release of trees in Finland in 1990–1999.*

| Year | Volumes (million $m^3$) | | | Tg C | | | Tg $CO_2$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | Incre-ment | Drain | Balance | Uptake | Release | Balance | Uptake | Release | Balance |
| 1990 | 73.4 | 55.1 | 18.3 | 26.2 | 19.7 | 6.5 | 95.9 | 72.1 | 23.8 |
| 1991 | 74.3 | 44.6 | 29.7 | 26.4 | 16.0 | 10.4 | 96.8 | 58.6 | 38.2 |
| 1992 | 75.8 | 51.0 | 24.8 | 26.9 | 18.2 | 8.7 | 98.6 | 66.7 | 31.9 |
| 1993 | 76.6 | 53.8 | 22.8 | 27.2 | 19.2 | 7.9 | 99.5 | 70.4 | 29.1 |
| 1994 | 75.4 | 61.6 | 13.8 | 26.7 | 22.0 | 4.7 | 97.8 | 80.6 | 17.3 |
| 1995 | 75.4 | 63.6 | 11.8 | 26.7 | 22.7 | 4.0 | 97.8 | 83.1 | 14.7 |
| 1996 | 75.5 | 59.0 | 16.5 | 26.7 | 21.0 | 5.7 | 98.0 | 77.0 | 21.0 |
| 1997 | 75.9 | 65.8 | 10.1 | 26.9 | 23.4 | 3.4 | 98.6 | 85.9 | 12.6 |
| 1998 | 77.2 | 69.4 | 7.8 | 27.3 | 24.7 | 2.6 | 100.1 | 90.4 | 9.7 |
| 1999 | 78.0 | 69.4 | 8.6 | 27.6 | 24.7 | 2.9 | 101.3 | 90.4 | 10.8 |

<u>Methodology</u>

The methodology used in the inventory is consistent with the methodology given in the IPCC guidelines, but national values for the parameters have been used. The changes in soil carbon have not been estimated for forest soils. The changes in carbon in agricultural soils have been estimated, but they are reported in the Agriculture sector.

Total drain figures (and corresponding emissions of $CO_2$) are estimated annually based on the statistics of cutting removals reported by the forest industry companies in Finland. The estimates of the households' use of timber are based on enquires, the estimate of the cutting waste is obtained from timber quality requirements and taper curve models. The volume of natural losses is based on estimates in the Finnish National Forest Inventory (Finnish Statistical Yearbook of Forestry 1999). Total increment figures (and corresponding uptake of $CO_2$) are updated annually, but the measured values for different years come from different parts of the country. The averages of increments of five years preceding the measurement year are applied. This is a commonly used practice in forest inventories.

The volume increment of the growing stock of trees is estimated using field measurements on the sample plots of the Finnish National Forest Inventory (FNFI). The measurements concern the increment of the tree stem volume. An average increment of five years preceding the measurement time is applied. The measurements of the FNFI progresses by regions and thus the data for the whole country comes from different parts of the country for different years (see Tomppo 2000, Tomppo et al. 1997 and 1998). Conversion factors used for converting tree stem volume to whole tree biomass can be found in Karjalainen and Kellomäki (1996) (for more details see Annex E).

Changes with respect to previous years

No changes in methods, activity data collection or parameters used in the calculation have been made since the previous submission.

Uncertainties

The activity data used in the estimation of the removals by forest growth and in emissions caused by tree harvesting and cutting is considered to be of high quality in Finland. No quantitative estimates on uncertainties on the removal figures are given in the Annex A. Reliability figures by means of statistical methods can be found in e.g. Tomppo 2000.

Key source identification

The Land-Use Change and Forestry -sector is not included in the key source identification in accordance with the IPCC good practice report.

Future improvement in methodology and input data

The estimates of changes in carbon in forest soils are anticipated in future inventory submissions.

# 7 WASTE

The estimates in the waste sector include emissions from solid waste disposal and wastewater treatment. Emissions from waste incineration are reported in the Energy sector. $CH_4$ emissions from land disposal of solid municipal, industrial, construction and demolition wastes as well as of municipal and industrial sludges are presented. $CH_4$ emissions from municipal (excluding uncollected domestic wastewaters) and industrial wastewater handling have been estimated. In addition, $N_2O$ emissions caused by nitrogen input of domestic and industrial wastewaters, and also fish farming, into waterways, are included in the Finnish inventory.

## 7.1 EMISSIONS IN 1999

Solid waste disposal on land (landfills and dumps) cause relatively large $CH_4$ emissions in Finland (about 2 % of total emissions in 1999), the emissions from wastewater treatment are much smaller (see Fig. 7.1)

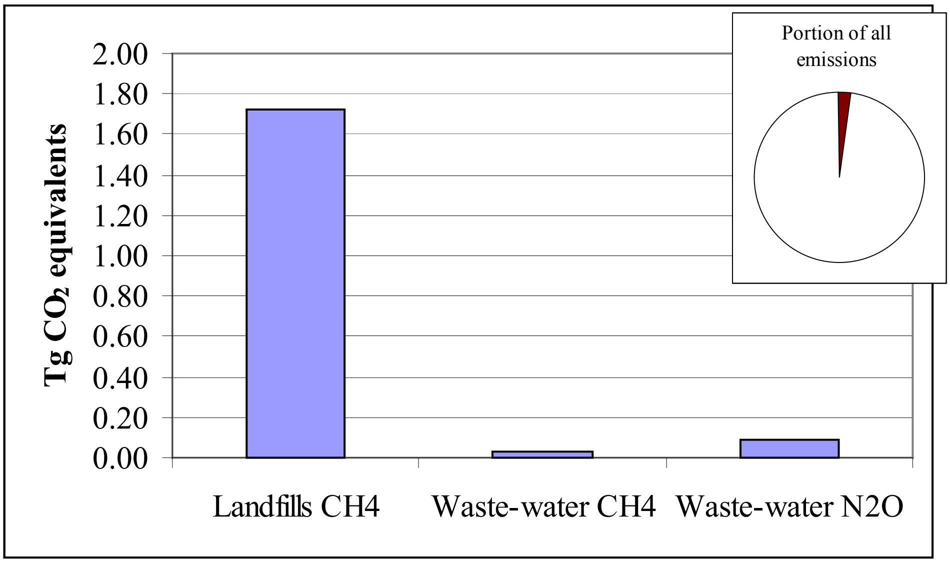


*Figure 7.1 Greenhouse gas emissions (1.7 Tg $CO_2$ eq) from the waste sector in Finland in 1999 and their share of the total emissions.*

## 7.2 EMISSION TRENDS IN THE WASTE SECTOR IN 1990–1999

The greenhouse gas emission from the waste sector in 1990–1999 are given in Table 7.1.

*Table 7.1. Greenhouse gas emissions from landfills and wastewater treatment in Finland in 1990–1999.*

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Tg $CO_2$ equivalents | | | | | | | | | |
| Landfills $CH_4$ | 3.6 | 3.4 | 3.1 | 2.8 | 2.4 | 2.3 | 2.1 | 1.9 | 1.8 | 1.7 |
| Wastewater $CH_4$ | 0.04 | 0.04 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Wastewater $N_2O$ | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| **Total** | **3.8** | **3.5** | **3.2** | **2.8** | **2.5** | **2.4** | **2.2** | **2.0** | **1.8** | **1.7** |

### 7.2.1 Solid waste disposal on land (landfills)

Emission trends

The most important greenhouse gas emissions in the waste sector, the $CH_4$ emissions from landfills have decreased with more that 50 % during the 1990 (see Table 7.1). The decrease in these emissions is mainly due to the implementation of the new waste law in Finland in 1994. In the beginning of the 1990s most municipal solid waste (around 80 % of the generated waste) waste taken to solid waste disposal sites (landfills) (Advisory board of Waste Management 1992). After the implementation the new waste law minimisation of waste generation, recycling and reuse of waste material and alternative treatment methods to landfills have been endorsed. The development in treatment of industrial waste, municipal and industrial sludges has been similar (Dahlbo et al. 2000).

Landfill gas recovery was practised on a minor scale at the beginning of the 1990s, but is now increasing rapidly. In 1990 the impact of recovery was estimated to be null, in 1995 about 3 Gg $CH_4$ and in 1999 already almost 9 Gg $CH_4$ (Leinonen & Kuittinen 2000).

Methodology

The Finnish $CH_4$ emissions from solid waste disposal on land have been calculated using the default methodology in the IPCC guidelines (mass balance methodology) using both IPCC default and national emission factors (see Annex F). The waste treatment data is based on the VAHTI registry. All landfills in Finland require a permit and are obliged to inform the Regional Environmental Agencies of the amount, type and origin of waste disposed of in the landfills. This information is stored in the VAHTI registry.

Change with respect to previous years

No major changes have been made since the previous submission. Smaller improvements in the activity data and DOC factors have been made. The changes are also reflected in the recalculation reported for the year 1998 (reduction of about -6.5 % to the previously reported figures).

Uncertainties

The uncertainties in the $CH_4$ emissions from solid waste disposal are estimated to be considerable (see e.g. Pipatti et al. 1996). These can, however, be mainly attributed to the nature of the source. The uncertainties in activity data are estimated to be 30 %, uncertainties in emission factors are estimated to be somewhat larger (40 %). The accuracy of the activity data has improved much during the last years, as many of the landfills have been equipped with scales to weigh the amounts landfilled. The collection of the data on solid waste disposal in the VAHTI registry is also a clear improvement to the earlier system. The emission factors used are based mainly on the IPCC Guidelines and their accuracy and suitability to Finnish conditions it not well known.

Key source identification and implications

$CH_4$ emissions from solid waste disposal on land have been identified as a key source in Finland. The emissions have been estimated with the IPCC default method, whereas the IPCC good practice report recommends use of the first order decay model. The change of model is under consideration.

Future improvement in methodology and input data

Solid waste disposal has been identified as an important source in the Finnish inventory and the emission estimates have been improved considerably during the last years, mainly due to improved activity data but also through more precise modelling. The change of method ("mass balance model" to "first order decay model") is under consideration and in an ongoing project of the Finnish Technology and Climate Change (Climtech) Programme efforts to estimate the historical data and emission factors (decay coefficients) are made. Results of the project are expected at the end of the year 2001.

### 7.2.2 Wastewater treatment

Emission trends

The greenhouse gas emissions ($CH_4$ and $N_2O$) from wastewater treatment are small in Finland (annual emissions around 0.1 Tg $CO_2$ equivalents) of which most is $N_2O$ emissions. The emissions have declined during the 1990s, $CH_4$ emissions by about 6 % and the $N_2O$ emissions by 25 %. The estimated $N_2O$ emissions include only emissions from the nitrogen load into waterways by domestic and industrial wastewaters caused by domestic and industrial wastewaters, as well as fish farming. The large decline in the emissions is attributed mainly to more effective nitrogen removal during wastewater treatment.

Methodology

The $CH_4$ emissions from wastewater treatment are calculated with a national method that corresponds to the methodology given in the IPCC Guidelines. The emission estimates for municipal wastewater treatment are based on the BOD load and the estimates for industrial wastewater treatment on the COD load of the wastewaters. The estimate includes emissions from both wastewater and sludge treatment. The emissions from sludge disposal on land are, however, estimated and reported in the Solid waste disposal on land (landfills) subsector.

The $N_2O$ emissions from wastewater treatment cover only the emissions from the increased nitrogen load to waterways. The data on the nitrogen load is received from the VAHTI registry. The methodology and emission factor is based on the IPCC guidelines' Agriculture sector. The emissions from fish farming are also taken into account here, as the methodology and emissions factors, as well as the source of activity data are the same (for more details see Annex F).

Change with respect to previous years

No changes in methods or input data have been made since the last inventory submission.

Uncertainties

The $CH_4$ emissions from wastewater and sludge treatment are uncertain as many of the input parameters are based on expert opinions. The $N_2O$ emissions from wastewater treatment and fish farming are also uncertain.

Key source identification and implications

Neither $CH_4$ nor $N_2O$ emissions from wastewater treatment were identified as key sources in the Finnish inventory.

Future improvement in methodology and input data

The methodologies and parameters (emission factors) used in the estimation of the $CH_4$ and $N_2O$ emissions from wastewater treatment need improvement. The activity data for the sources considered is based on data reported by the wastewater treatment facilities and considered reliable. This data should, however, be complemented with data on uncollected wastewaters from rural areas.

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ANNEX A

# KEY SOURCES IN THE FINNISH GREENHOUSE GAS INVENTORY – PRELIMINARY IDENTIFICATION

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## 1 IDENTIFICATION OF KEY SOURCES IN THE FINNISH INVENTORY

### 1.1 OBJECTIVE

Intergovernmental Panel on Climate Change (IPCC) has prepared a report "Good practice guidance and uncertainty management in national greenhouse gas inventories" (Penman et al. 2000). The IPCC good practice report gives advice how to identify the key source categories in the national inventory. A key source is one that has a significant influence on the total inventory in terms of the absolute level of emissions, the trend in emissions, or both. There are two alternative approaches for determining these key sources, Tier 1 and Tier 2 (see Fig. A-1). Any country that has done an inventory can implement Tier 1. Tier 2 is more complex. Key sources are those who cover 90 % of inventory uncertainty. The aim of defining the key sources is to enhance the accuracy of the inventory. When considering the use of available resources to improve the inventory precision, attention should be paid to those source categories, which have the greatest contribution to overall inventory uncertainty.

A preliminary determination of national key source categories in the Finnish greenhouse gas inventories 1998 and 1999 has been done. The key source categories were determined using both the Tier 1 and Tier 2 methods. The results from these methods were compared. The results of the key source identification for the year 1999 are presented here. The key source identification was done some months before the final compilation of the 1999 inventory. There may therefore be some differences in the numbers in the tables given in this Annex and the CRFs tables provided for the years 1990 and 1998. The differences are few and do not affect the key source identification.

The results of the key source category determination will be most useful if the analysis is done at the appropriate level of detail. The IPCC Good practice report recommends that the analysis is performed at the level of IPCC source categories for each greenhouse gas using $CO_2$ equivalent emissions. Whether certain sub-source categories within the key sources are particularly significant (i.e. represent a significant share of the emissions) should also be determined. It may be appropriate to focus efforts towards methodological improvements on these most significant sub-source categories and they can be taken as their own category in the analysis. In this analysis the IPCC emission source categories have been used. No subcategories relevant to this analysis were considered separately, on the contrary some groups like the new greenhouse gases (HFCs, PFCs and $SF_6$) in industrial processes were bundled together. The choice of level at which the key source identification is done and the results of the analysis are preliminary and will be improved in the future.

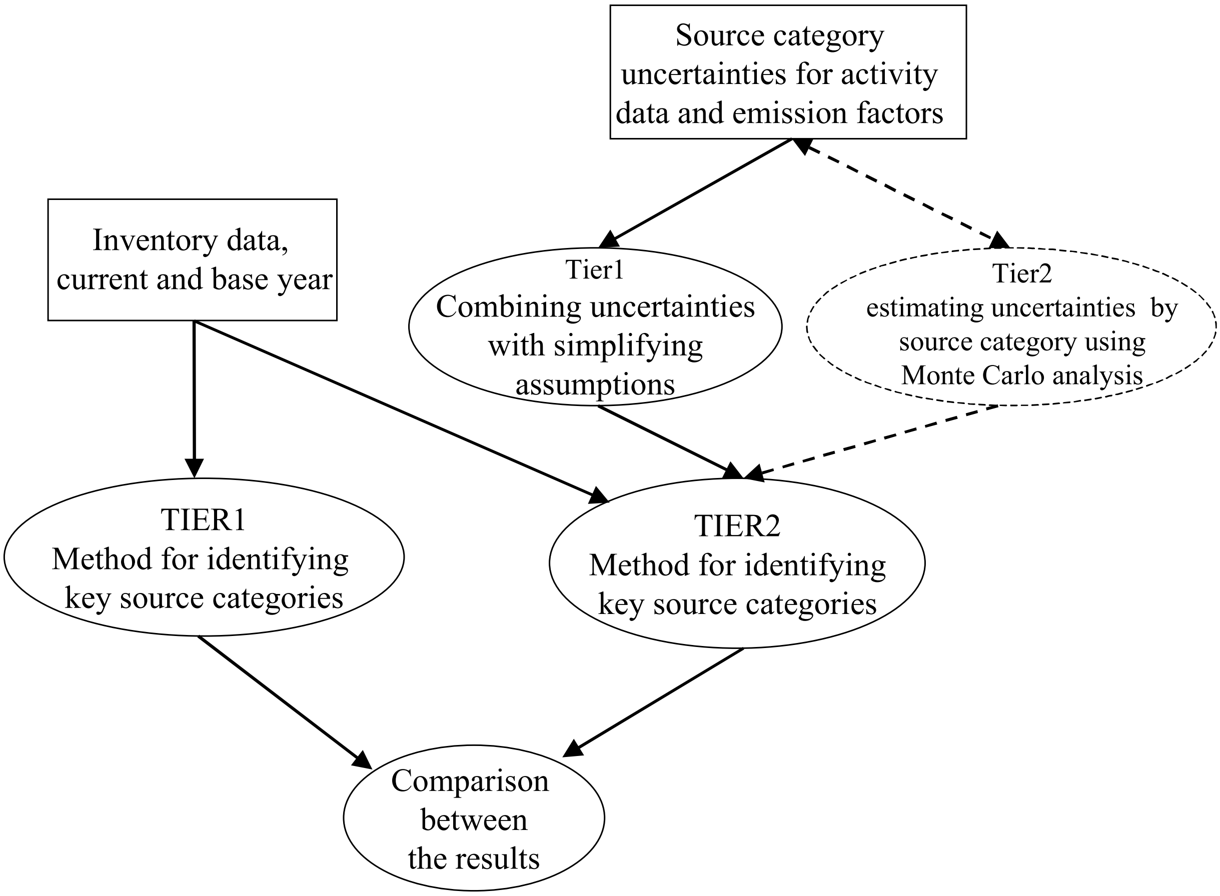


*Figure A-1. Determining national key source categories – process description.*

## 1.2 TIER 1

In the Tier 1 method source categories whose level has a significant effect on total national emissions are identified (level assessment). When emission inventories for more than one year are available, also sources that are key because of their contribution to the total trend of national emissions can be identified (trend assessment). In the trend analysis information on the inventory data of the current (1999) and the base year are used. Key source categories are those which, when summed together in descending order of magnitude, add up to over 95 % of the total of level assessment or contribution to trend. The proposed threshold of 95 % is recommend by IPCC and it was developed from a review of emission and uncertainty estimates for several inventories.

Emissions in 1999 (and 1988) and 1990 were used in the Tier 1 method. The level assessment was made using inventory data for the year 1999 (and 1998) and the trend assessment was made using data from both years. Results from the Tier 1 analysis can be seen in Table A-1.

## 1.3 TIER 2

If quantified data on the uncertainties for the activity and emission factor data relevant to the national greenhouse gas inventory source categories are available, then the key source categories can be identified using the Tier 2 approach. Tier 2 can provide additional insight into the reasons that particular source categories are key and can assist in prioritising activities to improve inventory quality and reduce overall uncertainty. The Tier 2 approach is likely to reduce the number of key source categories that need to be considered. In the Tier 2 analysis the Tier 1 level and trend assessment results are weighted by the source category's uncertainty.

The Tier 2 method can incorporate either uncertainty estimates done by using the simplifying assumptions or a Monte Carlo analysis. Rather than applying the pre-determined threshold of 95 % of the Level and Trend Assessments used in the Tier 1 method, in the Tier 2 method also other thresholds based on uncertainty analyses can be used. In this analysis all uncertainty estimates are based on expert judgement and those sources which cover 90 % of the inventory uncertainty are identified as key sources.

As was expected, less key source categories were identified when the Tier 2 method was used. Totally 33 key sources were identified with the Tier 1 method and 26 with the Tier 2 method. Most key sources, which came out from the Tier 2 approach, were also identified by the Tier 1 method. The key sources identified with the Tier 2 method but not with the Tier 1 method were $CH_4$ emissions from biomass burning, $N_2O$ emissions from road vehicles and air traffic. These emissions are rather small in quantity, but the uncertainties are relatively large. The results of the Tier 2 method can be seen in Table A-2 and comparison between the tiers in Table A-3.

## 1.4 QUALITATIVE APPROACH

There are other criteria to consider when determining key source categories that are not easily assessed through a quantitative analysis. These criteria include:

- Mitigation techniques and technologies: If emissions from a source category are being reduced significantly through the use of mitigation techniques or technologies, it is good practice to identify these source categories as key.
- High expected emission growth.
- High uncertainty.
- Unexpectedly low or high emissions.

In most cases, the application of these qualitative criteria will identify source categories already defined as key through the quantitative analysis. Some additional source categories may be identified and these may be added to the list of key source categories.

The quantitative analysis has been the basis of this key source determination. A systematic determination of key sources based on qualitative criteria has not been made. It was, however, noticed that most of the categories, which could have been taken as key sources due to qualitative criteria, were also identified as key source by quantitative criteria. Key source determination based on qualitative criteria will be looked at in more detail in future inventories.

# 2 DETERMINING UNCERTAINTIES

## 2.1 IDENTIFYING UNCERTAINTIES

Uncertainties should be determined separately for activity and emission factor of each source category. These uncertainties should be represented using probability density functions. The shape of the probability density function should be determined empirically, if possible. Otherwise, expert judgement will be necessary.

Emission factors and their probability functions are determined using different methods. Continuous monitoring is one method, which is usually consistent with the good practise. In some cases, periodic emission measurements can be used to determine the uncertainty of the emission factor. In that case it should be noticed that there are also some untypical operating conditions like start-up and shut down, emissions can depend on load and that measurements taken for another purpose may not be representative for emissions. If no information on the emission factor uncertainties is available, the IPCC default values can be used.

Activity data are often more closely linked to economic activity than are emission factors. There are often established price incentives and fiscal requirements for accurate accounting of economic activity. Activity data therefore tend to have lower uncertainties and a lower correlation between years. Activity data are often collected and published regularly by national statistical agencies. It is possible that these agencies have already assessed the uncertainties associated with their data as part of their data collection procedures. These uncertainties can be used to construct probability density functions. This information will not necessarily have been published, so it is good practice to contact the statistical agencies directly.

When empirical data are lacking, estimates of uncertainty in emission factors or direct emission measurements will need to be based on expert judgement.

The following experts were interviewed for the uncertainty analysis of the Finnish inventory. Kari Grönfors from Statistics Finland defined the uncertainties for the emissions from energy sector, Teemu Oinonen from Finnish Environment Institute for the new gases, Juhani Laurikko from VTT Energy for transportation and Riitta Pipatti from VTT Energy for the rest of the categories. These expert judgements have not been obtained using the formal method (expert elicitation) defined by the IPCC Good practice report.

## 2.2 TIER1 – ESTIMATING UNCERTAINTIES BY SOURCE CATEGORY WITH SIMPLIFYING ASSUMPTIONS

After the source uncertainties have been determined they are combined to get the inventory uncertainty. There are 2 alternative methods for this combining. The Tier 1 method uses simplifying assumptions of uncertainties, is very easy to apply and hardly any additional effort is needed if the key sources are identified at the same time undertaking the Tier 2 method.

In this analysis the Tier 1 method has been used for combining the uncertainties in emission factor and activity data using the error propagation equation. There are weaknesses in this method, as it assumes that the uncertainties are relatively small, have Gaussian distribution and have no significant covariance. In the Finnish inventory there are quite big uncertainties in some categories and the form of the probability functions is asymmetric in many cases, which means that the error propagation equation does not apply. However, approximate results with this method can still be obtained. The estimated uncertainties for the year 1999 are given in the Table A-4.

## 2.3 TIER2 – ESTIMATING UNCERTAINTIES BY SOURCE CATEGORIES USING MONTE CARLO ANALYSIS

The other alternative, Tier 2, uses Monte Carlo analysis to combine source category uncertainties. The principle of Monte Carlo analysis is to select random values of emission factor and activity data from within their individual probability density functions, and to calculate the corresponding emission values. This procedure is repeated many times, using a computer, and the results of each calculation run build up the overall emission probability density function.

Monte Carlo analysis can be performed at the source category level, for aggregations of source categories or for the inventory as a whole. Monte Carlo analysis can deal with probability density functions of any physically possible shape and width, can handle varying degrees of correlation (both in time and between source categories) and can deal with more complex as well as simple emission factor times activity data calculations.

This time this method has not been used. In the future, it could be useful to test if this method gives different results than the error propagation function in the Tier 1 method. It could also be interesting to see the effect of asymmetric probability distributions, which many of our emissions distributions are.

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*Table A-1. Key sources in the 1999 inventory identified by the Tier 1 method.*

| **IPCC Greenhouse Gas Source Categories** | **Gas** | **Key source category** | **Identification criteria** |
|---|---|---|---|
| 1. Energy | | | |
| A. Fuel Combustion (Sectoral Approach) | | | |
| 1. Energy Industries | | | |
| Liquid fuels | $CO_2$ | YES | Level, Trend |
| Liquid fuels | $CH_4$ | NO | |
| Liquid fuels | $N_2O$ | NO | |
| Solid fuels | $CO_2$ | YES | Level, Trend |
| Solid fuels | $CH_4$ | NO | |
| Solid fuels | $N_2O$ | NO | |
| Gaseous fuels | $CO_2$ | YES | Level, Trend |
| Gaseous fuels | $CH_4$ | NO | |
| Gaseous fuels | $N_2O$ | NO | |
| Biomass | $CH_4$ | NO | |
| Biomass | $N_2O$ | YES | Trend |
| Other fuels (including peat) | $CO_2$ | YES | Level, Trend |
| Other fuels (including peat) | $CH_4$ | NO | |
| Other fuels (including peat) | $N_2O$ | YES | Trend |
| 2. Manufacturing Industries and Construction | | | |
| Liquid fuels | $CO_2$ | YES | Level, Trend |
| Liquid fuels | $CH_4$ | NO | |
| Liquid fuels | $N_2O$ | YES | Trend |
| Solid fuels | $CO_2$ | YES | Level, Trend |
| Solid fuels | $CH_4$ | NO | |
| Solid fuels | $N_2O$ | NO | |
| Gaseous fuels | $CO_2$ | YES | Level, Trend |
| Gaseous fuels | $CH_4$ | NO | |
| Gaseous fuels | $N_2O$ | NO | |
| Biomass | $CH_4$ | NO | |
| Biomass | $N_2O$ | YES | Level, Trend |
| Other fuels | $CO_2$ | YES | Level, Trend |
| Other fuels | $CH_4$ | NO | |
| Other fuels | $N_2O$ | YES | Trend |
| 3. Transport | | | |
| Mobile combustion: road vehicles | $CO_2$ | YES | Level |
| Mobile combustion: road vehicles | $CH_4$ | NO | |
| Mobile combustion: road vehicles | $N_2O$ | NO | |
| Mobile combustion: waterborne navigation | $CO_2$ | YES | Level, Trend |

| | | | |
|---|---|---|---|
| Mobile combustion: waterborne navigation | $CH_4$ | NO | |
| Mobile combustion: waterborne navigation | $N_2O$ | NO | |
| Mobile combustion: aircraft | $CO_2$ | YES | Level |
| Mobile combustion: aircraft | $CH_4$ | NO | |
| Mobile combustion: aircraft | $N_2O$ | NO | |
| Mobile combustion: railways | $CO_2$ | NO | |
| Mobile combustion: railways | $CH_4$ | NO | |
| Mobile combustion: railways | $N_2O$ | NO | |
| Mobile combustion: other off-road-machinery | $CO_2$ | YES | Level |
| Mobile combustion: other off-road-machinery | $CH_4$ | NO | |
| Mobile combustion: other off-road-machinery | $N_2O$ | NO | |
| 4. Other Sectors | | | |
| Liquid fuels | $CO_2$ | YES | Level, Trend |
| Liquid fuels | $CH_4$ | NO | |
| Liquid fuels | $N_2O$ | NO | |
| Solid fuels | $CO_2$ | NO | |
| Solid fuels | $CH_4$ | NO | |
| Gaseous fuels | $CO_2$ | YES | Trend |
| Gaseous fuels | $CH_4$ | NO | |
| Gaseous fuels | $N_2O$ | NO | |
| Biomass | $CH_4$ | NO | |
| Biomass | $N_2O$ | NO | |
| Other fuels | $CO_2$ | NO | |
| Other fuels | $CH_4$ | NO | |
| Other fuels | $N_2O$ | NO | |
| 5. Other | | | |
| Liquid fuels | $CO_2$ | YES | Level, Trend |
| Liquid fuels | $CH_4$ | NO | |
| Liquid fuels | $N_2O$ | NO | |
| Gaseous fuels | $CO_2$ | NO | |
| Gaseous fuels | $CH_4$ | NO | |
| Gaseous fuels | $N_2O$ | NO | |
| B. Fugitive Emissions from Fuels | | | |
| 1. Solid Fuels | $CO_2$ | YES | Level |
| | $CH_4$ | NO | |
| 2. Oil and Natural Gas | $CO_2$ | NO | |
| | $CH_4$ | NO | |
| 2. Industrial Processes | | | |
| $CO_2$ emissions from cement production | $CO_2$ | YES | Level, Trend |
| $CO_2$ emissions from lime production | $CO_2$ | YES | Level, Trend |

| | | | |
|---|---|---|---|
| $CH_4$ emissions from iron and steel production | $CH_4$ | YES | Trend |
| $CH_4$ emissions from chemical industry and storage of chemicals | $CH_4$ | NO | |
| $N_2O$ emissions from nitric acid production | $N_2O$ | YES | Level, Trend |
| $SF_6$, $HFC_S$, $PFC_S$ | $SF_6$, $HFC_S$, $PFC_S$ | YES | Trend |
| Total solvent and other product use | $N_2O$ | NO | |
| 4. Agriculture | | | |
| $CO_2$ emissions from agricultural soils | $CO_2$ | YES | Level, Trend |
| $CH_4$ emissions from enteric fermentation in domestic livestock | $CH_4$ | YES | Level, Trend |
| $CH_4$ emissions from manure management | $CH_4$ | NO | |
| $N_2O$ emissions from manure management | $N_2O$ | YES | Level, Trend |
| Direct $N_2O$ emissions from agricultural soils | $N_2O$ | YES | Level, Trend |
| Indirect $N_2O$ emissions from nitrogen used in agriculture | $N_2O$ | YES | Level, Trend |
| 6. Waste | | | |
| $CH_4$ emissions from solid waste disposal sites | $CH_4$ | YES | Level, Trend |
| Emissions from wastewater handling | $CH_4$ | NO | |
| Emissions from wastewater handling | $N_2O$ | NO | |
| 7. Other (non-energy use of fuels) | $CO_2$ | YES | Level, Trend |

*Table A-2. Key sources in the 1999 inventory identified by the Tier 2 method.*

| **IPCC Greenhouse Gas Source Categories** | **Gas** | **Key source category** | **Identification criteria** |
|---|---|---|---|
| 1. Energy | | | |
| A. Fuel Combustion (Sectoral Approach) | | | |
| 1. Energy Industries | | | |
| Liquid fuels | $CO_2$ | NO | |
| Liquid fuels | $CH_4$ | NO | |
| Liquid fuels | $N_2O$ | NO | |
| Solid fuels | $CO_2$ | YES | Level |
| Solid fuels | $CH_4$ | NO | |
| Solid fuels | $N_2O$ | NO | |
| Gaseous fuels | $CO_2$ | NO | |
| Gaseous fuels | $CH_4$ | NO | |
| Gaseous fuels | $N_2O$ | NO | |
| Biomass | $CH_4$ | NO | |
| Biomass | $N_2O$ | YES | Trend |
| Other fuels | $CO_2$ | YES | Level, Trend |
| Other fuels | $CH_4$ | NO | |
| Other fuels | $N_2O$ | YES | Level, Trend |
| 2. Manufacturing Industries and Construction | | | |
| Liquid fuels | $CO_2$ | NO | |
| Liquid fuels | $CH_4$ | NO | |
| Liquid fuels | $N_2O$ | NO | |
| Solid fuels | $CO_2$ | YES | Level |
| Solid fuels | $CH_4$ | NO | |
| Solid fuels | $N_2O$ | NO | |
| Gaseous fuels | $CO_2$ | NO | |
| Gaseous fuels | $CH_4$ | NO | |
| Gaseous fuels | $N_2O$ | NO | |
| Biomass | $CH_4$ | NO | |
| Biomass | $N_2O$ | YES | Level, Trend |
| Other fuels | $CO_2$ | YES | Level, Trend |
| Other fuels | $CH_4$ | NO | |
| Other fuels | $N_2O$ | YES | Trend |
| 3. Transport | | | |
| Mobile combustion: road vehicles | $CO_2$ | YES | Level |
| Mobile combustion: road vehicles | $CH_4$ | NO | |
| Mobile combustion: road vehicles | $N_2O$ | YES | Level, Trend |
| Mobile combustion: waterborne navigation | $CO_2$ | YES | Level, Trend |

| | | | |
|---|---|---|---|
| Mobile combustion: waterborne navigation | $CH_4$ | NO | |
| Mobile combustion: waterborne navigation | $N_2O$ | NO | |
| Mobile combustion: aircraft | $CO_2$ | NO | |
| Mobile combustion: aircraft | $CH_4$ | NO | |
| Mobile combustion: aircraft | $N_2O$ | YES | Trend |
| Mobile combustion: railways | $CO_2$ | NO | |
| Mobile combustion: railways | $CH_4$ | NO | |
| Mobile combustion: railways | $N_2O$ | NO | |
| Mobile combustion: other off-road-machinery | $CO_2$ | YES | Level |
| Mobile combustion: other off-road-machinery | $CH_4$ | NO | |
| Mobile combustion: other off-road-machinery | $N_2O$ | NO | |
| 4. Other Sectors | | | |
| Liquid fuels | $CO_2$ | YES | Level, Trend |
| Liquid fuels | $CH_4$ | NO | |
| Liquid fuels | $N_2O$ | NO | |
| Solid fuels | $CO_2$ | NO | |
| Solid fuels | $CH_4$ | NO | |
| Gaseous fuels | $CO_2$ | NO | |
| Gaseous fuels | $CH_4$ | NO | |
| Gaseous fuels | $N_2O$ | NO | |
| Biomass | $CH_4$ | YES | Level, Trend |
| Biomass | $N_2O$ | NO | |
| Other fuels | $CO_2$ | NO | |
| Other fuels | $CH_4$ | NO | |
| Other fuels | $N_2O$ | NO | |
| 5. Other | | | |
| Liquid fuels | $CO_2$ | YES | Level |
| Liquid fuels | $CH_4$ | NO | |
| Liquid fuels | $N_2O$ | NO | |
| Gaseous fuels | $CO_2$ | NO | |
| Gaseous fuels | $CH_4$ | NO | |
| Gaseous fuels | $N_2O$ | NO | |
| B. Fugitive Emissions from Fuels | | | |
| 1. Solid Fuels | $CO_2$ | YES | Level |
| | $CH_4$ | NO | |
| 2. Oil and Natural Gas | $CO_2$ | NO | |
| | $CH_4$ | NO | |
| 2. Industrial Processes | | | |
| $CO_2$ emissions from cement production | $CO_2$ | NO | |
| $CO_2$ emissions from lime production | $CO_2$ | NO | |

| | | | |
|---|---|---|---|
| $CH_4$ emissions from iron and steel production | $CH_4$ | NO | |
| $CH_4$ emissions from chemical industry and storage of chemicals | $CH_4$ | NO | |
| $N_2O$ emissions from nitric acid production | $N_2O$ | YES | Level, Trend |
| $SF_6$, $HFC_S$, $PFC_S$ | $SF_6$, $HFC_S$, $PFC_S$ | YES | Trend |
| Total solvent and other product use | $N_2O$ | NO | |
| 4. Agriculture | | | |
| $CO_2$ emissions from agricultural soils | $CO_2$ | YES | Level, Trend |
| $CH_4$ emissions from enteric fermentation in domestic livestock | $CH_4$ | YES | Level, Trend |
| $CH_4$ emissions from manure management | $CH_4$ | NO | |
| $N_2O$ emissions from manure management | $N_2O$ | YES | Level, Trend |
| Direct $N_2O$ emissions from agricultural soils | $N_2O$ | YES | Level, Trend |
| Indirect $N_2O$ emissions from nitrogen used in agriculture | $N_2O$ | YES | Level, Trend |
| 6. Waste | | | |
| $CH_4$ emissions from solid waste disposal sites | $CH_4$ | YES | Level, Trend |
| Emissions from wastewater handling | $CH_4$ | NO | |
| Emissions from wastewater handling | $N_2O$ | NO | |
| 7. Other (non-energy use of fuels) | $CO_2$ | YES | Level, Trend |

*Table A-3. Comparison of key source identification with the Tier 1 and 2 methods.*

| | | Tier 1 | | Tier 2 | |
|---|---|---|---|---|---|
| IPCC Greenhouse Gas Source Categories | Gas | Key source category | Identification criteria | Key source category | Identification criteria |
| 1. Energy | | | | | |
| A. Fuel Combustion (Sectoral Approach) | | | | | |
| Energy Industries: Liquid fuels | $CO_2$ | YES | Level, Trend | NO | |
| Energy Industries: Liquid fuels | $CH_4$ | NO | | NO | |
| Energy Industries: Liquid fuels | $N_2O$ | NO | | NO | |
| Energy Industries: Solid fuels | $CO_2$ | YES | Level, Trend | YES | Level |
| Energy Industries: Solid fuels | $CH_4$ | NO | | NO | |
| Energy Industries: Solid fuels | $N_2O$ | NO | | NO | |
| Energy Industries: Gaseous fuels | $CO_2$ | YES | Level, Trend | NO | |
| Energy Industries: Gaseous fuels | $CH_4$ | NO | | NO | |
| Energy Industries: Gaseous fuels | $N_2O$ | NO | | NO | |
| Energy Industries: Biomass | $CH_4$ | NO | | NO | |
| Energy Industries: Biomass | $N_2O$ | YES | Trend | YES | Trend |
| Energy Industries: Other fuels | $CO_2$ | YES | Level, Trend | YES | Level, Trend |
| Energy Industries: Other fuels | $CH_4$ | NO | | NO | |
| Energy Industries: Other fuels | $N_2O$ | YES | Trend | YES | Level, Trend |
| 2. Manufacturing Industries and Construction | | | | | |
| Liquid fuels | $CO_2$ | YES | Level, Trend | NO | |
| Liquid fuels | $CH_4$ | NO | | NO | |
| Liquid fuels | $N_2O$ | YES | Trend | NO | |
| Solid fuels | $CO_2$ | YES | Level, Trend | YES | Level |
| Solid fuels | $CH_4$ | NO | | NO | |
| Solid fuels | $N_2O$ | NO | | NO | |
| Gaseous fuels | $CO_2$ | YES | Level, Trend | NO | |
| Gaseous fuels | $CH_4$ | NO | | NO | |
| Gaseous fuels | $N_2O$ | NO | | NO | |
| Biomass | $CH_4$ | NO | | NO | |
| Biomass | $N_2O$ | YES | Level, Trend | YES | Level, Trend |
| Other fuels | $CO_2$ | YES | Level, Trend | YES | Level, Trend |
| Other fuels | $CH_4$ | NO | | NO | |
| Other fuels | $N_2O$ | YES | Trend | YES | Trend |
| 3. Transport | | | | | |
| Mobile combustion: road vehicles | $CO_2$ | YES | Level | YES | Level |
| Mobile combustion: road vehicles | $CH_4$ | NO | | NO | |
| Mobile combustion: road vehicles | $N_2O$ | NO | | YES | Level, Trend |

| | | | | | |
|---|---|---|---|---|---|
| Mobile combustion: waterborne navigation | $CO_2$ | YES | Level, Trend | YES | Level, Trend |
| Mobile combustion: waterborne navigation | $CH_4$ | NO | | NO | |
| Mobile combustion: waterborne navigation | $N_2O$ | NO | | NO | |
| Mobile combustion: aircraft | $CO_2$ | YES | Level | NO | |
| Mobile combustion: aircraft | $CH_4$ | NO | | NO | |
| Mobile combustion: aircraft | $N_2O$ | NO | | YES | Trend |
| Mobile combustion: railways | $CO_2$ | NO | | NO | |
| Mobile combustion: railways | $CH_4$ | NO | | NO | |
| Mobile combustion: railways | $N_2O$ | NO | | NO | |
| Mobile combustion: other off-road-machinery | $CO_2$ | YES | Level | YES | Level |
| Mobile combustion: other off-road-machinery | $CH_4$ | NO | | NO | |
| Mobile combustion: other off-road-machinery | $N_2O$ | NO | | NO | |
| 4. Other Sectors | | | | | |
| Liquid fuels | $CO_2$ | YES | Level, Trend | YES | Level, Trend |
| Liquid fuels | $CH_4$ | NO | | NO | |
| Liquid fuels | $N_2O$ | NO | | NO | |
| Solid fuels | $CO_2$ | NO | | NO | |
| Solid fuels | $CH_4$ | NO | | NO | |
| Gaseous fuels | $CO_2$ | YES | Trend | NO | |
| Gaseous fuels | $CH_4$ | NO | | NO | |
| Gaseous fuels | $N_2O$ | NO | | NO | |
| Biomass | $CH_4$ | NO | | YES | Level, Trend |
| Biomass | $N_2O$ | NO | | NO | |
| Other fuels | $CO_2$ | NO | | NO | |
| Other fuels | $CH_4$ | NO | | NO | |
| Other fuels | $N_2O$ | NO | | NO | |
| 5. Other | | | | | |
| Liquid fuels | $CO_2$ | YES | Level, Trend | YES | Level |
| Liquid fuels | $CH_4$ | NO | | NO | |
| Liquid fuels | $N_2O$ | NO | | NO | |
| Gaseous fuels | $CO_2$ | NO | | NO | |
| Gaseous fuels | $CH_4$ | NO | | NO | |
| Gaseous fuels | $N_2O$ | NO | | NO | |
| B. Fugitive Emissions from Fuels | | | | | |
| 1. Solid Fuels | $CO_2$ | YES | Level | YES | Level |
| | $CH_4$ | NO | | NO | |
| 2. Oil and Natural Gas | $CO_2$ | NO | | NO | |
| | $CH_4$ | NO | | NO | |

| | | | | | |
|---|---|---|---|---|---|
| 2. Industrial Processes | | | | | |
| $CO_2$ emissions from cement production | $CO_2$ | YES | Level, Trend | NO | |
| $CO_2$ emissions from lime production | $CO_2$ | YES | Level, Trend | NO | |
| $CH_4$ emissions from iron and steel production | $CH_4$ | Yes | Trend | NO | |
| $CH_4$ emissions from chemical industry and storage of chemicals | $CH_4$ | NO | | NO | |
| $N_2O$ emissions from nitric acid production | $N_2O$ | YES | Level, Trend | YES | Level, Trend |
| $SF_6$, HFCs, PFCs | $SF_6$, HFCs, PFCs | YES | Trend | YES | Trend |
| Total solvent and other product use | $N_2O$ | NO | | NO | |
| 4. Agriculture | | | | | |
| $CO_2$ emissions from agricultural soils | $CO_2$ | YES | Level, Trend | YES | Level, Trend |
| $CH_4$ emissions from enteric fermentation in domestic livestock | $CH_4$ | YES | Level, Trend | YES | Level, Trend |
| $CH_4$ emissions from manure management | $CH_4$ | NO | | NO | |
| $N_2O$ emissions from manure management | $N_2O$ | YES | Level, Trend | YES | Level, Trend |
| Direct $N_2O$ emissions from agricultural soils | $N_2O$ | YES | Level, Trend | YES | Level, Trend |
| Indirect $N_2O$ emissions from nitrogen used in agriculture | $N_2O$ | YES | Level, Trend | YES | Level, Trend |
| 6. Waste | | | | | |
| CH4 emissions from solid waste disposal sites | $CH_4$ | YES | Level, Trend | YES | Level, Trend |
| Emissions from wastewater handling | $CH_4$ | NO | | NO | |
| Emissions from wastewater handling | $N_2O$ | NO | | NO | |
| 7. Other (non-energy use of fuels) | $CO_2$ | YES | Level, Trend | YES | Level, Trend |

*Table A-4. Uncertainty estimates in the Finnish greenhouse gas emission inventory for the year 1999.*

| IPCC Greenhouse Gas Source and Sink Categories | Gas | Emissions 1990 | Emissions 1999 | Activity data uncertainty | Emission factor uncertainty | Combined uncertainty | Combined uncertainty as part of total emissions in 1999 | Type A sensitivity | Type B sensitivity | Uncertainty in trend in emissions due to EF uncertainty | Uncertainty in trend in emissions due to activity data uncertainty | Uncertainty in the trend in total emissions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Energy | | | | | | | | | | | | |
| A. Fuel Combustion (Sectoral Approach) | | | | | | | | | | | | |
| 1. Energy Industries | | | | | | | | | | | | |
| Liquid fuels | $CO_2$ | 2602.8 | 2871.4 | 2 % | 2 % | 3 % | 0.0011 | 0.0037 | 0.0376 | 0.0011 | 0.0011 | 0.0015 |
| Liquid fuels | $CH_4$ | 5.67 | 5.88 | 2 % | 30 % | 30 % | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| Liquid fuels | $N_2O$ | 24.8 | 37.2 | 2 % | 50 % | 50 % | 0.0002 | 0.0002 | 0.0005 | 0.0003 | 0.0000 | 0.0003 |
| Solid fuels | $CO_2$ | 9279.2 | 8308.9 | 2 % | 3 % | 4 % | 0.0039 | -0.0121 | 0.1089 | 0.0046 | 0.0031 | 0.0056 |
| Solid fuels | $CH_4$ | 9.66 | 6.72 | 2 % | 30 % | 30 % | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| Solid fuels | $N_2O$ | 89.9 | 68.2 | 2 % | 50 % | 50 % | 0.0004 | -0.0003 | 0.0009 | 0.0006 | 0.0000 | 0.0006 |
| Gaseous fuels | $CO_2$ | 2659.3 | 4755.5 | 1 % | 1 % | 1 % | 0.0007 | 0.0276 | 0.0623 | 0.0004 | 0.0009 | 0.0010 |
| Gaseous fuels | $CH_4$ | 2.31 | 5.88 | 1 % | 30 % | 30 % | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| Gaseous fuels | $N_2O$ | 12.4 | 31 | 1 % | 50 % | 50 % | 0.0002 | 0.0002 | 0.0004 | 0.0003 | 0.0000 | 0.0003 |
| Biomass | $CH_4$ | 2.1 | 6.93 | 20 % | 50 % | 54 % | 0.0000 | 0.0001 | 0.0001 | 0.0001 | 0.0000 | 0.0001 |
| Biomass | $N_2O$ | 9.3 | 155 | 20 % | 100 % | 102 % | 0.0021 | 0.0019 | 0.0020 | 0.0029 | 0.0006 | 0.0029 |
| Other fuels | $CO_2$ | 3971.8 | 5093 | 5 % | 5 % | 7 % | 0.0047 | 0.0149 | 0.0668 | 0.0047 | 0.0047 | 0.0067 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Other fuels | $CH_4$ | 5.25 | 3.57 | 5 % | 50 % | 50 % | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Other fuels | $N_2O$ | 142.6 | 241.8 | 5 % | 100 % | 100 % | 0.0032 | 0.0013 | 0.0032 | 0.0045 | 0.0002 | 0.0045 |
| 2. Manufacturing Industries and Construction | | | | | | | | | | | | |
| Liquid fuels | $CO_2$ | 4293.5 | 4782.2 | 2 % | 2 % | 3 % | 0.0018 | 0.0067 | 0.0627 | 0.0018 | 0.0018 | 0.0025 |
| Liquid fuels | $CH_4$ | 7.56 | 7.14 | 2 % | 30 % | 30 % | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| Liquid fuels | $N_2O$ | 83.7 | 161.2 | 2 % | 50 % | 50 % | 0.0011 | 0.0010 | 0.0021 | 0.0015 | 0.0001 | 0.0015 |
| Solid fuels | $CO_2$ | 6409.6 | 5734.1 | 2 % | 3 % | 4 % | 0.0027 | -0.0084 | 0.0752 | 0.0032 | 0.0021 | 0.0038 |
| Solid fuels | $CH_4$ | 4.41 | 3.57 | 2 % | 30 % | 30 % | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Solid fuels | $N_2O$ | 108.5 | 68.2 | 2 % | 50 % | 50 % | 0.0004 | -0.0005 | 0.0009 | 0.0006 | 0.0000 | 0.0006 |
| Gaseous fuels | $CO_2$ | 2093.46 | 2723.7 | 1 % | 1 % | 1 % | 0.0004 | 0.0084 | 0.0357 | 0.0003 | 0.0005 | 0.0006 |
| Gaseous fuels | $CH_4$ | 4.62 | 5.67 | 1 % | 30 % | 30 % | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| Gaseous fuels | $N_2O$ | 18.6 | 43.4 | 1 % | 50 % | 50 % | 0.0003 | 0.0003 | 0.0006 | 0.0004 | 0.0000 | 0.0004 |
| Biomass | $CH_4$ | 20.16 | 28.35 | 15 % | 50 % | 52 % | 0.0002 | 0.0001 | 0.0004 | 0.0003 | 0.0001 | 0.0003 |
| Biomass | $N_2O$ | 111.6 | 393.7 | 15 % | 100 % | 101 % | 0.0052 | 0.0037 | 0.0052 | 0.0073 | 0.0011 | 0.0074 |
| Other fuels | $CO_2$ | 1561.15 | 2596.4 | 5 % | 5 % | 7 % | 0.0024 | 0.0137 | 0.0340 | 0.0024 | 0.0024 | 0.0034 |
| Other fuels | $CH_4$ | 3.78 | 4.41 | 5 % | 50 % | 50 % | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| Other fuels | $N_2O$ | 55.8 | 170.5 | 5 % | 100 % | 100 % | 0.0022 | 0.0015 | 0.0022 | 0.0032 | 0.0002 | 0.0032 |
| 3. Transport | | | | | | | | | | | | |
| Mobile combustion: road vehicles | $CO_2$ | 11110.6 | 11104.2 | 1 % | 2 % | 2 % | 0.0033 | 0.0006 | 0.1456 | 0.0041 | 0.0021 | 0.0046 |
| Mobile combustion: road vehicles | $CH_4$ | 57.96 | 48.3 | 1 % | 50 % | 50 % | 0.0003 | -0.0001 | 0.0006 | 0.0004 | 0.0000 | 0.0004 |
| Mobile combustion: road vehicles | $N_2O$ | 421.6 | 368.9 | 1 % | 100 % | 100 % | 0.0049 | -0.0007 | 0.0048 | 0.0068 | 0.0001 | 0.0068 |
| Mobile combustion: waterborne navigation | $CO_2$ | 226.8 | 501.6 | 50 % | 2 % | 50 % | 0.0033 | 0.0036 | 0.0066 | 0.0002 | 0.0046 | 0.0047 |
| Mobile combustion: waterborne navigation | $CH_4$ | 0.21 | 14.91 | 50 % | 50 % | 71 % | 0.0001 | 0.0002 | 0.0002 | 0.0001 | 0.0001 | 0.0002 |
| Mobile combustion: waterborne navigation | $N_2O$ | 34.1 | 46.5 | 50 % | 100 % | 112 % | 0.0007 | 0.0002 | 0.0006 | 0.0009 | 0.0004 | 0.0010 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mobile combustion: aircraft | $CO_2$ | 402.6 | 461.6 | 5 % | 2 % | 5 % | 0.0003 | 0.0008 | 0.0061 | 0.0002 | 0.0004 | 0.0005 |
| Mobile combustion: aircraft | $CH_4$ | 10.5 | 0.42 | 5 % | 50 % | 50 % | 0.0000 | -0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Mobile combustion: aircraft | $N_2O$ | 58.9 | 6.2 | 5 % | 100 % | 100 % | 0.0001 | -0.0007 | 0.0001 | 0.0001 | 0.0000 | 0.0001 |
| Mobile combustion: railways | $CO_2$ | 192.3 | 158.6 | 5 % | 2 % | 5 % | 0.0001 | -0.0004 | 0.0021 | 0.0001 | 0.0001 | 0.0002 |
| Mobile combustion: railways | $CH_4$ | 0.21 | 0.084 | 5 % | 50 % | 50 % | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Mobile combustion: railways | $N_2O$ | 31 | 21.7 | 5 % | 100 % | 100 % | 0.0003 | -0.0001 | 0.0003 | 0.0004 | 0.0000 | 0.0004 |
| Mobile combustion: other off-road-machinery | $CO_2$ | 542.9 | 519.4 | 50 % | 2 % | 50 % | 0.0034 | -0.0003 | 0.0068 | 0.0002 | 0.0048 | 0.0048 |
| Mobile combustion: other off-road-machinery | $CH_4$ | 0.42 | 2.52 | 50 % | 50 % | 71 % | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Mobile combustion: other off-road-machinery | $N_2O$ | 89.9 | 62 | 50 % | 100 % | 112 % | 0.0009 | -0.0004 | 0.0008 | 0.0011 | 0.0006 | 0.0013 |
| 4. Other Sectors | | | | | | | | | | | | |
| Liquid fuels | $CO_2$ | 7274.3 | 5972.6 | 20 % | 2 % | 20 % | 0.0158 | -0.0166 | 0.0783 | 0.0022 | 0.0221 | 0.0223 |
| Liquid fuels | $CH_4$ | 19.32 | 16.8 | 20 % | 30 % | 36 % | 0.0001 | 0.0000 | 0.0002 | 0.0001 | 0.0001 | 0.0001 |
| Liquid fuels | $N_2O$ | 201.5 | 173.6 | 20 % | 50 % | 54 % | 0.0012 | -0.0004 | 0.0023 | 0.0016 | 0.0006 | 0.0017 |
| Solid fuels | $CO_2$ | 56.7 | 24.3 | 10 % | 5 % | 11 % | 0.0000 | -0.0004 | 0.0003 | 0.0000 | 0.0000 | 0.0001 |
| Solid fuels | $CH_4$ | 0.21 | 0.63 | 10 % | 30 % | 32 % | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Gaseous fuels | $CO_2$ | 98.5 | 259.7 | 5 % | 1 % | 5 % | 0.0002 | 0.0021 | 0.0034 | 0.0000 | 0.0002 | 0.0002 |
| Gaseous fuels | $CH_4$ | 0.21 | 0.21 | 5 % | 30 % | 30 % | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Gaseous fuels | $N_2O$ | 0 | 3.1 | 5 % | 50 % | 50 % | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Biomass | $CH_4$ | 244.23 | 293.37 | 15 % | 100 % | 101 % | 0.0039 | 0.0007 | 0.0038 | 0.0054 | 0.0008 | 0.0055 |
| Biomass | $N_2O$ | 24.8 | 31 | 15 % | 100 % | 101 % | 0.0004 | 0.0001 | 0.0004 | 0.0006 | 0.0001 | 0.0006 |
| Other fuels | $CO_2$ | 141.3 | 112.6 | 25 % | 20 % | 32 % | 0.0005 | -0.0004 | 0.0015 | 0.0004 | 0.0005 | 0.0007 |
| Other fuels | $CH_4$ | 4.62 | 6.09 | 25 % | 50 % | 56 % | 0.0000 | 0.0000 | 0.0001 | 0.0001 | 0.0000 | 0.0001 |
| Other fuels | $N_2O$ | 0 | 0.62 | 25 % | 100 % | 103 % | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 5. Other | | | | | | | | | | | | |
| Liquid fuels | $CO_2$ | 736.16 | 666.4 | 50 % | 2 % | 50 % | 0.0044 | -0.0009 | 0.0087 | 0.0002 | 0.0062 | 0.0062 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Liquid fuels | $CH_4$ | 2.184 | 1.89 | 50 % | 30 % | 58 % | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Liquid fuels | $N_2O$ | 6.2 | 6.2 | 50 % | 50 % | 71 % | 0.0001 | 0.0000 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| Gaseous fuels | $CO_2$ | 235.97 | 187.4 | 20 % | 1 % | 20 % | 0.0005 | -0.0006 | 0.0025 | 0.0000 | 0.0007 | 0.0007 |
| Gaseous fuels | $CH_4$ | 0.294 | 0.63 | 20 % | 30 % | 36 % | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Gaseous fuels | $N_2O$ | 1.24 | 3.1 | 20 % | 50 % | 54 % | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| B. Fugitive Emissions from Fuels | | | | | | | | | | | | |
| 1. Solid Fuels | $CO_2$ | 3500 | 3500 | 100 % | 10 % | 100 % | 0.0463 | 0.0002 | 0.0459 | 0.0065 | 0.0649 | 0.0652 |
| | $CH_4$ | 21 | 21 | 100 % | 10 % | 100 % | 0.0003 | 0.0000 | 0.0003 | 0.0000 | 0.0004 | 0.0004 |
| 2. Oil and Natural Gas | $CO_2$ | 41.9 | 24.36 | 10 % | 20 % | 22 % | 0.0001 | -0.0002 | 0.0003 | 0.0001 | 0.0000 | 0.0001 |
| | $CH_4$ | 3.57 | 7.35 | 10 % | 20 % | 22 % | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 2. Industrial Processes | | | | | | | | | | | | |
| $CO_2$ emissions from cement production | $CO_2$ | 777.49 | 617.54 | 5 % | 5 % | 7 % | 0.0006 | -0.0020 | 0.0081 | 0.0006 | 0.0006 | 0.0008 |
| $CO_2$ emissions from lime production | $CO_2$ | 352.31 | 496.53 | 10 % | 5 % | 11 % | 0.0007 | 0.0019 | 0.0065 | 0.0005 | 0.0009 | 0.0010 |
| $CH_4$ emissions from iron and steel production | $CH_4$ | 80.22 | 9.45 | 3 % | 20 % | 20 % | 0.0000 | -0.0009 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| $CH_4$ emissions from chemical industry and storage of chemicals | $CH_4$ | 3.99 | 5.46 | 5 % | 20 % | 21 % | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| $N_2O$ emissions from nitric acid production | $N_2O$ | 1596.5 | 1323.7 | 5 % | 20 % | 21 % | 0.0036 | -0.0035 | 0.0174 | 0.0049 | 0.0012 | 0.0051 |
| $SF_6$, $HFC_S$, $PFC_S$ | $SF_6$, $HFC_S$, $PFC_S$ | 48.64 | 369.34 | 10 % | 40 % | 41 % | 0.0020 | 0.0042 | 0.0048 | 0.0027 | 0.0007 | 0.0028 |
| Total solvent and other product use | $N_2O$ | 62 | 62 | 30 % | 20 % | 36 % | 0.0003 | 0.0000 | 0.0008 | 0.0002 | 0.0003 | 0.0004 |
| 4. Agriculture | | | | | | | | | | | | |
| $CO_2$ emissions from agricultural | $CO_2$ | 2595.15 | 1990.05 | 30 % | 100 % | 104 % | 0.0274 | -0.0078 | 0.0261 | 0.0369 | 0.0111 | 0.0385 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| soils | | 008 | | | | | | | | | | |
| $CH_4$ emissions from enteric fermentation in domestic livestock | $CH_4$ | 1823.92 355 | 1554.21 | 10 % | 30 % | 32 % | 0.0065 | -0.0034 | 0.0204 | 0.0086 | 0.0029 | 0.0091 |
| $CH_4$ emissions from manure management | $CH_4$ | 198.794 908 | 210.21 | 10 % | 30 % | 32 % | 0.0009 | 0.0002 | 0.0028 | 0.0012 | 0.0004 | 0.0012 |
| $N_2O$ emissions from manure management | $N_2O$ | 553.681 03 | 409.2 | 10 % | 100 % | 100 % | 0.0054 | -0.0019 | 0.0054 | 0.0076 | 0.0008 | 0.0076 |
| Direct $N_2O$ emissions from agricultural soils | $N_2O$ | 3385.2 | 2607.1 | 30 % | 100 % | 104 % | 0.0359 | -0.0100 | 0.0342 | 0.0483 | 0.0145 | 0.0505 |
| Indirect $N_2O$ emissions from nitrogen used in agriculture | $N_2O$ | 982.7 | 790.5 | 40 % | 150 % | 155 % | 0.0162 | -0.0025 | 0.0104 | 0.0220 | 0.0059 | 0.0228 |
| 6. Waste | | | | | | | | | | | | |
| $CH_4$ emissions from solid waste disposal sites | $CH_4$ | 3642.45 | 1659.42 | 30 % | 40 % | 50 % | 0.0109 | -0.0258 | 0.0218 | 0.0123 | 0.0092 | 0.0154 |
| Emissions from wastewater handling | $CH_4$ | 35.91 | 33.6 | 30 % | 40 % | 50 % | 0.0002 | 0.0000 | 0.0004 | 0.0002 | 0.0002 | 0.0003 |
| Emissions from wastewater handling | $N_2O$ | 111.6 | 83.7 | 30 % | 100 % | 104 % | 0.0012 | -0.0004 | 0.0011 | 0.0016 | 0.0005 | 0.0016 |
| 7. Other (non-energy use of fuels) | | | | | | | | | | | | |
| | $CO_2$ | 640.29 | 750 | 100 % | 5 % | 100 % | 0.0099 | 0.0015 | 0.0098 | 0.0007 | 0.0139 | 0.0139 |
| | | | | | | | | | | | | |
| TOTAL | - | 76278.6 | 75915.4 | | | | 0.0721 | | | | | 0.1015 |

# METHODOLOGY FOR ESTIMATING $CO_2$, $CH_4$ AND $N_2O$ EMISSIONS FROM THE ENERGY SECTOR

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## 1 EMISSIONS FROM FUEL COMBUSTION

### 1.1 ILMARI CALCULATION SYSTEM

Carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$) are calculated with the ILMARI calculation system of Statistics Finland. ILMARI uses a bottom-up methodology consistent with the IPCC Tier 2 approach. $NO_x$, $SO_x$, CO, NMVOC and particle emissions from the energy sector are also calculated with ILMARI. The methodologies for these gases are, however, not addressed in detail in this Annex. ILMARI uses input data from various models, databases and other information sources. Figure B-1 gives a general overview of ILMARI and its links to various data sources providing activity and emission factor data to the system.

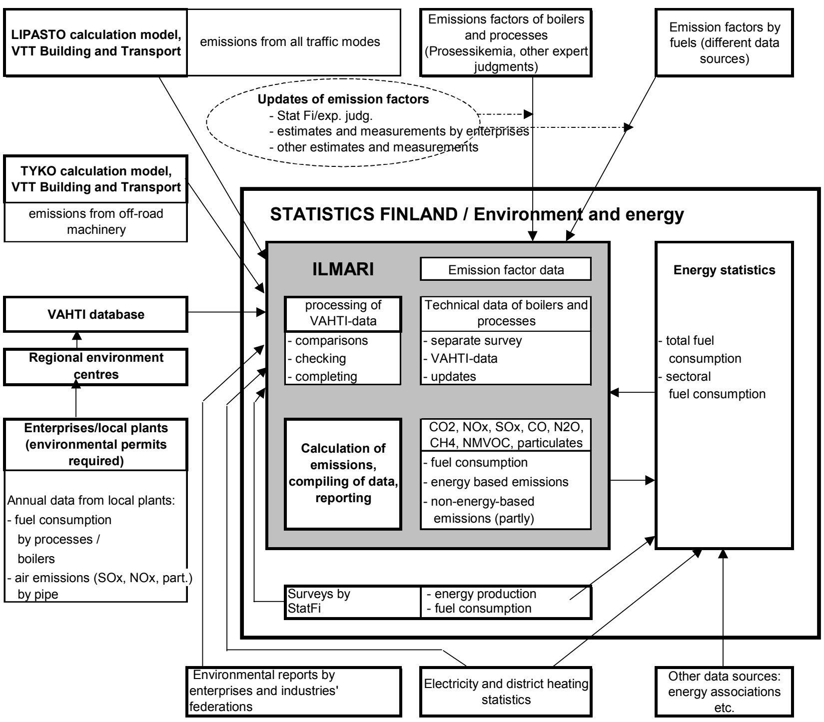


*Figure B-1. A diagram of the ILMARI calculation systems and its links to various databases and information sources.*

### 1.1.1 Activity data and emissions factors

ILMARI contains and collects data on stationary and other fuel consuming sources. Much of the data is collected at point source level (power plants and boilers ($P_{fuel}$ > 5 MW and industrial plants; total number of plants approximately 1000 including 2000 boilers and industrial processes). The main data sources used by the system are the Regional Environment Centres' VAHTI database, Energy statistics and Technical Research Centre of Finland's LIPASTO and TYKO calculation models (described more in detail later in this Annex).

ILMARI contains data on local units of stationary sources classified by the branch of industry, and by the main characteristics of the process and emission reduction equipment. The branch of industry division is at present based on the Finnish application of the ISIC 1968 (International Standard Industrial Classification). In the system 248 branches of industry from agriculture, forestry, transport and other industries are included and aggregated into 43 or 16 groups. Change to the NACE (official industrial classification of the European Union) is underway. The ILMARI categories are linked to the IPCC categories, too.

ILMARI includes approximately 50 fuel items. The fuels, as aggregated into main classes, are as follows: coal, coke, light fuel oil, heavy fuel oil, motor gasoline, other gasolines, diesel oil, peat, wood, natural gas, process gases, black liquor and other fuels.

Most annual fuel consumption data from stationary sources are based on the air emission register. The register contains the air emissions and fuel data from the Regional Environment Centres' VAHTI database. The fuel consumption data is compared with data from other sources such as manufacturing industry statistics, electricity statistics and district heating statistics. Other fuel consumption data, e.g. in the transport and small combustion sectors, is based on annual energy statistics and complemented with data from several other sources (see Fig. B-1).

Emission factors for both stationary and other sources are based on the database on emission factors for boilers and processes developed by the engineering office Prosessikemia Ky (detailed description of the database can be found in Boström et al. 1992 and Boström 1994). The $CO_2$ emission factors in the database are based mainly on IPCC default values, national values are used for some fuels. The $CH_4$ and $N_2O$ emission factors are based on mainly national research (includes evaluation and application of international research and measurement data) (Boström et al. 1991a and b and others). IPCC default values are used to a lesser degree.

The emission factors (including calorific values and values for the fraction of carbon oxidised) used in the inventory for the year 1999 are given in Tables B-1 to B-4 at the end of the Annex.

### 1.1.2 Calculation methods

ILMARI calculates emissions by a bottom-up method taking into account the combustion and emission reduction techniques as well as the boiler main fuel and capacity.

$CO_2$ emissions from stationary and other sources are calculated according to fuel consumption (in energy units) and emission factors characteristic of each fuel. Adjustments are made for the fraction of carbon that is oxidised.

$$\textit{Emissions } (CO_2) = \sum (\textit{Emission Factor}_a \times \textit{Fraction of Carbon Oxidised}_a \times \textit{Fuel Consumption}_{ab})$$

Where:
a = fuel type
b = plant or source category.

The fraction of fuel carbon oxidised depends on fuel type (see Table B-2).

$CH_4$ and $N_2O$ emissions are calculated using specific emission factors for each boiler, process or technology type.

$$\textit{Emissions } (CH_4 \textit{ and } N_2O) = \sum (\textit{Emission Factor}_{abc} \times \textit{Fuel Consumption}_{abc})$$

Where:
a = fuel type
b = plant or source category
c = boiler, process or technology.

The IPCC 1996 Revised Guidelines (Houghton et al. 1997) give in the Agriculture sector (page 4.105 in the Guidelines) a method and an emission factor for estimation of indirect $N_2O$ emissions due to atmospheric nitrogen deposition of $NH_3$ and $NO_x$ emissions. In the Finnish inventory these emissions are calculated also for energy-related and industrial $NO_x$ emissions using the IPCC methodology and default emission factor (0.01 kg $N_2O$-N/kg $NO_x$-N emitted). The indirect $N_2O$ emissions caused by nitrogen deposition due to $NO_x$ emissions in the energy sector are included in the emission estimates for the relevant sectors.

In the CRF tables[1] the indirect $N_2O$ emissions from $NO_x$ deposition are added to the direct $N_2O$ emissions in Table 1 sectoral report for energy as well as in all summary tables (1A, 1B, 2). However, they are not included in the sectoral background data tables for energy (1Aa) to avoid confusion in the comparison of the emission factors with international data.

Emissions from different traffic modes and off-road machinery are estimated making use of the results of the Technical Research Centre of Finland's (VTT) LIPASTO and

[1] see http://www.vyh.fi/eng/environ/state/air/emis/ghg/ghg.htm

TYKO models. The level of detail to which LIPASTO is utilised in the inventory calculation differs for the different transportation modes. Aggregate road vehicle emissions are taken directly from LIPASTO. Concerning the other transportation modes, ILMARI utilises the specific fuel consumption, emissions factor and other data of the LIPASTO model to the extent possible. Different calculation specifications on e.g. calculation of emissions from international bunkers complicate the integration of all LIPASTO results to ILMARI.

### 1.1.3 Reporting and allocation of emissions

ILMARI can make summaries of emission data in accordance with the user's criteria. The emissions can be calculated either according to individual criteria or as an arbitrary combination.

The main criteria for emission sources are branch of industry, branch of sub-process, fuel type, combustion technique and fuel capacity. The criteria by emission are the emission type, energy based and non-energy-based emissions, fuel consumption and average emission factors, for example. Bunker fuels can either be included or excluded from the summaries. Data from point sources are available on the level of municipality, region or province.

The main category division of sub-processes is made on the basis of the type of process in which the fuel is combusted. The criteria for the branch of the sub-process are based on technical characteristics instead of economical activities. Combustion technique and capacity data can be found only for sub-processes of stationary sources, and all the breakdowns listed in the summarising criteria are not applicable to all of the sub-processes.

The allocation of the emissions to IPCC source categories and summarising in the Common Reporting format categories is now included in ILMARI. There is, however, one main exception to this. In Finland many CHP power plants produce electricity and steam to the manufacturing industry, especially to pulp and paper plants. These power plants are usually economically part of the industrial sectors themselves, and in this case, the power plants are regarded as 'autoproducers' according to the IEA definitions. In the Finnish inventory (CRF tables) these autoproducer power plants are allocated to the corresponding industrial sectors. During the last years a growing number of these autoproducer power plants have been sold to the energy companies (i.e. companies, the primary activity of which is to produce and sell electricity and heat to the market). By definition, these plants should be allocated to the Energy Industries sector (CRF 1A1). However, in the Finnish inventories these plants are treated as autoproducers. Also some new power plants which have been built by the energy companies to serve the manufacturing industry have been categorised in the same way in the Finnish inventory. This allocation has been used in cases where there is a direct connection (steam pipe) between the power plant and the industrial plant and the industrial plant uses most of the energy (usually steam) produced by the power plant. The reasoning and justification for this allocation is that it enables linking of the emissions more closely to the actual production processes. The time series are also more logic using this approach.

A more detailed description of ILMARI can be found in “Finland's Greenhouse Gas Inventory to the UN's Framework Convention on Climate Chance. Years 1990, 1995–1997” or in the reference Statistics Finland (1998).

### 1.1.4 International bunkers

The Finnish calculation method for international bunkers is consistent with the methodology given in the IPCC guidelines. The emissions are calculated with ILMARI using data on fuels sold to ships and aircraft with a destination abroad, the emission factors are based either on the LIPASTO model or the IPCC default values (see Figure B-2).

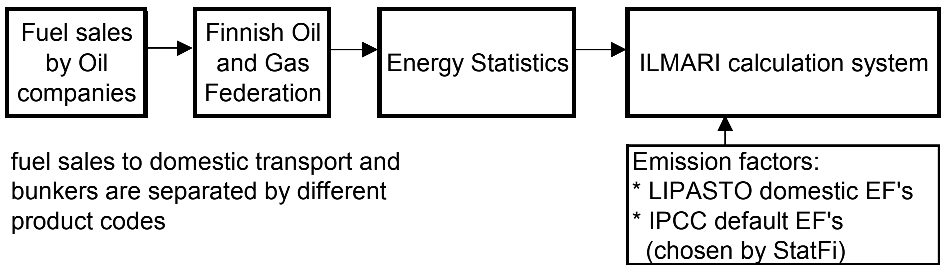


*Figure B-2. Principle of calculation of greenhouse gas emissions from international bunkers in the Finnish inventory.*

There is, however, one exception to the IPCC methodology. The emissions from ships to Sweden that stop in Åland are calculated as international bunker emissions for the whole trip. The ships stop in Åland mainly due to the regulations on tax free trade within the European Union and usually only a small part of the passengers and the cargo leaves or enters the ships there. According to the IPCC good practice report these emissions should be reported separately for the domestic and international part.

## 1.2 LIPASTO AND TYKO

The calculation system LIPASTO covers emissions and energy consumption of all traffic modes in Finland. The calculation system has been developed and is maintained by the Technical Research Centre of Finland (VTT Building and Transport). A description of the system and the results of the calculations can be found at the website: http://www.vtt.fi/rte/projects/lipastoe/index.htm.

The LIPASTO system is comprised of four sub-models

LIISA, road traffic (http://www.vtt.fi/rte/projects/yki6/liisae/emission.htm)
RAILI, railway traffic (http://www.vtt.fi/rte/projects/lipastoe/railie/railie.htm)
MEERI, waterborne traffic (http://www.vtt.fi/rte/projects/lipastoe/meerie/meerie.htm)
ILMI, air traffic (http://www.vtt.fi/rte/projects/lipastoe/ilmie/ilmie.htm)

The LIPASTO system calculates traffic exhaust gas emissions in Finland for the following compounds: carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides ($NO_x$), particles (PM), sulphur dioxide ($SO_2$) and carbon dioxide ($CO_2$). Nitrous oxide ($N_2O$) and methane ($CH_4$) emission calculation is included only in the LIISA sub-model but not to the others due to lacking emission factor data. The LIPASTO 1999 system calculates the emissions for the year 1999. Estimates for emissions and energy consumption are also given for the years 1980–2019. Most accurate time series are available for road traffic based on the LIISA model. The first version of the LIISA model was completed in 1989 and it calculated the emissions for the year 1987. The LIISA model was renewed completely in 1995 and emission estimates from the year 1993 have been calculated with the renewed model. The MEERI, ILMI and RAILI models were included in the system 1996. The time series for the previous years are calculated using the same principles, but the input data is rougher. The updating of the LIPASTO system is carried out annually with data of the previous year. The system is primarily meant for the use of the Ministry of Transport and Communications, and the representative organisations responsible for the sub-models and VTT.

The way the LIPASTO sub-models are run differs somewhat. The Civil Aviation Administration (CAA) runs the ILMI sub-model and the results (emissions, fuel consumption etc.) are fed to the LIPASTO system. A description of the model is found at the ILMI website and in the reference (Savola & Viinikainen 1995). The LIISA, MEERI and RAILI sub-models are run by VTT. Finnish Maritime Administration (waterborne traffic) and the VR Ltd (railway traffic) provide most of the activity data for the two last mentioned sub-models. All models use detailed information on the transportation operation, performance, fuel and energy use, and other relevant technical data in estimating the energy consumption of the traffic modes. In the selection of emission factors for different years the technological changes are taken into account, to the extent information is available. More data on the sub-models can be found at their websites (see list above) and in references Mäkelä et al. 2000a, b, c and d.

The TYKO model for the estimation of emissions and energy consumption of off-road machinery was completed during the summer 2000. The model is, as the LIPASTO calculation system, developed and maintained by VTT Building and Transport. More information on the model and results of the calculations can be found at the website http://www.vtt.fi/rte/projects/tyko/tyko.htm (only in Finnish at the moment) and in reference Mäkelä et al. 2000e.

ILMARI utilises the results of the TYKO model directly. However, at present the results of TYKO have been used only in the calculation of the 1999 inventory. The revision of 1990–1998 inventories to incorporate the TYKO results is underway.

### 3.1 Calculation methods in LIPASTO and TYKO

#### LIISA

The LIISA model calculates road traffic $CH_4$ and $N_2O$ emissions based on vehicle mileage (km/a) of different vehicle types on different road types and emission coefficients determined per kilometre driven (g/km). $CO_2$ calculation is based on fuel consumed (kg/a) and emission coefficient (g/kg fuel).

The principal calculation method is given in the equation below. In some cases emission factors for different categories are the same (e.g. in urban traffic the same emission factor is used for all speed categories). Emission factors for $CO_2$ are based on fuel consumption and the equation looks somewhat different. The emission factor for hot driving ${}^{a}b$ is the product of the base emission factor and factors that describe the changes in time in fuels and vehicle technology, as well as the ageing of vehicles.

$$E_{y,v} = \sum_{l=1}^{9} \sum_{m=1}^{20} \sum_{p=1}^{8} \sum_{r=1}^{6} s_{l,m,p,r,u,v} \left( {}^{a}b_{l,m,p,r,u,v,y} + {}^{j}b_{l,m,p,r,u,v,y} + {}^{k}b_{l,m,p,r,u,v,y} \right)$$

Where:

$E_{y,v}$ = emission of the gas y in the year v
s is vehicle mileage
${}^{a}b$ = emission factor for hot driving
${}^{j}b$ = emission factor for idle motion
${}^{k}b$ = emission factor for start up and cold start

and

$l$ = vehicle type
$m$ = vehicle model year
$p$ = road type
$r$ = speed class
$u$ = fuel type.

The base emission factors in the model (see Tables B-5 to B-7)) are emission factors for vehicles of model year 1993. The emission factor for cars without catalytic converters correspond to 1990 models (personal cars) and 1992 models (vans) (the last years when these cars could be sold in Finland without catalytic converters). For other model years the emission factors can be obtained using the conversion coefficients given in Tables B-8 to B-9). This way the technical development and ageing of cars can be taken into account in the model.

The vehicles types considered in the model are personal cars, vans, buses, semitrailers and articulated vehicles. The emissions estimates are based on vehicle and ton mileage which are calculated for eight driveway types.

| | |
|---|---|
| Roads managed by municipalities | - main streets<br>- collector streets<br>- access streets<br>- roads marked in building plans and private roads |
| Roads (public roads) managed by the Finnish Road Administration | - roads in urban areas, main roads<br>- roads in urban areas, other roads<br>- country roads, main roads<br>- country roads, other roads. |

The activity data on vehicle and ton mileage for public roads is based on the road registry of the Finnish Road Administration (1999). For other roads the data is taken from the street registry of the Finnish Road Administration and the geographical distribution is estimated proportional to the population in municipalities.

**MEERI**

The MEERI model calculates emissions and energy consumption caused by waterborne traffic in base year 1999. Calculation results are presented both countrywide and on individual port level. The calculation system includes sea and inland water traffic, leisure boating and fishing, and icebreaker traffic in Finland. Boats and vessels of the Finnish army are not included. MEERI 1999 is an update of the version MEERI 98.

MEERI calculation system is based on port traffic service data. The system calculates emission amounts and energy consumption caused by waterborne traffic in shipping channels and in ports during base year 1999. Data is specified according to a type of ship (passenger ship, freight ship), its traffic service area (domestic traffic, international traffic), its origin (Finnish, international) and its tonnage (gross registered tons). In countrywide calculation it is possible to make an even more detailed choice of vessel type (e.g. passenger car ferry, tanker). Finnish waterborne traffic emissions can be calculated for following compounds: carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), particles (PM), sulphur dioxides (SO2) and carbon dioxides (CO2). Fuel consumption is calculated as well.

In addition to the base year calculations MEERI 1999 includes an estimation of emissions for the years 1980–1998, and forecasts for the years 2000–2019.

**RAILI**

Traffic service data of each railroad division and marshalling yard forms the basis of RAILI 1999 calculation model. The system calculates the amount of exhaust gas emissions and energy consumption that was caused by railway traffic in rail sections and yards in the base year (1999). Data is analysed according to train type (passenger train, freight train, locomotive), locomotive type (electric trains: two different types + Pendolino), diesel locomotives (6 different) and tonnage. The emissions can be calculated from the following compounds: carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), particles (PM), sulphur dioxide ($SO_2$) and carbon dioxide ($CO_2$).

The calculation includes fuel consumption and energy usage. The emission data can be gathered both countrywide and on a rail section and yard level. Emissions are calculated as a product of emission factors and energy consumption of trains. The emissions and energy consumption caused by local traffic can also be estimated. Local traffic has been divided in two parts: local traffic of the Helsinki Metropolitan Area and local traffic of the rest of the country.

In addition to the base year calculations RAILI 1999 includes a rough estimation of emissions for the years 1980–1995. More accurate figures are available for the years 1996, 1997 and 1998 calculated by versions RAILI 96, RAILI 97 and RAILI 1998 respectively, and forecasts for the years 2000–2019.

**ILMI**

ILMI calculates gaseous emissions and energy consumption of civil aviation within Finnish flight information regions. The model developed by the CAA is meant for emission studies on jet and turboprop powered aircraft (turbine engined fleet). Furthermore, it also includes a simplified routine for estimating emissions from piston engined aircraft's.

The calculated emissions of jet and turboprop powered aircraft include nitrogen oxides ($NO_x$), carbon monoxide (CO) and unburned hydrocarbons (HC). Also fuel burn is assessed. The methodology is based on traffic statistics, aircraft performance data and engine emission factors from the ICAO (International Civil Aviation Organisation) database. The carbon dioxide ($CO_2$) and sulphur dioxide ($SO_2$) emissions are calculated directly from the estimated fuel consumption. The used traffic data is taken from CAA's database for the year 1999. The data includes

- aircraft type
- carrier
- departure and landing airport
- total time of a time
- flight time of a flight inside Finnish FIRs
- the number of similar flights between airport.

In the calculation each operation is divided into the following flight segments: taxi, take-off, climb-out, cruise, descent, approach, taxi. All flights are classified into one of the following categories: domestic traffic, departing international traffic, arriving international traffic and over-flights. Emissions are calculated separately for each aircraft type and category. Only the flight segments within Finnish flight information regions are included.

The methodology for assessing emission from piston engined aircraft is different from the one used for turbine engined aircraft. It is based on the annually published statistics of total flight hours for one- and two-engine piston aircraft. The fuel burn and emission indexes used are generalised for two typical reference aircraft types only. Therefore, the results are not as reliable as for turbine engined aircraft.

Helicopters are not included in the calculations due to the small number of flights and the lack of emission factors.

**TYKO**

Emission estimates for off-road machinery are based on the work done (kWh) with the machines and emission factors (g/kWh) which are based on average emissions per working hour. The calculation method can be described with the equation

$$Emissions\ (CO_2,\ CH_4\ and\ N_2O) = \sum N_{abcde}\ x\ P\ x\ \%P\ x\ t\ x\ Emission\ Factor_{abcde}$$

Where:
N = number of machines
P = nominal power (kW)
%P = driving power (as percentage of nominal power)
t = working hours (h/year)

and

a = engine type (2-stroke, 4-stroke, diesel (6 subclasses) or LPG)
b = power class
c = model year
d = service life
e = professional or private use.

The machine database is based on information collected by Puranen (1992, et al. 1993, 1994 and et al. 1995) and annual sales statistics (Association of Technical Trade). Decommissioning is taken into account using specific decommissioning factors based on a method developed by US EPA but adapted to Finnish circumstances. Sales statistics for all machines are lacking and for some machines the figures used in the calculation are based on the experts' estimates on how many machines have been sold so that the machine database (vehicle register) would correspond to the estimated values.

The classification in the TYKO database and the emission factors used are taken from the European Unions' Emission Inventory Guidebook (1996) and Andrias et al. (1994) with small changes. The $N_2O$ emission factors given for diesel machines in the references are ten times higher than usually used for transportation. A limited number of measurements in Finland (Kudjoi 1992) indicate that the use of lower emission factor (0.03 g $N_2O$/kWh; Ricardo and Scania motors) could be justified, a Swedish study indicates the opposite (emission factor for Volvo motors 0.35 g $N_2O$ /kWh). The emission factors given by Andrias et al. 1994 have therefore been used in the model.

1.3 ENERGY STATISTICS

Statistics Finland runs the energy statistics, which contain fuel consumption and energy production data from all relevant sources. The most detailed data on fuel consumption is available from mining and quarrying, manufacturing industry, and from energy and water supply. This data is based on a special energy inquiry made by Statistics Finland's industrial statistics unit. The respondents state the quantity of fuels they use for electricity and heat generation, for heating and for operating machines, equipment and vehicles.

In industrial statistics, the industrial sector of the unit is categorised according to the sector in which the unit produces most commodities in terms of the value of sales. The energy inquiry provides supplementary data for the identification of the industrial sector of the establishments included in the air emission register part of VAHTI and additional data on fuel use in these establishments. Data on fuel use in those sectors of economic activity, which are not included in the industrial statistics, are compiled by the Energy Statistics using information from other statistics and studies on individual sectors and fuels.

More information on the Energy Statistics of Statistics Finland can be found at its website at http://www.stat.fi/tk/yr/ye608_en.html.

## 1.4 VAHTI DATABASE

The monitoring and environmental loading data system (VAHTI) is a database for the input and storage of information on the environmental permits of the entities and their discharges into water, emissions into air and wastes. The main purpose of the data system is to function as a tool for the regional environment centres in processing and monitoring permits. The system produces annual baseline data on emissions into air, discharges into water and on wastes. The data is provided by entities subject to environmental permits and competent authorities (Regional Environmental Agencies) check the validity of the data. The VAHTI database contains information on all entities that are subject to environmental permits, which covers most energy producers and industries as well as all landfills and many other activities in Finland.

The VAHTI database was implemented in 1997. VAHTI combined three former registers of the environmental administration (air emissions register, water emissions register and the registers of the waste sector). The detail in which information is stored in the system varies by sector. Shortcomings, especially during the start-up phase, in data entries according to the set dead lines have occurred occasionally and led to small changes in the inventories. A confidence check of the VAHTI database will be finalised in spring 2001.

# 2 FUGITIVE EMISSIONS

## 2.1 FUGITIVE EMISSIONS FROM PEAT

In Finland, fugitive greenhouse gas emissions arise particularly from peat production (preparation and profiling of peat soils and stockpiling of peat). The peat production area in Finland is around 50 000–60 000 ha. The estimates on the emissions from these areas are based on measurements in the Finnish Research Programme on Climate Change (SILMU, 1990–1995).

Nykänen et al. (1996) report annual greenhouse gas fluxes for mined peat production areas in the order of 5 % of emissions caused by peat combustion. Most of the emissions are $CO_2$ emissions (surface flux around 880 g $CO_2$ $m^{-2}a^{-1}$ including the loss of average annual carbon accumulation 20 g C $m^{-2}a^{-1}$ occurring in natural mires, emissions from stockpiles around 175 g $CO_2$ $m^{-2}a^{-1}$ and from ditches around 9 g $CO_2$ $m^{-2}a^{-1}$). Corresponding emission factors for $CH_4$ are 5 g $CO_2$ $m^{-2}a^{-1}$ (surface) and 4.6 g $CO_2$ $m^{-2}a^{-1}$ (ditch) and for $N_2O$ 12 g $CO_2$ $m^{-2}a^{-1}$ (surface) and 0.05 g $CO_2$ $m^{-2}a^{-1}$ (ditch). The estimates do not include emissions from ditching or emissions from the first phase of the site preparation because of lack of experimental data. The $CH_4$ or $N_2O$ emissions from peat stockpiles were not estimated.

Using the emission factors from the above study the total annual $CO_2$ emissions from peat production would be around 0.6 Tg $CO_2$, the $CH_4$ emissions around 0.007 Tg $CO_2$ equivalents and the $N_2O$ emissions around 0.008 Tg $CO_2$ equivalents. The $CO_2$ emission estimate given in the inventory (1 Tg $CO_2$) is somewhat higher as the emission estimate has been rounded upwards to the nearest integer expressed in Tg $CO_2$. The reported $CH_4$ emissions (1 Gg $CH_4$ = 0.02 Tg $CO_2$ equivalents) are also rounded upward, no $N_2O$ emissions are reported. These values have been reported for all years (1990–1999) in the inventory.

A large part of Finnish peatlands have been drained for forestry, and carbon accumulation in these peatlands is higher than in virgin peatlands (see e.g. Crill et al. 2000; Minkkinen & Laine 1998; Minkkinen 1999). As peat production is predominantly taking place in forestry drained peatlands, these research results indicate that the $CO_2$ emission factor for surface emissions including the loss of carbon accumulation in the peatland could be higher than the value given above.

Additionally $CO_2$ emissions from arable peatlands that are classified as reservoirs for future peat production (and are no longer used for agricultural purposes) are estimated. Laine et al. (1998) estimated that approximately 100 000 to 150 000 hectares of peatland arable fields will be available in future for peat production purposes. The upper range of this estimate has been used as the bases for the emission estimate (2.5 Tg $CO_2$ $a^{-1}$) in the inventory. The emission factor used for these cultivated peatlands that are classified as peatland reservoirs is 450 g C $m^{-2}$ $a^{-1}$ (1 650 g $CO_2$ $m^{-2}$ $a^{-1}$).

The areas and the emission factor used in the estimate are uncertain. According to Selin (1999) less than 1 000 ha arable peatlands are in production or reserved for production, and approximately 67 000 ha of the remaining area of arable peatlands could be suitable for peat production. Using these areas and the emission factor given above the $CO_2$ emissions from arable peatlands that could be classified as reservoirs for future peat production would be only about 1 Tg $CO_2$ per year. Maljanen (et al. 2001) have estimated the $CO_2$ emissions from agricultural peatlands to be approximately 400–750 g C $m^{-2}$ $a^{-1}$ (1 500–2 750 g $CO_2$ $m^{-2}$ $a^{-1}$) based on direct measurements. Using this emission factor range the annual $CO_2$ emissions would vary from 0.9 to 4.1 Tg $CO_2$ (area range 68 000 ha to 150 000 ha).

Peat production affects also the $CH_4$ and $N_2O$ emissions. The decrease in $CH_4$ emissions from virgin peatlands due to ditching has probably the most important effect on the estimates. The $N_2O$ emissions from arable peatlands can also be significant. The methodologies should be improved to incorporate also these emissions in the inventory.

There are various options for restoration of peat production sites when the production ceases. The greenhouse gas emissions and removals for these options will also vary. These emissions have not yet been incorporated in the inventory. According to Mälkki & Frilander (1997) the $CO_2$ emissions from restoration of peat production sites could reduce the total net greenhouse gas emissions per MWh of produced energy with 5–10 % when a restoration period of 100 years is considered.

The total greenhouse gas impact of peat production in Finland has been assessed in lifecycle studies (e.g. Savolainen et al. 1994, Mälkki & Frilander 1997 and Leijting 1999). According to all three studies the main greenhouse gas impact of peat utilisation in Finland comes from peat combustion. The importance of the emissions from the peat production sites can vary much depending on the specific site (e.g. virgin mire, forestry drained mire or arable peatland) and production method.

## 2.2 OTHER FUGITIVE EMISSIONS

There are no coal mines in Finland and fugitive emissions from other solid fuels than peat are estimated to be negligible. $CO_2$ emission from venting and flaring from oil refineries are also relatively small.

Fugitive $CH_4$ emissions include emissions due to leakage from emptying of natural gas pipelines for extension work. Other leakages from the pipelines are estimated to be negligible as the pipelines are relatively new and only 5 % of the natural gas is distributed via local networks to small consumers (households, restaurants, greenhouses etc.)

The reported fugitive emissions from other fuels than peat are based on information received from the oil and gas companies (Fortum Oil and Gas, Gasum).

*Table B-1. Carbon dioxide emission factors for fuel combustion*

| | g $CO_2$/MJ | kg C /GJ | Ref for EF | NCV | |
|---|---|---|---|---|---|
| Gasoline | 73.5 | 20.0 | 2 | 43.0 | GJ/t |
| Diesel Oil | 74.5 | 20.3 | 2 | 42.8 | GJ/t |
| Light Fuel Oil (Gasoil) | 74.1 | 20.2 | 1 | 42.4 | GJ/t |
| Residual Fuel Oil | 77.4 | 21.1 | 1 | 40.7 | GJ/t |
| Jet Fuel | 71.5 | 19.5 | 1 | 42.3 | GJ/t |
| Kerosene | 73.5 | 20.0 | | 43.4 | GJ/t |
| Naphtha | 72.0 | 19.6 | 1 | 44.3 | GJ/t |
| LPG | 63.1 | 17.2 | 1 | 45.7 | GJ/t |
| Waste Oil | 77.4 | 21.1 | 4 | 40.9 | GJ/t |
| Refinery Gas | 65.0 | 17.7 | 7 | 47.5 | GJ/t |
| Refinery Coke | 97.0 | 26.5 | 7 | 33.3 | GJ/t |
| Hard Coal | 94.6 | 25.8 | 1 | 25.4 | GJ/t |
| Coke | 108.0 | 29.5 | 1 | 29.2 | GJ/t |
| Anthracite and Briquettes | 94.6 | 25.8 | 1 | | GJ/t |
| Blast Furnace Gas | 0.0 | 0.0 | 9 | 3.8 | GJ/1000 m3 |
| Coke Oven Gas | 40.5 | 11.0 | 7 | 16.7 | GJ/1000 m3 |
| Tars derived from Coking Coal | 75.0 | 20.5 | 8 | 36.4 | GJ/t |
| Natural Gas | 56.1 | 15.3 | 1 | 36.0 | GJ/1000 m3 |
| Peat | 106.0 | 28.9 | 1 | 10.1 - 12.3 | GJ/t |
| Fuelwood | 109.6 | 29.9 | 1 | NCVs vary | |
| Bark | 109.6 | 29.9 | 1 | NCVs vary | |
| Wood chips | 109.6 | 29.9 | 1 | NCVs vary | |
| Sawdust | 109.6 | 29.9 | 1 | NCVs vary | |
| Wood Proc. Ind.: Other Residues | 109.6 | 29.9 | 5 | NCVs vary | |
| Black Liquor | 110.0 | 30.0 | 3 | 12.6 | GJ/tdm |
| Sulphite Liquor | 112.0 | 30.5 | 3 | 9.9 | GJ/tdm |
| Wood Proc. Ind.: Malodorous gases | 59.0 | 16.1 | | 44.9 | |
| 0-fibres/biosludge | 109.6 | 29.9 | 5 | 5.4 | GJ/t |
| Waste paper | 109.6 | 29.9 | 5 | 14.0 | GJ/t |
| Municipal Waste | 31.8 | 8.7 | 10 | 10–21 | GJ/t |
| Construction & demolition waste | 31.8 | 8.7 | 10 | 10.0 | GJ/t |
| Industrial Waste | 75.0 | 20.5 | 8 | 42.9 | GJ/t |
| Plastic waste | 74.1 | 20.2 | 8 | 40.0 | GJ/t |
| Other Wastes | 75.0 | 20.5 | 8 | 8.8 | GJ/t |
| Other Fuels | 74–150 | | 6 | 5–40 | GJ/t |

| References: | |
|---|---|
| 1 | IPCC Guidelines 1995 |
| 2 | Mäkelä et al. 2000a |
| 3 | Boström et al. 1992, Boström 1994 |
| 4 | Assumed same as for residual fuel oil |
| 5 | Assumed same as for fuelwood |
| 6 | Depends on type of fuel; assumed same as for best corresponding fuels |
| 7 | Plant specific data |
| 8 | Ref. not specified (expert estimate) |
| 9 | Assumed zero to avoid double-counting [CO2 emissions from blast furnaces included in Coke and RFO used in these plants] |
| 10 | Expert estimate by VTT/StatFi |

*Table B-2. Fraction of carbon oxidised*

| Fuel | Fraction of carbon oxidised % |
|---|---|
| Coal | 0.98 |
| Oil and oil products | 0.99 |
| Peat | 0.99 |
| Gas | 0.995 |

*Table B-3. $CH_4$ and $N_2O$ (mg/MJ) emission factors for stationary sources in the ILMARI calculation system.*

| **Combustion technique** | **Main category / main fuel** | **$CH_4$** | **$N_2O$** |
|---|---|---|---|
| **CFB** | Coal fired boiler(>80 % coal) | 4 - 5 | 70 |
| | Peat fired boiler (>80 % peat) | 2 - 7 | 30 |
| | Multi-fuel/peat fired boiler (> 50% peat) | 5 | 30 |
| | Wood/bark fired boiler (>80 % wood) | 30 | 30 |
| | Multi-fuel/wood/bark fired boiler (> 50% wood) | 4 - 35 | 30 |
| | Multi-fuel fired boiler | 30 | 30 |
| **BFB** | Coal fired boiler(>80 % coal) | 5 | 70 |
| | Peat fired boiler (>80 % peat) | 2 - 7 | 30 |
| | Multi-fuel/peat fired boiler (> 50% peat) | 2 - 5 | 30 |
| | Wood/bark fired boiler (>80 % wood) | 30 | 30 |
| | Multi-fuel/wood/bark fired boiler (> 50% wood) | 4 - 35 | 30 |
| | Multi-fuel fired boiler | 15 | 30 |
| **PFB** | Multi-fuel/coal fired boiler (> 50% coal) | 4 | 30 |
| **Stoker, grate** | Coal fired boiler(>80 % coal) | 4 - 8 | 4 |
| | Peat fired boiler (>80 % peat) | 2 - 7 | 2 |
| | Multi-fuel/peat fired boiler (> 50% peat) | 2 - 15 | 2 |
| | Wood/bark fired boiler (>80 % wood) | 30 - 50 | 2 |
| | Multi-fuel/wood/bark fired boiler (> 50% wood) | 20 - 50 | 2 |
| | Multi-fuel fired boiler | 10 - 35 | 2 |
| **Burners** | Coal fired boiler(>80 % coal) | 4 | 2 |
| | Oil fired boiler(> 80 % oil) | 8 | 2 |
| | Peat fired boiler (>80 % peat) | 2 - 7 | 2 |
| | Wood/bark fired boiler (>80 % wood) | 50 | 2 |
| | Gas fired boiler (>80 % gas) | 3 | 1 |
| | Soda recovery boiler (>80 % black liquor) | 1 | 1 |
| | Multi-fuel fired boiler | 2 - 50 | 1 - 2 |
| **Gas turbine** | Gas turbine plant (oil) | 8 - 10 | 1 |
| | Gas turbine plant (gas) | 3 | 1 |
| **Gas turbine (Combined cycle)** | Gas turbine /Combined cycle | 3 | 1 |
| **Diesel engine** | Diesel power plant (oil) | 2 | 31 |
| **Diesel engine** | Diesel power plant (gas) | 2 | 31 |
| **Internal combustion engine (Otto)** | Other combustion engine power plant | 2 | 31 |
| **Other combustion (not specified)** | Not specified | 8 | 2 |
| | Hospital waste incineration | 8 - 50 | 2 |
| | Asphalt station | 8 | 2 |
| | Coking plant | 0 | 2 |
| | Drying oven | 8 | 2 |
| | Blast furnace | 0 | 0 |
| | Sinter plant | 4 | 2 |
| | Rolling mill | 0 | 2 |
| | Melting oven | 0 | 2 |
| | Brick furnace | 8 | 2 |
| | Cupola oven | 10 | 2 |

*TableB-4. $CH_4$ and $N_2O$ emission factors for small scale fuel combustion.*

| Main category | Source category | Fuel | Combustion technique | Capacity category | $CH_4$ mg/MJ | $N_2O$ mg/MJ | Source for EF's |
|---|---|---|---|---|---|---|---|
| Coal Boiler | Heating (residential & agriculture) | Coal/coke/anthracite | Grate | ≤ 1 MW | 300.0 | 4.0 | IPCC96 & 1 |
| Light fuel oil boiler (> 80 % oil) | Heating (residential & agriculture) | Light fuel oil (gasoil) | Burner | ≤ 1 MW | 10.0 | 2.0 | 1 |
| Heavy fuel oil boiler (> 80 % oil) | Heating (residential & agriculture) | Residual fuel oil | Burner | ≤ 1 MW | 10.0 | 2.0 | 1 |
| Sod peat boiler (>80 % peat) | Heating (residential & agriculture) | Peat | Grate | ≤ 1 MW | 300.0 | 2.0 | assumption: same as for wood boilers |
| Wood/Bark boiler (>80 % wood) | Heating (residential & agriculture) | Wood/chips | Grate | ≤ 1 MW | 300.0 | 2.0 | IPCC96 & 1 |
| Gas boiler (>80 % gas) | Heating (residential & agriculture) | Natural gas | Burner | ≤ 1 MW | 3.0 | 1.0 | 1 |
| Light fuel oil boiler (> 80 % oil) | Heating (commercial & institutional) | Light fuel oil (gasoil) | Burner | ≤ 1 MW | 10.0 | 2.0 | 1 |
| Heavy fuel oil boiler (> 80 % oil) | Heating (commercial & institutional) | Residual fuel oil | Burner | ≤ 1 MW | 10.0 | 2.0 | 1 |
| Sod peat boiler (>80 % peat) | Heating (commercial & institutional) | Peat | Grate | ≤ 1 MW | 300.0 | 2.0 | assumption: same as for wood boilers |
| Wood/Bark boiler (>80 % wood) | Heating (commercial & institutional) | Wood/chips | Grate | ≤ 1 MW | 300.0 | 2.0 | IPCC96 & 1 |
| Gas boiler (>80 % gas) | Heating (commercial & institutional) | Natural gas | Burner | ≤ 1 MW | 3.0 | 1.0 | 1 |
| Crop drying-house | Agriculture (grain drying) | Light fuel oil (gasoil) | Burner | ≤ 1 MW | 10.0 | 2.0 | assumption: same as for small fuel oil boilers |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Domestic rail traffic | Railways | Light fuel oil (gasoil) | Diesel engine | | 2.0 | 31.0 | 2 |
| Domestic road traffic | Road transport | Diesel oil | Diesel engine | | 6.3 | 3.7 | aggregated from LIISA99 |
| Domestic road traffic | Road transport | Gasoline | Otto engine | | 25.1 | 12.6 | aggregated from LIISA99 |
| Domestic road traffic | Road transport | Natural gas | Diesel engine | | 3.0 | 1.0 | assumption: same as for small gas boilers |
| Domestic waterborne traffic | Domestic navigation | Light fuel oil (gasoil) | Diesel engine | | 2.0 | 31.0 | 2 |
| Domestic waterborne traffic | Domestic navigation | Residual fuel oil | Marine diesel engine (RFO) | | 2.0 | 32.0 | 2 |
| Leisure boats | Leisure boats | Gasoline | Otto engine | | 350.0 | 3.0 | LIPASTO99 (part of HC-emissions estimated to be methane; less than 10 %; may change!) $N_2O$ expert judgement |
| Leisure boats | Leisure boats | Light fuel oil (gasoil) | Diesel engine | | 2.0 | 31.0 | assumption: same as for other diesel engines using gasoil |
| International waterborne traffic | International navigation (marine bunkers) | Light fuel oil (gasoil) | Diesel engine | | 2.0 | 31.0 | 2 |
| International waterborne traffic | International navigation (marine bunkers) | Residue fuel oil | Marine diesel engine (RFO) | | 2.0 | 32.0 | 2 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Domestic air traffic | Domestic aviation | Jet fuel | Jet engine | | 3.0 | 3.0 | expert judgement based on IPCC 96: RefManTable1-50 |
| Domestic air traffic | Domestic aviation | Aviation gasoline | Otto engine | | 25.1 | 12.6 | assumption: same as for gasoline engines in road traffic |
| International air traffic | International aviation (air bunkers) | Jet fuel | Jet engine | | 3.0 | 3.0 | expert judgement based on IPCC 96: RefManTable1-50 |
| Agricultural machinery | Off-road machinery in agriculture | Light fuel oil (gasoil) | Diesel engine | | 3.9 | 31.9 | TYKO99 |
| Agricultural machinery | Off-road machinery in agriculture | Gasoline | Otto engine | | 130.5 | 1.6 | TYKO99 |
| Fishing | Fishing boats | Light fuel oil (gasoil) | Diesel engine | | 2.0 | 31.0 | assumption: same as for other diesel engines using gasoil |
| Forest machinery | Forest machinery | Light fuel oil (gasoil) | Diesel engine | | 3.9 | 31.5 | TYKO99 |
| Forest machinery | Forest machinery | Gasoline | Otto engine | | 138.3 | 0.3 | TYKO99 |
| Construction machinery | Construction machinery | Light fuel oil (gasoil) | Diesel engine | | 4.1 | 30.8 | TYKO99 |
| Construction machinery | Construction machinery | Gasoline | Otto engine | | 133.3 | 1.7 | TYKO99 |
| Other machinery | Other machinery | Gasoline | Otto engine | | 93.8 | 1.1 | TYKO99 |
| Other machinery | Other machinery | Light fuel oil (gasoil) | Diesel engine | | 4.0 | 30.9 | TYKO99 |
| Other machinery | Other machinery | LPG | Diesel engine | | 63.9 | 3.2 | TYKO99 |
| Others (unknown) | Others (unknown) | Light fuel oil (gasoil) | Burner / unknown | ≤ 1 MW | 10.0 | 2.0 | assumption: same as for small fuel oil boilers |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Others (unknown) | Others (unknown) | Residue fuel oil | Burner / unknown | ≤ 1 MW | 10.0 | 2.0 | assumption: same as for small fuel oil boilers |
| Others (unknown) | Others (unknown) | Natural gas | Burner / unknown | ≤ 1 MW | 10.0 | 2.0 | assumption: same as for small fuel oil boilers |
| Others (unknown) | Others (unknown) | LPG | Burner / unknown | ≤ 1 MW | 10.0 | 2.0 | assumption: same as for small fuel oil boilers |
| **References:** | | | | | | | |
| 1 Boström et al 1992 | | | | | | | |
| 2 Laurikko 1990 | | | | | | | |

*Table B-5. $CH_4$ emissions factors used by the LIISA 1999 model for different speed limits by road, fuel and vehicle type.*

| **Methane** | Speed | CAR | | | VAN | | | BUS | SEMI TRAILER | ARTICULATED VEHICLE |
|---|---|---|---|---|---|---|---|---|---|---|
| **$CH_4$** | limit | gasoline | | diesel | gasoline | | diesel | diesel | diesel | diesel |
| g/km | km/h | no cat. | cat. | | no cat. | cat. | | | | |
| Built-up areas | 50 | 0.064 | 0.0225 | 0.005 | 0.04 | 0.004 | 0.005 | 0.08 | 0.08 | 0.08 |
| Main roads | 60 | 0.043 | 0.02 | 0.005 | 0.04 | 0.004 | 0.005 | 0.08 | 0.08 | 0.08 |
| | 70 | 0.029 | 0.02 | 0.005 | 0.04 | 0.004 | 0.005 | 0.08 | 0.08 | 0.08 |
| | 80 | 0.021 | 0.0225 | 0.005 | 0.03 | 0.003 | 0.005 | 0.075 | 0.075 | 0.075 |
| | 100 | 0.026 | 0.0275 | 0.005 | 0.025 | 0.002 | 0.005 | 0.07 | 0.07 | 0.07 |
| | 120 | 0.057 | 0.0375 | 0.005 | 0.025 | 0.002 | 0.005 | 0.07 | 0.07 | 0.07 |

| **Methane** | Speed | CAR | | | VAN | | | BUS | SEMI TRAILER | ARTICULATED VEHICLE |
|---|---|---|---|---|---|---|---|---|---|---|
| **$CH_4$** | limit | gasoline | | diesel | gasoline | | diesel | diesel | diesel | diesel |
| g/km | km/h | no cat. | cat. | | no cat. | cat. | | | | |
| Built-up areas | 50 | 0.064 | 0.0225 | 0.005 | 0.04 | 0.004 | 0.005 | 0.08 | 0.08 | 0.08 |
| Classified roads | 60 | 0.043 | 0.02 | 0.005 | 0.04 | 0.004 | 0.005 | 0.08 | 0.08 | 0.08 |
| | 70 | 0.029 | 0.02 | 0.005 | 0.04 | 0.004 | 0.005 | 0.08 | 0.08 | 0.08 |
| | 80 | 0.021 | 0.0225 | 0.005 | 0.04 | 0.004 | 0.005 | 0.075 | 0.075 | 0.075 |
| | 100 | 0.026 | 0.0275 | 0.005 | 0.04 | 0.004 | 0.005 | 0.07 | 0.07 | 0.07 |
| | 120 | 0.05 | 0.0325 | 0.005 | 0.04 | 0.004 | 0.005 | 0.07 | 0.07 | 0.07 |

| **Methane** | Speed | CAR | | | VAN | | | BUS | SEMI TRAILER | ARTICULATED VEHICLE |
|---|---|---|---|---|---|---|---|---|---|---|
| **$CH_4$** | limit | gasoline | | diesel | gasoline | | diesel | diesel | diesel | diesel |
| g/km | km/h | no cat. | cat. | | no cat. | cat. | | | | |
| Rural areas | 50 | 0.064 | 0.0225 | 0.005 | 0.04 | 0.004 | 0.005 | 0.08 | 0.08 | 0.08 |
| Main roads | 60 | 0.043 | 0.02 | 0.005 | 0.04 | 0.004 | 0.005 | 0.08 | 0.08 | 0.08 |
| | 70 | 0.029 | 0.02 | 0.005 | 0.04 | 0.004 | 0.005 | 0.08 | 0.08 | 0.08 |
| | 80 | 0.021 | 0.0225 | 0.005 | 0.04 | 0.004 | 0.005 | 0.075 | 0.075 | 0.075 |
| | 100 | 0.026 | 0.0275 | 0.005 | 0.04 | 0.004 | 0.005 | 0.07 | 0.07 | 0.07 |
| | 120 | 0.057 | 0.0375 | 0.005 | 0.04 | 0.004 | 0.005 | 0.07 | 0.07 | 0.07 |

| **Methane** | Speed | CAR | | | VAN | | | BUS | SEMI TRAILER | ARTICULATED VEHICLE |
|---|---|---|---|---|---|---|---|---|---|---|
| **$CH_4$** | limit | gasoline | | diesel | gasoline | | diesel | diesel | diesel | diesel |
| g/km | km/h | no cat. | cat. | | no cat. | cat. | | | | |
| Rural areas | 50 | 0.064 | 0.0225 | 0.005 | 0.04 | 0.004 | 0.005 | 0.08 | 0.08 | 0.08 |
| Classified roads | 60 | 0.043 | 0.02 | 0.005 | 0.04 | 0.004 | 0.005 | 0.08 | 0.08 | 0.08 |
| | 70 | 0.029 | 0.02 | 0.005 | 0.04 | 0.004 | 0.005 | 0.08 | 0.08 | 0.08 |
| | 80 | 0.021 | 0.0225 | 0.005 | 0.04 | 0.004 | 0.005 | 0.075 | 0.075 | 0.075 |
| | 100 | 0.026 | 0.0275 | 0.005 | 0.04 | 0.004 | 0.005 | 0.07 | 0.07 | 0.07 |
| | 120 | 0.05 | 0.0325 | 0.005 | 0.04 | 0.004 | 0.005 | 0.07 | 0.07 | 0.07 |

*Table B-6. $N_2O$ base emissions factors used in the LIISA 1999 model for different speed limits by road, fuel and vehicle type.*

| **Nitrous Oxide** | Speed | CAR | | | VAN | | | BUS | SEMI TRAILER | ARTICULATED VEHICLE |
|---|---|---|---|---|---|---|---|---|---|---|
| **$N_2O$** | limit | gasoline | | diesel | gasoline | | diesel | diesel | diesel | diesel |
| g/km | km/h | no cat. | cat. | | no cat. | cat. | | | | |
| Built-up areas | 50 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |
| Main roads | 60 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |
| | 70 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |
| | 80 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |
| | 100 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |
| | 120 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |

| **Nitrous Oxide** | Speed | CAR | | | VAN | | | BUS | SEMI TRAILER | ARTICULATED VEHICLE |
|---|---|---|---|---|---|---|---|---|---|---|
| **$N_2O$** | limit | gasoline | | diesel | gasoline | | diesel | diesel | diesel | diesel |
| g/km | km/h | no cat. | cat. | | no cat. | cat. | | | | |
| Built-up areas | 50 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |
| Classified roads | 60 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |
| | 70 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |
| | 80 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |
| | 100 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |
| | 120 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |

| **Nitrous Oxide** | Speed | CAR | | | VAN | | | BUS | SEMI TRAILER | ARTICULATED VEHICLE |
|---|---|---|---|---|---|---|---|---|---|---|
| **$N_2O$** | limit | gasoline | | diesel | gasoline | | diesel | diesel | diesel | diesel |
| g/km | km/h | no cat. | cat. | | no cat. | cat. | | | | |
| Rural areas | 50 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |
| Main roads | 60 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |
| | 70 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |
| | 80 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |
| | 100 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |
| | 120 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |

| **Nitrous Oxide** | Speed | CAR | | | VAN | | | BUS | SEMI TRAILER | ARTICULATED VEHICLE |
|---|---|---|---|---|---|---|---|---|---|---|
| **$N_2O$** | limit | gasoline | | diesel | gasoline | | diesel | diesel | diesel | diesel |
| g/km | km/h | no cat. | cat. | | no cat. | cat. | | | | |
| Rural areas | 50 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |
| Classified roads | 60 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |
| | 70 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |
| | 80 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |
| | 100 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |
| | 120 | 0.005 | 0.05 | 0.014 | 0.006 | 0.06 | 0.017 | 0.03 | 0.03 | 0.03 |

*Table B-7. $CH_4$ and $N_2O$ base emission factors of the LIISA 1999 model by road, fuel and vehicle type.*

| **Methane** | CAR | | | VAN | | | BUS | SEMI TRAILER | ARTICULATED VEHICLE |
|---|---|---|---|---|---|---|---|---|---|
| **$CH_4$** g/km | gasoline no cat. | gasoline cat. | diesel | gasoline no cat. | gasoline cat. | diesel | diesel | diesel | diesel |
| Main streets | 0.068 | 0.05 | 0.005 | 0.09 | 0.08 | 0.007 | 0.09 | 0.09 | 0.18 |
| Collector streets | 0.08 | 0.06 | 0.005 | 0.12 | 0.1 | 0.007 | 0.12 | 0.12 | 0.24 |
| Residential streets | 0.06 | 0.04 | 0.005 | 0.06 | 0.06 | 0.007 | 0.09 | 0.06 | 0.12 |
| Local plan roads | 0.06 | 0.04 | 0.005 | 0.06 | 0.06 | 0.007 | 0.09 | 0.06 | 0.12 |

| **Nitrous Oxide** | CAR | | | VAN | | | BUS | SEMI TRAILER | ARTICULATED VEHICLE |
|---|---|---|---|---|---|---|---|---|---|
| **$N_2O$** g/km | gasoline no cat. | gasoline cat. | diesel | gasoline no cat. | gasoline cat. | diesel | diesel | diesel | diesel |
| Main streets | 0.005 | 0.05 | 0.01 | 0.006 | 0.07 | 0.017 | 0.03 | 0.02 | 0.03 |
| Collector streets | 0.005 | 0.05 | 0.01 | 0.006 | 0.07 | 0.017 | 0.03 | 0.02 | 0.03 |
| Residential streets | 0.005 | 0.05 | 0.01 | 0.006 | 0.07 | 0.017 | 0.03 | 0.02 | 0.03 |
| Local plan roads | 0.005 | 0.05 | 0.01 | 0.006 | 0.07 | 0.017 | 0.03 | 0.02 | 0.03 |

*Table B-8. Correction factors reflecting the change in fuels and vehicle technologies for $CH_4$ emissions.*

| **Methane** | CAR | | | VAN | | | BUS | SEMI TRAILER | ARTICULATED VEHICLE |
|---|---|---|---|---|---|---|---|---|---|
| **$CH_4$** | gasoline | | diesel | gasoline | | diesel | diesel | diesel | diesel |
| Year | no cat. | cat. | | no cat. | cat. | | | | |
| < 1980 | 1.60 | - | 1.60 | 1.50 | - | 1.50 | 2.90 | 2.90 | 2.90 |
| 1980 | 1.40 | - | 1.50 | 1.30 | - | 1.30 | 2.80 | 2.80 | 2.80 |
| 1981 | 1.30 | - | 1.45 | 1.25 | - | 1.25 | 2.70 | 2.70 | 2.70 |
| 1982 | 1.30 | - | 1.45 | 1.25 | - | 1.25 | 2.70 | 2.70 | 2.70 |
| 1983 | 1.20 | - | 1.45 | 1.20 | - | 1.20 | 2.60 | 2.60 | 2.60 |
| 1984 | 1.20 | - | 1.40 | 1.20 | - | 1.20 | 2.60 | 2.60 | 2.60 |
| 1985 | 1.10 | - | 1.40 | 1.15 | - | 1.15 | 2.40 | 2.40 | 2.40 |
| 1986 | 1.10 | 1.00 | 1.20 | 1.15 | - | 1.15 | 2.20 | 2.20 | 2.20 |
| 1987 | 1.10 | 1.00 | 1.15 | 1.10 | - | 1.10 | 1.80 | 1.80 | 1.80 |
| 1988 | 1.10 | 1.00 | 1.10 | 1.10 | - | 1.10 | 1.60 | 1.60 | 1.60 |
| 1989 | 1.07 | 1.00 | 1.07 | 1.05 | - | 1.05 | 1.20 | 1.20 | 1.20 |
| 1990 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.20 | 1.20 | 1.20 |
| 1991 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1992 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1993 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1994 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1995 | 1.00 | 1.00 | 1.00 | 1.00 | 0.90 | 0.90 | 0.83 | 0.83 | 0.83 |
| 1996 | 1.00 | 0.80 | 0.80 | 1.00 | 0.80 | 0.80 | 0.83 | 0.83 | 0.83 |
| 1997 | 1.00 | 0.80 | 0.80 | 1.00 | 0.80 | 0.80 | 0.67 | 0.67 | 0.67 |
| 1998 | 1.00 | 0.80 | 0.80 | 1.00 | 0.80 | 0.80 | 0.67 | 0.67 | 0.67 |
| **1999** | **1.00** | **0.80** | **0.80** | **1.00** | **0.80** | **0.80** | **0.67** | **0.67** | **0.67** |

*Table B-9. Correction factors reflecting the change in fuels and vehicle technologies for $N_2O$ emissions.*

| **Nitrous Oxide** | CAR | | | VAN | | | BUS | SEMI TRAILER | ARTICULATED VEHICLE |
|---|---|---|---|---|---|---|---|---|---|
| **$N_2O$** | gasoline | | diesel | gasoline | | diesel | diesel | diesel | diesel |
| Year | no cat. | cat. | | no cat. | cat. | | | | |
| < 1980 | 1.20 | - | 1.50 | 1.43 | - | 1.43 | 2.40 | 2.40 | 2.40 |
| 1980 | 1.10 | - | 1.30 | 1.30 | - | 1.30 | 2.25 | 2.25 | 2.25 |
| 1981 | 1.10 | - | 1.30 | 1.30 | - | 1.30 | 2.25 | 2.25 | 2.25 |
| 1982 | 1.05 | - | 1.20 | 1.20 | - | 1.20 | 2.13 | 2.13 | 2.13 |
| 1983 | 1.05 | - | 1.20 | 1.20 | - | 1.20 | 2.00 | 2.00 | 2.00 |
| 1984 | 1.05 | - | 1.10 | 1.20 | - | 1.20 | 1.88 | 1.88 | 1.88 |
| 1985 | 1.05 | - | 1.10 | 1.10 | - | 1.10 | 1.75 | 1.75 | 1.75 |
| 1986 | 1.05 | 1.00 | 1.07 | 1.10 | - | 1.10 | 1.63 | 1.63 | 1.63 |
| 1987 | 1.05 | 1.00 | 1.07 | 1.08 | - | 1.08 | 1.50 | 1.50 | 1.50 |
| 1988 | 1.00 | 1.00 | 1.00 | 1.04 | - | 1.04 | 1.38 | 1.38 | 1.38 |
| 1989 | 1.00 | 1.00 | 1.00 | 1.00 | - | 1.00 | 1.25 | 1.25 | 1.25 |
| 1990 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.13 | 1.13 | 1.13 |
| 1991 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.13 | 1.13 | 1.13 |
| 1992 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1993 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1994 | 1.00 | 1.00 | 1.00 | 1.00 | 0.95 | 0.95 | 1.00 | 1.00 | 1.00 |
| 1995 | 1.00 | 1.00 | 1.00 | 1.00 | 0.90 | 0.90 | 0.93 | 0.93 | 0.93 |
| 1996 | 1.00 | 0.88 | 0.88 | 1.00 | 0.85 | 0.85 | 0.93 | 0.93 | 0.93 |
| 1997 | 1.00 | 0.88 | 0.88 | 1.00 | 0.85 | 0.85 | 0.86 | 0.86 | 0.86 |
| 1998 | 1.00 | 0.88 | 0.88 | 1.00 | 0.80 | 0.80 | 0.86 | 0.86 | 0.86 |
| **1999** | **1.00** | **0.75** | **0.75** | **1.00** | **0.80** | **0.80** | **0.86** | **0.86** | **0.86** |

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# INDUSTRIAL PROCESSES

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## 1 GENERAL METHOLOGY

The industrial emission are estimated using the general methodology given in the IPCC Guidelines (Houghton et al. 1997):

$$Emissions_{ij} = A_j \; x \; EF_{ij} \qquad (1)$$

Where:
A = amount of activity or production
EF = emission factor

i = greenhouse gas
j = industrial production process.

IPCC default emission factors are used in most cases. National emission factors are used when available.

The danger for double counting in estimating industrial $CO_2$ emissions from fuels used for non-energy purposes and energy emissions is considered to be small, as the emissions in the energy sector are calculated (sectoral approach) with a bottom-up method which is based on data from the plants using the fuels.

## 2 $CO_2$ EMISSIONS

### 2.1 CEMENT PRODUCTION

$CO_2$ emissions from cement production are estimated using the default emission factors given in the IPCC Guidelines (the Tier 1 method of the IPCC Good Practice report (Penman et al. 2000)). The activity data for cement is obtained from the Manufacturing Industry Statistics as well as from the industrial plants directly.

### 2.2 LIME PRODUCTION

$CO_2$ emissions from lime production are estimated using the default emissions factor for calcite and dolomite lime given in the IPCC guidelines. The activity data for cement is obtained from the Manufacturing Industry Statistics as well as from the industrial plants directly.

### 2.3 OTHER INDUSTRIAL $CO_2$ EMISSIONS

The $CO_2$ emissions from coke (and residual fuel oil) used in the blast furnaces in the iron and steel industry have been allocated to the Energy sector to avoid double-counting and arbitrary emission factors.

Other industrial $CO_2$ emissions have not been estimated in the Finnish inventory. In the IPCC guidelines some other sources are identified that could be probable sources in Finland too. These are limestone and dolomite use (agricultural use is estimated and reported in the Agriculture sector), soda ash production and use, asphalt roofing and road paving with asphalt. None of these sources is expected to be significant in Finland.

Ammonia production is also given as a possible source of $CO_2$ (and $CH_4$). Ammonia was produced, mainly from peat and sawdust, in small quantities in Finland in the year 1990–1993. However, the $CO_2$ emissions from this production have not been estimated.

## 3 $CH_4$ EMISSIONS

### 3.1 COKE PRODUCTION

Emissions from coke production are estimated with using the default emission factor (0.5 kg $CH_4$/t coke produced) given in the IPCC guidelines. The activity data is taken from the Energy Statistics (see description in Annex B). The activity data used in the calculation is given in Table C-1.

*Table C-1. Coke production (t/year) in Finland in 1990–1999.*

| 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|
| 487000 | 471000 | 498171 | 873610 | 922000 | 920000 | 910000 | 879000 | 912000 | 900379 |

### 3.2 ETHYLENE PRODUCTION

Emissions from ethylene production are estimated with using the default emission factor (1 kg $CH_4$/t ethylene produced) given in the IPCC guidelines. The activity data is received from the company producing ethylene (Borealis Polymers Oy, Jouko Veikkola). The activity data used in the calculation is given in Table C-2.

*Table C-2. Ethylene production in Finland in 1990–1999.*

| 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|
| 187559 | 223079 | 216029 | 177026 | 225018 | 225246 | 230312 | 183303 | 254854 | 259910 |

3.3 OTHER INDUSTRIAL $CH_4$ SOURCES

Other industrial sources have not been identified in Finland. Other industrial processes identified in the IPCC Guidelines as possible $CH_4$ emission sources do not occur in Finland (dichloroethylene, styrene and methanol production).

In the IPCC 1995 Guidelines emission factors were given for pig iron and sinter production. These emission factors have been omitted from the Revised 1996 IPCC Guidelines. $CH_4$ emission measurements (Hemminki 2000) have been made by the Finnish steel industry (Rautaruukki Oy) for coke, pig iron and sinter production processes. The emission factors based on these measurements were much smaller than the IPCC default values (0.1 kg $CH_4$/t coke, 0.05 kg $CH_4$/t sinter and 6.5 x $10^{-5}$ kg $CH_4$/t pig iron). The estimated emissions for pig iron, based on these results and the fact that IPCC Guidelines no longer give emission factors for these sources, have been excluded from the Finnish inventory. The IPCC default emission factor is still used for coke production and it is assumed to cover all $CH_4$ emissions from the steel industry.

# 4 $N_2O$ EMISSIONS

4.1 $N_2O$ EMISSIONS FROM NITRIC ACID PRODUCTION

Nitric acid production is a major industrial source of $N_2O$ globally, and also in Finland. The $N_2O$ emission emissions have been estimated using national emission factors based on a series of measurements done at the production plants of Kemira Agro Oy in Uusikaupunki (2 plants) and Siilinjärvi. The emissions at the plant in Oulu were estimated based on these measurements and taking the process technology (similar to the plant 2 in Uusikaupunki) into account. DEKATI Measurements Oy did the measurements in 1999. The emission factors are plant specific (range 9.2 to 9.7 kg $N_2O$/t nitric acid produced) and the total national mean emission factor may therefore vary from year to year. The new emission factors are in good agreement with recent international research data and values for emission factors given in the IPCC good practice report.

The measured emissions (ppmv), emission factors and production data for the plants are given in Table C-3 below.

*Table C-3. $N_2O$ emission factors and production data (1990–1999, 1000 t/year) for nitric acid plants in Finland.*

| | | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Uusikaupunki** | | | | | | | | | | | |
| Plant 1 production | | 116.5 | 111.2 | 105.6 | 117.3 | 121 | 124.5 | 131.4 | 131.8 | 122.6 | 125 |
| ppmv | 1460 | | | | | | | | | | |
| EF kg $N_2O$/t | 9.2 | | | | | | | | | | |
| Plant 2 production | | 168.7 | 186.1 | 189.8 | 187 | 197.8 | 197.9 | 197.2 | 198.7 | 182.1 | 187 |
| ppmv | 1543 | | | | | | | | | | |
| EF kg $N_2O$/t | 9.7 | | | | | | | | | | |
| **Siilinjärvi** | | | | | | | | | | | |
| production | | 142 | 106 | 114 | 141 | 142 | 154 | 148 | 149 | 147 | 141 |
| ppmv | 1485 | | | | | | | | | | |
| EF kg $N_2O$/t | 9.3 | | | | | | | | | | |
| **Oulu** | | | | | | | | | | | |
| production | | 121.5 | 77 | 19 | | | | | | | |
| ppmv | | | | | | | | | | | |
| EF kg $N_2O$/t | 9.2 | 121.5 | 77 | 19 | | | | | | | |

1000 ppmv = 6.282 kg/t

### 4.2 OTHER INDUSTRIAL $N_2O$ SOURCES

So far other industrial processes that produce $N_2O$ in Finland have not been identified. IPCC guidelines give examples of processes that could produce $N_2O$: production of caprolactam, acrylonitrile and catalytic cracking of oil. The two first mentioned chemicals are not produced in Finland, cracking of oil is done at the refineries. The IPCC guidelines give, however, no methodology or emission factors for the estimation of the $N_2O$ emissions from catalytic cracking of oil.

## 5 HFC, PFC AND $SF_6$ EMISSIONS

### 5.1 METHODOLOGY

HFC, PFC and $SF_6$ are not produced in Finland and emissions of these gases are based on their consumption in various equipment and manufacturing and use of industrial products. Both the potential and actual emissions are estimated. The potential emissions are estimated with the IPCC Tier 1b method

*Potential emissions = Imports in bulk + Quantity of chemicals imported in products – Exports in bulk – Quantity of chemicals exported in products – Destruction (2).*

The actual emissions are calculated with the tier 2 methodology given in the IPCC Guidelines. The emissions caused by the activity j (specified types of equipment, products or processes) were estimated taking three phases into account: (i) manufacture or assembly, (ii) operation or use and (iii) disposal (equation 3). All phases were not relevant for all sources.

$$Emissions_t = \sum_{i=1}^{n}\sum_{j=1}^{n} A_{a,ijt}EF_{a,ijt} + A_{k,ijt}EF_{k,ijt} + A_{p,ijt}EF_{p,ijt} \quad (3)$$

where a refers to manufacturing or assembly, k to use and p to disposal, t is the inventory year.

The definition of the terms $A_{a,ijt}$, $A_{k,ijt}$ and $A_{p,ijt}$ differs depending on the emissions source and data available. For equipment or installations (refrigeration devices or air conditioner, electrical equipment)

$A_{a,ijt}$ = the amount of substance i consumed in the equipment or installation in the sector j in the year t

$A_{k,ijt}$ = the amount of substance i stored in the equipment or installation in the sector j in the year t

$A_{p,ijt}$ = the amount of substance i disposed of in the equipment or installation in the sector j in the year t.

The amount of substance $A_{k,ijt}$ stored in the equipment or installations in the year t is calculated as the difference of the consumed and disposed amounts in previous years:

$$A_{k,ijt} = \sum_{t=0}^{n} A_{a,ijt} - \sum_{t=0}^{n} A_{p,ijt} \quad (4).$$

The year t = 0 depends on when the consumption of the substances has begun in Finland (e.g. for refrigeration and air conditioning $t$ = 0 is 1993, 1994 or 1995 depending on the subsector).

The term $A_{p,ijt}$ depends on the assumed operating or service life of the equipment or other source:

$$A_{p,ijt} = A_{a,ijt-l} \quad (5)$$

where $l$ = operating or service life.

The terms describing the activity data take the number of equipment or installations and the average fill in account as follows:

$$A_{a,ijt} = N_{a,ijt}c_{ijt} \quad (6)$$

$$A_{k,ijt} = N_{k,ijt}c_{ijt} = \sum_{t=0}^{n} N_{a,ijt}c_{ijt} - \sum_{t=0}^{n} N_{p,ijt}c_{ijt} = \sum_{t=0}^{n} N_{a,ijt}c_{ijt} - \sum_{t=0}^{n} N_{a,ijt-l}c_{ijt} \quad (7)$$

$$A_{p,ijt} = N_{p,ijt}c_{ijt} \quad (8).$$

$N_a$ = number of manufacture or assembly
$N_k$ = number of equipment or installation in use
$N_p$ = number of equipment or installation disposed of
$c_{ijt}$ = average fill.

The actual emissions from other stationary refrigeration and air conditioning for the year 1999 have been calculated with Tier 2 Top-down approach given in the IPCC good practice report. For the other years (1993–1998) a national method has been used. The method is in principle the same as the good practice method, but the emissions are calculated from data on annual sales, use and disposal. A detailed description of the method can be found in the reference Oinonen (2000). The 1999 emissions for this subcategory were also estimated with this method. The difference of the estimates by the two methods was approximately 5 %. The need for recalculation of the whole time series will be assessed when more information on the proportional difference in the estimates produced by the two methods is gained.

More information on the Finnish HFC, PFC and $SF_6$ emissions can be found in Oinonen (2000) and Oinonen and Soimakallio (2001).

## 5.2 ACTIVITY DATA AND EMISSION FACTORS

The import and export data is collected from member companies of the Association of Finnish Technical Traders (AFTT) and other non-member companies that import HFCs, PFCs and $SF_6$. Data on thermal destruction is obtained from Ekokem Ltd. The detailed information needed in the estimation of the actual emissions is based on questionnaires to the importers (companies importing passenger cars, vans, lorries and buses (mobile air conditioning devices)), manufacturers (domestic refrigeration appliances, polyurethane thermal insulation foams, electronics, $SF_6$ insulated electrical equipment, die casted magnesium products) and end users (users of gas insulated switchgear, circuit breakers and other $SF_6$ insulated electrical equipment). In addition annual statistics on sales of domestic refrigeration appliances and registration on new vehicles in Finland have been used. Interviews with e.g manufacturers and importers have also contributed to the information needed in the estimation of the emissions.

The emission factors used in the calculation are given in Table C-4.

*Table C-4. The emissions factors used in the calculation of the actual HFC, PFC and $SF_6$ emissions in Finland.*

| Source | Emission factors (%) | | | Notes |
|---|---|---|---|---|
| | Manu-facturing | Use | Disposal | |
| Domestic refrigeration | 2,7 | 1 | 0 | National factor for manufacturing, IPCC default factor for use, disposal emissions assumed near zero (young equipment stock) |
| Mobile air conditioning | 0 | 30 | 0 | Manufacturing and disposal emissions assumed near zero, IPCC default factor for use |
| Others stationary refrigeration and air conditioning | 5 | 17 | 0 | Disposal emissions assumed zero, calculation according to simple model assuming emission factors shown and average lifetime of 15 years |
| Electrical equipment | 15 (prior to 1995) 6 (1995 onwards) | 5 (prior to 1996) 1(1996 onwards) | 0 | Emission factors 15 % and 6 % refer to installing of electrical equipment (IPCC Good Practice Guidance), default assumed for leakage and near zero emissions for disposal |
| Fixed fire fighting systems | 3 | 1 | 0 | National factors |
| Foam blowing | 7.5 | 1 | 0 | Application specific factors from IPCC Good Practice Guidance |
| Magnesium die casting | NA | 100 | NA | No factors used, emissions assumed to equal consumption |
| Electronics manufacturing | NA | 100 | NA | No factors used, emissions assumed to equal consumption |
| Aerosols | NA | 100 | NA | No factors required when the IPCC default method is used |

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# METHODOLOGY FOR ESTIMATING AGRICULTURAL GREENHOUSE GAS EMISSIONS

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MTT (Agricultural Research Centre) and VTT Energy (Technical Research Centre) have calculated the agricultural greenhouse gas emissions. MTT has been responsible for the $CO_2$ emission estimates and VTT Energy for $CH_4$ and $N_2O$ emission estimates. The scientific basis and methodologies for the calculations have been presented in many publications by MTT and VTT (see e.g. Kulmala & Esala 2000; Pipatti 1997; Pipatti et al. 2000).

## 1 METHODOLOGY FOR ESTIMATING CARBON DIOXIDE EMISSIONS FROM AGRICULTURAL SOILS

### 1.1 Methodology

Agricultural $CO_2$ emissions have been estimate in accordance with IPCC Guidelines (Houghton et al. 1997) for

- net changes in organic carbon stocks of mineral soils associated with changes in land use and management
- cultivation of organic soils
- liming of agricultural soils.

The methods used in the estimation are those given in the IPCC Guidelines, but concerning mineral and organic soils the emission factors are based national research. In the IPCC Guidelines the methods for $CO_2$ emissions from agricultural soils are given in the Land-Use Change and Forestry Chapter. In the Finnish inventory these emission are, however, reported as agricultural emissions in order to treat them in analogous way as the $N_2O$ emissions from agriculture. Some of the input data used in the calculation of the emissions of these gases are also the same.

Net changes in organic carbon stocks of mineral soils are calculated taking into account changes in land use from a period of 20 years. The 1999 figures are obtained by comparing agricultural land-use in 1979 and in 1999, estimating the carbon stocks for both years and calculating the net change in soil carbon as the difference of these estimates. The calculation sheet for the year 1999 is in Table D1-1. The $CO_2$ emission or sink for the year is equal to the mean annual change in carbon stocks (the calculated total change is divided by 20) during this time.

The annual $CO_2$ emissions for all years 1990–1999 have been calculated with the same method.

The $CO_2$ emissions from cultivation of organic soils have been calculated by multiplying the area of organic soils cultivated with an emission factor. The emissions factor used in Finland is based on national research. As the land use classifications used in Finland differ somewhat from the IPCC classification the organic soils have been divided into to subclasses: peat soils and other organic soils.

*Table D1-1. Estimation of changes in carbon stocks in mineral soils in Finland for the period 1979–1999.*

| Landuse | Soil type | Mine-ral soils of total area | Land use area 1979 | Land use area 1999 | Soil carbon (Mg/ha) | Land area ha (t-20) | Land area ha (t) | C stock Mg (t-20) | C stock Mg (t) | Net change in soil carbon Mg |
|---|---|---|---|---|---|---|---|---|---|---|
| long-term cultivated | high activity | 0.11 | 1370600 | 1293800 | 56 | 150766 | 142318 | 8442896 | 7969808 | -473088 |
| | low activity | 0.41 | 1370600 | 1293800 | 56 | 561946 | 530458 | 31468976 | 29705648 | -1763328 |
| | sandy | 0.33 | 1370600 | 1293800 | 14 | 452298 | 426954 | 6332172 | 5977356 | -354816 |
| improved pasture | high activity | 0.11 | 943000 | 671400 | 88 | 103730 | 73854 | 9128240 | 6499152 | -2629088 |
| | low activity | 0.41 | 943000 | 671400 | 88 | 386630 | 275274 | 34023440 | 24224112 | -9799328 |
| | sandy | 0.33 | 943000 | 671400 | 22 | 311190 | 221562 | 6846180 | 4874364 | -1971816 |
| set aside <20 years | high activity | 0.11 | 87900 | 211400 | 64 | 9669 | 23254 | 618816 | 1488256 | 869440 |
| | low activity | 0.41 | 87900 | 211400 | 64 | 36039 | 86674 | 2306496 | 5547136 | 3240640 |
| | sandy | 0.33 | 87900 | 211400 | 16 | 29007 | 69762 | 464112 | 1116192 | 652080 |
| forested | high activity | 0.11 | 0 | 137900 | 88 | 0 | 15169 | 0 | 1334872 | 1334872 |
| | low activity | 0.41 | 0 | 137900 | 88 | 0 | 56539 | 0 | 4975432 | 4975432 |
| | sandy | 0.33 | 0 | 137900 | 22 | 0 | 45507 | 0 | 1001154 | 1001154 |
| abandoned | high activity | 0.11 | 0 | 87000 | 64 | 0 | 9570 | 0 | 612480 | 612480 |
| | low activity | 0.41 | 0 | 87000 | 64 | 0 | 35670 | 0 | 2282880 | 2282880 |
| | sandy | 0.33 | 0 | 87000 | 16 | 0 | 28710 | 0 | 459360 | 459360 |
| Total | | | | | | 2041275 | 2041275 | 99631328 | 98068202 | -1563126 |

Peat soils contain organic matter > 40 % and other organic soils 20–40 %. The emission factors (Mg C/ha/a) used in the calculation are following.

| | |
|---|---|
| Peat soils | |
| Pasture | 2 |
| Upland crops | 4 |
| Other organic soils | |
| Pasture | 0.5 |
| Upland crops | 1 |

The $CO_2$ emissions from liming are calculated using the method and emission factors used in the IPCC Guidelines (the emission factor in the IPCC workbook for Dolomite has been corrected). The emissions from limestone and dolomite use are calculated separately, in addition emission from briquette lime (a waste product of the sugar industry) are estimated. All the carbon in lime used for agricultural soils is assumed to be released to the atmosphere during the same year it is applied.

The carbon conversion factors used in the calculation are 0.12 for limestone and 0.13 for dolomite. The briquette lime contains varying amount of both compounds and the conversion factor is calculated accordingly.

### 2.2 Activity data sources

The areas of agricultural land-use in Finland are taken from agricultural soil statistic. The area of soil types has been calculated according to the unpublished statistics of the Finnish Soil Analysis Service (Nykänen et al. 1995; Berglund 1989). The Finnish Liming Association collects the data on agricultural lime use.

## 2 METHODOLOGY FOR ESTIMATING METHANE EMISSIONS FROM ENTERIC FERMENTATION

### 2.1 Methodology

Methane emissions from enteric fermentation for other livestock than cattle are calculated using the Tier 1 methodology of the IPCC Guidelines as elaborated by the good practice report (Penman et al. 2000). Emissions are defined for each livestock by equation

$$Emissions_i = Emission\ Factor_i \times animal\ population_i$$

Where:

i = animal type.

Emission factors for these animal types are given in Table D2-1.

*Table D2-1. IPCC default values for emission factors:*

| Livestock | Emission factor, kg $CH_4$ /animal /year |
|---|---|
| Swine | 1.5 |
| Sheep | 8 |
| Goats | 5 |
| Horses | 18 |

Methane emissions from cattle are estimated by Tier 2 methodology. In Tier 2 same equation is used for the emissions as given above, but emission factors (*EF*) are calculated as described below.

Emission factors (EF) for cattle are defined by

$$EF_i = [GE * Y_m * 365 \text{ days/year}] / [55.65 \text{ MJ/kg } CH_4]$$

Where:

| | | |
|---|---|---|
| GE | = | Gross energy intake, MJ/animal/day |
| $Y_m$ | = | Methane conversion rate, which is the fraction of gross energy in feed converted to methane. IPCC default value, 0.06, was used. |

GE is defined by:

$$GE = \left[\left(\left(NE_m + NE_a + NE_l + NE_p\right)/\left(NE_{ma} / DE\right)\right) + \left(\left(NE_g\right)/\left(NE_{ga} / DE\right)\right)\right] / \left(DE / 100\right)$$

Where:

| | | |
|---|---|---|
| $NE_M$ | = | Net energy required by the animal for maintenance, MJ/day |
| $NE_A$ | = | Net energy for animal activity, MJ/day |
| $NE_L$ | = | Net energy for lactation, MJ/day |
| $NE_P$ | = | Net energy required for pregnancy, MJ/day |
| $NE_{ma}$/DE | = | Ratio of net energy available in a diet for maintenance to digestible energy consumed |
| DE | = | Digestible energy expressed as percentage of gross energy, %, value 70 used |
| $NE_G$ | = | Net energy needed for growth, MJ/day |
| $NE_{ga}$/DE | = | Ratio of net energy available for growth in a diet to digestible energy consumed |

Equations for these parameters are:

$$NE_M = Cf_i * \left(Weight\right)^{0.75}$$

Where:

| | | |
|---|---|---|
| *Cf* | = | Coefficient, IPCC default value for dairy cattle 0.355 and for other cattle 0.322 |
| *Weight* | = | Animal weight, kg |

$$NE_A = \left( C_{AP} * \frac{t_p}{365} + C_{AO} * \left( 1 - \frac{t_p}{365} \right) \right) * NE_M$$

Where:

| | | |
|---|---|---|
| $t_p$ | | The length of pasture season, days |
| $C_{AP}$ | = | Coefficient for pasture, IPCC default value 0.17 |
| $C_{AO}$ | = | Coefficient for stall, IPCC default value 0.00 |

$$NE_L = \frac{M_Y}{365} * (1.47 + 0.40 * Fat)$$

Where:

| | | |
|---|---|---|
| $M_Y$ | = | Amount of milk produced per year, kg $a^{-1}$ /cow |
| *Fat* | = | Fat content of milk, % |

$$NE_P = C_{pregnancy} * NE_M$$

Where:

| | | |
|---|---|---|
| $C_P$ | = | Pregnancy coefficient, IPCC default value 0.1 |
| $NE_M$ | = | Net energy required by the animal for maintenance, MJ/day |

$$\left\{ \frac{NE_{ma}}{DE} \right\} = 1.123 - \left(4.092 * 10^{-3} * DE\right) + \left(1.126 * 10^{-5} * (DE)^2\right) - \left( \frac{25.4}{DE} \right)$$

Where:

| | | |
|---|---|---|
| DE | = | Digestible energy expressed as percentage of gross energy, %, value 70 used |

$$NE_G = 4.18 * \left\{ 0.0635 * \left[ 0.891 * (BW * 0.96) * \left( \frac{478}{C * MW} \right) \right]^{0.75} * (WG * 0.92)^{1.097} \right\}$$

Where:

| | | |
|---|---|---|
| BW | = | The live body weight of the animal, kg |
| *C* | = | Coefficient, value for heifers 0.8 and for bulls 1.2 (IPCC default values) and for calves calculated as an average from those |
| MW | = | The mature body weight of an adult animal, kg. |
| WG | = | Daily weight gain, kg/day |

$$\left\{ \frac{NE_{ga}}{DE} \right\} = 1.164 - \left(5.160 * 10^{-3} * DE\right) + \left(1.308 * 10^{-5} * (DE)^2\right) - \left(\frac{36.4}{DE}\right)$$

## 2.2 Activity data sources

Animal numbers (Table D2-2), yearly milk production (Table D2-3) and fat content of milk (Table D2-4) were obtained from The Information Centre of the Ministry of Agriculture and Forestry in Finland. Animal weights (Table D2-5). The Association of rural advisory centres (Juho Kyntäjä 11.10.2000) and VTT estimated the weight gains (Table D2-6). Values 570 and 750 were used for mature body weight for dairy cattle and bulls/mother cows respectively. These estimates were received from The Association of Rural Advisory Centres. The Association of Rural Advisory Centres (personal communications: Korpilo 1993, Mälkiä 1996/1999) also estimated DE value.

*Table D2-2. Livestock population, thousand head.*

| Animal type | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Dairy cattle | 489.9 | 445.6 | 428.2 | 426.4 | 416.7 | 398.7 | 392.2 | 390.9 | 383.1 | 372.4 |
| Mother cows | 14.2 | 21.2 | 27.9 | 33.1 | 32.6 | 29.1 | 31.1 | 32.4 | 30.6 | 29.6 |
| Bulls ( > 1 year) | 148.9 | 144.1 | 143.3 | 139.2 | 143.5 | 109.2 | 114.7 | 120.5 | 114.8 | 118.1 |
| Heifers | 218.8 | 213.5 | 211.1 | 216.7 | 214.8 | 189.0 | 201.1 | 196.8 | 190.3 | 187.5 |
| Calves ( < 1 year) | 487.9 | 485.5 | 462.7 | 436.9 | 425.4 | 422.1 | 406.5 | 401.8 | 398.3 | 379.2 |
| Swine | 1394.1 | 1344.3 | 1297.9 | 1272.7 | 1298.3 | 1400.3 | 1395.4 | 1467.0 | 1401.0 | 1351.3 |
| Sheep | 103.3 | 106.7 | 108.4 | 120.4 | 121.1 | 158.6 | 149.5 | 150.1 | 128.3 | 106.6 |
| Goats | 5.9 | 5.4* | 4.8 | 4.8 | 5.7 | 6.1 | 6.5 | 8.0 | 8.1 | 7.9 |
| Horses | 43.9 | 45.4 | 49.2 | 49.1 | 49.0 | 49.5 | 52.0 | 53.1 | 55.2 | 54.5 |
| Poultry | | | | | | | | | | |
| Chickens > 5 months, cocks , broiler mothers | 4844.8 | 4138.0 | 3968.9 | 4024.9 | 4089.8 | 4436.2 | 4486.7 | 4482.7 | 4178.4 | 3760.9 |
| Chickens < 5 months | 1632.5 | 1303.5 | 1597.5 | 1522.3 | 1421.6 | 1482.3 | 1245.6 | 1287.8 | 1184.7 | 1025.3 |
| Broilers | 2551.0 | 2884.1* | 3217.2* | 3550.2* | 3883.3* | 4216.4 | 4052.4 | 4911.1 | 5507.2 | 5998.2 |

* These numbers were not available. They have been interpolated from the data of the surrounding years.

*Table D2-3. Animal weights, kg.*

| Livestock | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Dairy cattle | 503 | 506 | 511 | 517 | 522 | 527 | 533 | 538 | 541 | 544 |
| Mother cows | 650 | 650 | 650 | 650 | 650 | 650 | 650 | 650 | 650 | 650 |
| Bulls ( > 1 year) | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 |
| Heifers | 460 | 460 | 460 | 460 | 460 | 460 | 460 | 460 | 460 | 460 |
| Calves ( < 1 year) | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |

*Table D2-4. Daily weight gain, kg/day.*

| Livestock | 1990 - 1999 |
|---|---|
| Dairy cattle | 0 |
| Mother cows | 0 |
| Bulls (over 1 year) | 1 |
| Heifers | 0.7 |
| Calves (under 1 year) | 0.8 |

*Table D2-5. Annual milk production per cow, kg a-1 /cow.*

| Livestock | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Dairy cattle | 5713 | 5788 | 5781 | 5817 | 6045 | 6161 | 6173 | 6368 | 6412 | 6636 |
| Mother cows | 1620 | 1620 | 1620 | 1620 | 1620 | 1620 | 1620 | 1620 | 1620 | 1620 |

*Table D2-6. Fat content of milk, %.*

| Livestock | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Dairy cattle | 4.35 | 4.35 | 4.34 | 4.38 | 4.35 | 4.34 | 4.33 | 4.32 | 4.31 | 4.24 |

# 3 METHODOLOGY FOR ESTIMATING METHANE EMISSIONS FROM MANURE MANAGEMENT

## 3.1 Methodology

$CH_4$ emissions from manure management are calculated with the same general equation as emissions from enteric fermentation by the equation. Emission factors, $EF_i$ for each livestock are defined by

$$EF_i = VS_i * 365 \text{ days/year} * \text{Bo}_\text{i} * 0.67 \text{kg/m}^3 * \sum_{jk} \left( MCF_{jk} * MS_{ijk} \right)$$

Where:

| | | |
|---|---|---|
| VS | = | Volatile solid excretion per day on a dry-matter weight basis, $kg_{dm}$/day |
| Bo | = | Maximum $CH_4$ producing capacity for manure produced by an animal within defined population, $m^3$/kg VS |
| $MCF_{jk}$ | = | $CH_4$ conversion factors for each manure management system *j* by climate region *k* |
| $MS_{ijk}$ | = | Fraction of animal species/category *i*'s manure handled using manure system *j* in climate region *k* |

VS for cattle is defined

$$VS = GE * \left( \frac{1 \text{ kg - dm}}{18.45 \text{ MJ}} \right) * \left( 1 - \frac{DE}{100} \right) * \left( 1 - \frac{ASH}{100} \right)$$

Where:

| | | |
|---|---|---|
| GE | = | Estimated daily average feed intake, MJ/animal/day |
| DE | = | Digestible energy of the feed in percent, % |
| ASH | = | Ash content of the manure in percent, % |
| | | Energy density of feed, 18.45 MJ/$kg_{dw}$ |

The equation for GE is given earlier in this Annex (Chapter 2.1).

*Table D3-1. Used IPCC default values for VS, Bo and ash content.*

| Livestock | VS | Bo | ASH |
|---|---|---|---|
| Dairy cattle | - | 0.24 | 8 |
| Other cattle | - | 0.17 | 8 |
| Swine | 0.5 | 0.45 | 2 |
| Sheep | 0.4 | 0.19 | 8 |
| Goats | 0.28 | 0.17 | 8 |
| Horses | 1.72 | 0.33 | 4 |
| Poultry | 0.10 | 0.32 | - |

Fraction of manure that ends up on fields during the pasture season is calculated by equation $MS_{pasture} = t_p / 365$, where $t_p$ is the length of pasture season. The rest manure is divided between liquid/slurry and solid storage with the certain fractions (Table D3-2).

*Table D3-2. IPCC default values for MCF coefficients.*

| Manure management system | *MCF*-coefficients /IPCC default values |
|---|---|
| Liquid/slurry | 0.1 |
| Solid storage | 0.01 |
| Pasture | 0.01 |

*MCF*-values for each livestock are calculated as a weighted average of these coefficients.

## 3.2 Activity data sources

Used animal numbers are given in Table D2-2. Juho Kyntäjä/The Association of rural advisory centres and others (e.g. Keränen & Niskanen 1987) estimated the length of the pasture season (Table D3-3). Ratio of liquid/slurry to total manure managed (Table F-4) was calculated from data obtained from The Association of rural advisory centres (Seppänen & Matinlassi 1998). It was also taken into account that about 20 % of dairy cattle spend their nights in the stall also during the pasture season. This data was received from the Finnish Environment Institute.

*Table D3-3. The length of the pasture season, days.*

| Animal type | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Dairy cattle | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 |
| Mother cows | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 |
| Bulls ( > 1 year) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Heifers | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 |
| Calves ( < 1 year) | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 |
| Swine | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sheep | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 |
| Goats | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 |
| Horses | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 |
| Poultry | | | | | | | | | | |
| Chickens > 5 months, Cocks , broiler mother | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Chickens <5 months | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Broilers | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

*Table D3-4. Ratio of liquid/slurry to total manure managed (pasture not included).*

| Animal type | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Dairy cattle | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| Mother cows | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |
| Bulls ( > 1 year) | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| Heifers | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.36 | 0.36 | 0.36 | 0.36 | 0.36 |
| Calves ( < 1 year) | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.38 | 0.38 | 0.38 | 0.38 | 0.38 |
| Swine | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 |
| Sheep | 0 | 0 | 0 | 0 | 0 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 |
| Goats | 0 | 0 | 0 | 0 | 0 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 |
| Horses | 0 | 0 | 0 | 0 | 0 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 |
| Poultry | | | | | | | | | | |
| Chickens > 5 months, cocks , broiler mother | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 |
| Chickens < 5 months | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 |
| Broilers | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 |

# 4 METHODOLOGY FOR ESTIMATING NITROUS OXIDE EMISSIONS FROM MANURE MANAGEMENT

## 4.1 Methodology

$N_2O$ emissions from manure management are defined:

$$N_2O - emission = \sum_{(s)} \left\{ \left[ \sum_{(T)} \left( N_{(T)} * Nex_{(T)} * MS_{(T,S)} \right) \right] * EF_{(S)} \right\} * \frac{44}{28}$$

Where:

| | | |
|---|---|---|
| $N_{(T)}$ | = | number of head of livestock species/category *T* in the country |
| $Nex_{(T)}$ | = | annual average N excretion per head of species/category T in the country, kg N/animal /year |
| $MS_{(T,S)}$ | = | fraction of total annual excretion for each livestock species/category T that is managed in manure management system S in the country |
| $EF_{(S)}$ | = | $N_2O$ emission factor for manure management system S in the country, kg $N_2O$-N / kg N |
| S | = | manure management system |
| T | = | species/category of livestock |

*Table D4-1. Emissions factors for $N_2O$ emissions from manure management systems used in Finland.*

| Manure management system | **Emission factor, $EF_{(S)}$ (IPCC default value)** |
|---|---|
| Liquid/slurry | 0.001 |
| Solid storage | 0.02 |
| Pasture | 0.02 |

## 4.2 Activity data sources

Numbers of head of livestock species are given in Table D2-2. The length of the pasture season is given in Table D3-3 and ratio of liquid/slurry to total manure managed in Table D3-4. Annual average N excretion per head of species (Table D4-2) was obtained from Finnish Environment Institute (Grönroos et al. 1998).

*Table D4-2. Annual average N excretion per head of species, kg N/animal/year.*

| Animal type | 1990 | 1991* | 1992* | 1993* | 1994* | 1995 | 1996* | 1997* | 1998* | 1999* |
|---|---|---|---|---|---|---|---|---|---|---|
| Dairy cattle | 92 | 94 | 95 | 97 | 98 | 100 | 99 | 98 | 97 | 96 |
| Mother cows | 50 | 51 | 52 | 53 | 54 | 55 | 55 | 54 | 54 | 53 |
| Bulls (over 1 year) | 50 | 51 | 52 | 53 | 54 | 55 | 54 | 54 | 53 | 53 |
| Heifers | 43 | 43 | 44 | 44 | 45 | 45 | 45 | 44 | 44 | 43 |
| Calves (under 1 year) | 23 | 23 | 24 | 24 | 25 | 25 | 25 | 25 | 24 | 24 |
| Swine | 12 | 12 | 12 | 11 | 11 | 11 | 11 | 10 | 10 | 10 |
| Sheep | 18 | 18 | 18 | 17 | 17 | 17 | 17 | 17 | 16 | 16 |
| Goats | 18 | 18 | 18 | 17 | 17 | 17 | 17 | 17 | 16 | 16 |
| Horses | 65 | 65 | 65 | 65 | 65 | 65 | 65 | 64 | 64 | 63 |
| Poultry | | | | | | | | | | |
| Chickens > 5 months, Cocks , broiler mother | 0.90 | 0.88 | 0.86 | 0.84 | 0.82 | 0.80 | 0.79 | 0.78 | 0.77 | 0.76 |
| Chickens <5 months | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Broilers | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |

*Data was not available. Values were interpolated from the data obtained.

# 5 METHODOLOGY FOR ESTIMATING NITROUS OXIDE EMISSIONS FROM AGRICULTURAL SOILS

## 5.1 Methodology

## Direct emissions

Emissions from synthetic fertiliser application

$$N_2O_{fert} = N_{fert} * (1 - Frac_{GASF}) * EF * \frac{44}{28}$$

Where:

| | | |
|---|---|---|
| $N_{fert}$ | = | Amount of synthetic fertiliser consumed annually, Gg N $a^{-1}$ |
| $Frac_{GASF}$ | = | Fraction that volatilises as $NH_3$ and $NO_X$. Used value 0.006, which was obtained from R. Pipatti/VTT. |
| EF | = | Emission factor, kg $N_2O$-N / kg N-load. IPCC default value, 0.0125 |

Emissions from animal manure nitrogen used as fertiliser

$$N_2O_{AM} = \sum_T \left(N_{(T)} * Nex_{(T)}\right) * \left(1 - Frac_{GASM}\right) * \left(1 - Frac_{FUEL-AM}\right) * EF * \frac{44}{28}$$

Where:

| | | |
|---|---|---|
| $N_{(T)}$ | = | Number of head of livestock species/category *T* in the country |
| $Nex_{(T)}$ | = | Annual average N excretion per head of species/category T in the country, kg N/animal /year |
| $Frac_{GASM}$ | = | Fraction that volatilises as $NH_3$ and $NO_X$, value 0.03 obtained from Riitta Pipatti/VTT |
| $Frac_{FUEL-AM}$ | = | Amount of animal manure that is burned for fuel, value 0.00 obtained from Riitta Pipatti/VTT |
| EF | = | Emission factor, kg $N_2O$-N / kg N-load. IPCC default value 0.0125 |

Emissions from crop residues returned to soils

$$N_2O_{CR} = \sum_i \left[ Crop_i * \frac{Res_i}{Crop_i} * Frac_{DMi} * Frac_{NCRi} \right] * EF * \frac{44}{28}$$

Where:

| | | |
|---|---|---|
| $Crop_i$ | = | Crop production |
| $Res_i/Crop_i$ | = | Residue to crop product mass ratio |
| $Frac_{DM}$ | = | The dry matter content of the aboveground biomass |
| $Frac_{NCR}$ | = | The nitrogen content of the aboveground biomass |
| EF | = | Emission factor, kg $N_2O$-N / kg N-load. IPCC default value 0.0125 |

It is assumed that crop residues are not burned in the fields in Finland or used as fuel, construction material nor fodder.

Emissions from N fixed by crops

$$N_2O_{BN} = \sum_i \left[ Crop_i * \left(1 + \frac{Res_i}{Crop_i}\right) * Frac_{DMi} * Frac_{NCRi} \right] * EF * \frac{44}{28},$$

where parameters and emission factor are same as for crop residues above. Only the crops cultivated that are fixing nitrogen are included.

Emissions from organic soils cultivated

$$N_2O_{Fos} = Fos * EF * \frac{44}{28}$$

Where:

| | |
|---|---|
| Fos | The area of organic soils cultivated annually, ha |
| EF | Emission factor, kg $N_2O$-N $ha^{-1}a^{-1}$, IPCC default value 8 (IPCC Good Practice report; Klemedtsson et al. 1999) |

**Indirect emissions**

$N_2O$ emissions from atmospheric deposition of $NH_4$ and $NO_X$

$$N_2O_{indirect\_G} = \left[\left(N_{FERT} * Frac_{GASF}\right) + \left(\sum_T \left(N_{(T)} * Nex_{(T)}\right) + N_{sewsludge}\right) * Frac_{GASM}\right] * EF * \frac{44}{28}$$

Where:

| | | |
|---|---|---|
| N*fert* | = | Amount of synthetic fertiliser consumed annually, Gg N $a^{-1}$ |
| $N_{(T)}$ | = | Number of head of livestock species/category *T* in the country |
| $Nex_{(T)}$ | = | Annual average N excretion per head of species/category T in the country, kg N/animal /year |
| $N_{SEWSLUDGE}$ | = | Sewage sludge nitrogen, Gg N $a^{-1}$ |
| EF | = | Emission factor, kg $N_2O$-N / kg N-load, IPCC default value 0.01 |

$N_2O$ emissions from leaching/runoff of applied or deposited nitrogen

$$N_2O_{indirect\_L} = \left[N_{FERT} + \sum_T \left(N_{(T)} * Nex_{(T)}\right) + N_{SEWSLUDGE}\right] * Frac_{LEACH} * EF * \frac{44}{28}$$

Where:

| | | |
|---|---|---|
| N*fert* | = | Amount of synthetic fertiliser consumed annually, Gg N $a^{-1}$ |
| $N_{(T)}$ | = | Number of head of livestock species/category *T* in the country |
| $Nex_{(T)}$ | = | Annual average N excretion per head of species/category T in the country, kg N/animal /year |
| $N_{SEWSLUDGE}$ | = | Sewage sludge nitrogen, Gg N $a^{-1}$ |
| $Frac_{LEACH}$ | = | Fraction of N input that is lost through leaching or runoff. Value 0.15 estimated by M Esala/ Agricultural Research Centre of Finland and R. Pipatti / VTT (see also e.g. Rekolainen et al. 1995) |
| EF | = | Emission factor, kg $N_2O$-N / kg N-load, IPCC default value 0.025 |

## Other emission sources

Emissions from sewage sludge applied to soils

$$N_2O_{fert} = N_{sludge} * EF * \frac{44}{28}$$

Where:

| | | |
|---|---|---|
| $N_{sewsludge}$ | = | Sewage sludge nitrogen, Gg N $a^{-1}$ |
| EF | = | Emission factor, kg $N_2O$-N / kg N-load, IPCC default value 0.025 |

### 5.2 Activity Data sources

Numbers of head of livestock species are given in Table D3-2 and annual average N excretion per head of species are given in Table D4-2. Amount of synthetic fertiliser consumed annually (Table D5-1) was taken from the sales statistics of Kemira Agro Oy. Annual crop production (Table D5-2) was obtained from The Information Centre of the Ministry of Agriculture and Forestry in Finland. Residue to crop production ratio (Table D5-3) was estimated based on the IPCC default values and numbers received from the Agricultural Research Centre of Finland (Merja Myllys). IPCC default values were used for the dry matter fraction (Table D5-3). For the fraction of crop biomass that is nitrogen ($Frac_{NCR}$, Table D5-3) IPCC default values and numbers from Agricultural Research Centre of Finland (Kontturi) were used. Amounts of N input in sludge spreading (Table D5-1) were received from Finnish Environment Institute. Area of organic soils cultivated annually (Table D5-4) was obtained from Agricultural Research Centre of Finland (Merja Myllys).

*Table D5-1. Nitrogen input (Mg N $a^{-1}$) in soils by synthetic fertilisers and sludge.*

| N input to soils | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| synthetic fertiliser consumed annually | 228470 | 202462 | 163229 | 168199 | 169138 | 195460 | 179529 | 169345 | 169928 | 162700 |
| sludge spreading | 2202 | 1749 | 1532 | 1404 | 2063 | 2160 | 2499 | 2285 | 2285* | 2285* |

* Value not available, assumed to be same as in year 1997.

*Table D5-2. Crop production, Gg/a.*

| Product | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| winter wheat | 137.4 | 149.1 | 35.2 | 62.1 | 42.3 | 52.5 | 108.4 | 83.7 | 95.9 | 30.9 |
| spring wheat | 489.5 | 281.4 | 177.1 | 296.4 | 295.1 | 327.0 | 350.9 | 380.4 | 301.0 | 223.2 |
| rye | 244.2 | 28.2 | 26.6 | 62.9 | 22.2 | 57.7 | 86.9 | 47.3 | 49.3 | 23.6 |
| barley | 1720.2 | 1778.8 | 1330.6 | 1678.9 | 1858.1 | 1763.5 | 1859.6 | 2003.5 | 1316.2 | 1567.7 |
| oats | 1661.8 | 1154.9 | 997.6 | 1202.3 | 1149.9 | 1097.2 | 1260.8 | 1243.4 | 975.1 | 990.1 |
| mixed crops | 0 | 0 | 0 | 0 | 0 | 0 | 31.0 | 48.5 | 35.4 | 43.7 |
| turnip rape /rape | 117.0 | 94.9 | 132.6 | 127.4 | 107.9 | 127.9 | 89.4 | 92.9 | 63.9 | 88.3 |
| peas* | 9.1 | 28.3 | 29.1 | 30.0 | 13.9 | 10.9 | 13.3 | 13.1 | 4.2 | 7.2 |
| potatoes | 881.4 | 672.1 | 673.2 | 777.2 | 725.6 | 798.0 | 765.7 | 754.1 | 590.7 | 760.4 |
| sugar beet | 1125.0 | 1042.8 | 1049.0 | 996.0 | 1096.9 | 1110.0 | 896.6 | 1360.0 | 892.0 | 1172.1 |
| red clover seed * | 0 | 0 | 0 | 0 | 0 | 0 | 0.2 | 0.2 | 0.1 | 0.2 |

* Values from Agricultural Research Centre of Finland

*Table D5-3. Residue to crop ratio, dry matter fraction and nitrogen content.*

| Product | $Res_i/Crop_i$ | $Frac_{DM}$ | $Frac_{NCR}$ |
|---|---|---|---|
| winter wheat | 1.30 | 0.83 | 0.028 |
| spring wheat | 1.30 | 0.83 | 0.028 |
| rye | 1.60 | 0.83 | 0.005 |
| barley | 1.20 | 0.83 | 0.004 |
| oats | 1.30 | 0.83 | 0.007 |
| mixed crops | 1.34 | 0.83 | 0.014 |
| turnip rape /rape | 3.00 | 0.83 | 0.015 |
| peas | 1.50 | 0.87 | 0.035 |
| potatoes | 0.40 | 0.45 | 0.011 |
| sugar beet | 0.20 | 0.15 | 0.023 |
| red clover seed | 1.30 | 0.83 | 0.048 |

*Table D5-4. Area of organic soils cultivated (ha).*

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Area, ha | 352700 | 350200 | 347700 | 345200 | 342700 | 313000 | 310500 | 308000 | 305500 | 303000 |

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# METHODOLOGY FOR ESTIMATING GREENHOUSE GAS REMOVALS FROM THE FORESTRY SECTOR

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## 1 METHODOLOGY AND EMISSION FACTORS

The Finnish inventory on Land-use Change and forestry cover the changes carbon stocks in Finnish forests caused by tree growth (above ground) and tree harvesting and cuttings.

*$CO_2$ emissions/removals = (carbon uptake by tree growth – carbon loss due to harvesting/cuttings) *44/12* (1)

The carbon uptake/loss figures are calculated from data on stem volume increment and drain ($m^3$) based on the National Forest Inventory of Finland (NFI) and on annual statistics on cutting removals ($m^3$) (Tomppo 2000). The tree stem volume increment and drain are converted to total C content using the coefficient given by Karjalainen and Kellomäki (1996). The conversion equation is:

$$cf = ef * dw * cc \qquad (2)$$

where cf = conversion factor from stem volume to total biomass C content
ef = expansion factor from stem volume to total tree biomass
dw = conversion factor to dry matter
cc = C- content.

The values of the components are given in Table E-1.

*Table E-1. The coefficients dw, ef, cc and cf according to Karjalainen and Kellomäki (1996).*

| Tree species | ef | dw | cc | cf |
|---|---|---|---|---|
| | | $Mg/m^3$ | | $Mg\ C/m^3$ |
| | | | | |
| pine | 1.527 | 0.390 | 0.519 | 0.3091 |
| spruce | 1.859 | 0.385 | 0.519 | 0.3715 |
| non-coniferous | 1.678 | 0.490 | 0.505 | 0.4152 |

The conversion factors depend on the site fertility and age structure of forests. However, the same factors have been used for all forests in Finland's national greenhouse gas inventory. More accurate, age structure dependent factors are going to be developed in the future.

# 2 ACTIVITY DATA

## 2.1 The National Forest Inventory of Finland

The stem volume increments are obtained from the National Forest Inventory (NFI). Finnish forests have been measured by National Forest Inventories (NFI) eight times. The first inventory was carried out in 1921–24 and the eighth one in 1986–94. In 1994, the oldest part of the data was updated by remeasuring 38 % of the field plots in South Finland. The field measurements of the updated eighth inventory thus come from the years 1989–94 (Tomppo & Henttonen 1996). The ninth forest inventory began in 1996.

The NFI is a sampling based forest inventory. Field plots are located on clusters (Figure E-1). The sampling design has been fitted to the variability of land use classes and variation of the structure of the growing stock in different parts of the country. The distance between two clusters in Central Finland in the ninth inventory was 7 km (Figure E-1). The distance between two field plots in a cluster was 300 m. Every fourth cluster consisted of permanent plots (14 plots) and the other of temporary plots (18 plots). The field plots 11–14 are not measured on the permanent plots (Figure E-1). Thus, about one fifth of the field sample plots have been established permanently. Re-measurements of the permanent sample plots provide information concerning those changes in trees and forests which cannot be easily assessed by means of temporary field plots, e.g. changes in site fertility and natural mortality of trees. Increment borings are carried out only on temporary plots. The permanent plots, together with new temporary plots will be utilised in the increment estimation in the coming forest inventories.

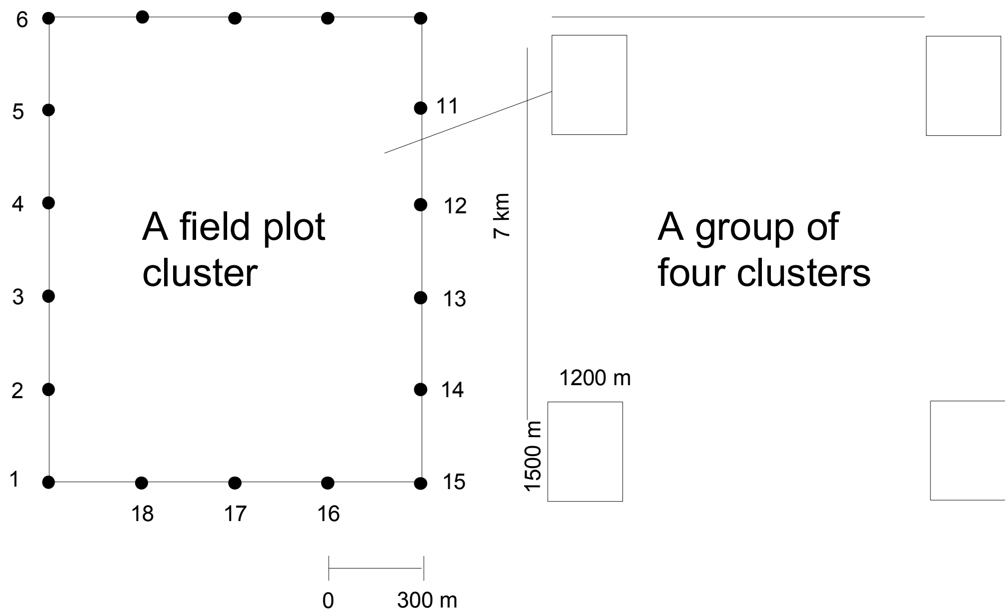


*Figure E-1. The sampling design of the 9th National Forest Inventory (NFI9) in Central Finland. Three of four clusters consist of temporary plots (18 plots) and one is established permanently (14 plots, the plots 11–14 are not measured).*

The workload of the 8th inventory was:

- over 70,000 field plots on forestry land;
- over 150 characteristics measured or assessed;
- half a million tallied trees (tree species, diameter, timber assortment class and its precision as well as crown layer were measured);
- every 7th tree was measured in more detail, e.g. height, diameter and height increments and age, health and timber assortments (Figure E-2).

The workload of the ninth inventory is similar and the whole country will be measured by the year 2003.

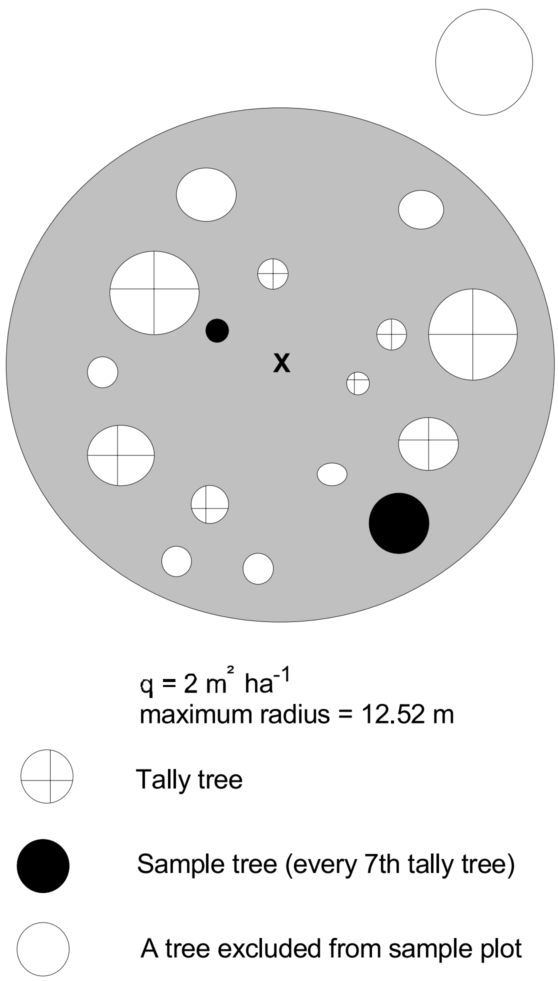


*Figure E-2. The field sample plot of the 9th National Forest Inventory (NFI9) in Central Finland. There are 10 tally trees of which 2 are sample trees.*

The measured characteristics include information about, e.g., soil, site fertility, structure and amount of growing stock of trees, tree growth, damage, accomplished and necessary silvicultural- and cutting measures and indicators of the biological diversity of forests. The forest inventory results concerning growing stock, its structure and increment, as well as the forest condition, have been employed in forest management planning, planning of forest industry, nature conservation, as well as in analysing the long-term changes of forests.

The field data are used to estimate statistics on forest resources for large areas, such as Forestry Centres. The sampling intensity has been designed in such a way that estimates of forest area and volume of growing stock are reliable for areas larger than 200 000 – 300 000 hectares (Figures E-1 and E-2).

A multi-source inventory method has been developed to produce forest resource information for small areas, e.g. municipalities, as well as thematic maps. Satellite images and other geo-referenced data are employed, such as digital maps, in addition to the field data. Landsat TM or Spot -images are currently employed (Tomppo 1991).

2.1.1 Estimation of the increment of the growing stock and its reliability

The increment of the growing stock of trees is estimated using field measurements from sample plots. The measurements are carried out at two different levels of intensity, at tally tree level and sample tree level (Figure E-2). A few characteristics, e.g. diameter, tree species, timber assortment class and canopy layer class, are measured for tally trees, while more characteristics are measured for sample trees, e.g. upper diameter, height, diameter and height increments. Volumes and volumes five years ago are computed for sample trees using taper curve models and estimated volume per basal area ratio curve as a function of tree height (Laasasenaho 1982, Kujala 1980). Volumes are estimated for tally trees using a non-parametric regression method (Tomppo *et al.* 1997, Tomppo *et al.* 1998). Volume increments are estimated for tally trees by computation strata and by diameter classes using the average 5-year increments of the sample trees of the stratum and the numbers of tally trees in the stratum. The annual increment is simply the 5-year increment divided by 5. The volume increment of the trees which have been removed or died during the increment estimation period (5-year period) is estimated using the annual drain estimates, see later, and the increment ratio of the drain and survived trees (Salminen 1993). The final total increment is the increment of the survived trees plus the increment of the drain.

The reliability of the estimates of the NFI is computed following the ideas presented by Matérn (1960). The relative standard error of the volume increment of the growing stock in the 8th inventory and its updating (1989–94) was 0.8 % (Tomppo & Henttonen 1996). The 95 % confidence interval for increment of 75.4 $Mm^3$ is thus (74.2 $Mm^3$, 76.6 $Mm^3$), see Table E-2. The confidence intervals for carbon (C) uptakes or releases cannot be computed in a reliable way due to the fact that the reliability of the coefficients given by Karjalainen & Kellomäki (1996) is unknown.

*Table E-2. Stem volume increment and drain, as well as C- and carbon dioxide uptake and release of trees, 1990 to 1999.*

| Year | Volumes (million $m^3$) | | | Tg C | | | Tg $CO_2$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | Incre-ment | Drain | Balance | Uptake | Release | Balance | Uptake | Release | Balance |
| 1990 | 73.4 | 55.1 | 18.3 | 26.2 | 19.7 | 6.5 | 95.9 | 72.1 | 23.8 |
| 1991 | 74.3 | 44.6 | 29.7 | 26.4 | 16.0 | 10.4 | 96.8 | 58.6 | 38.2 |
| 1992 | 75.8 | 51.0 | 24.8 | 26.9 | 18.2 | 8.7 | 98.6 | 66.7 | 31.9 |
| 1993 | 76.6 | 53.8 | 22.8 | 27.2 | 19.2 | 7.9 | 99.5 | 70.4 | 29.1 |
| 1994 | 75.4 | 61.6 | 13.8 | 26.7 | 22.0 | 4.7 | 97.8 | 80.6 | 17.3 |
| 1995 | 75.4 | 63.6 | 11.8 | 26.7 | 22.7 | 4.0 | 97.8 | 83.1 | 14.7 |
| 1996 | 75.5 | 59.0 | 16.5 | 26.7 | 21.0 | 5.7 | 98.0 | 77.0 | 21.0 |
| 1997 | 75.9 | 65.8 | 10.1 | 26.9 | 23.4 | 3.4 | 98.6 | 85.9 | 12.6 |
| 1998 | 77.2 | 69.4 | 7.8 | 27.3 | 24.7 | 2.6 | 100.1 | 90.4 | 9.7 |
| 1999 | 78.0 | 69.4 | 8.6 | 27.6 | 24.7 | 2.9 | 101.3 | 90.4 | 10.8* |

* The calculation of the $CO_2$ removal for the year 199 is presented in more detail in Table E-3 at the end of this chapter.

The stem volume increments in the NFI are computed as an average of the increments of the inventory year and four years previous to the inventory (as mean of the five years preceding the inventory up to July 31) (Kuusela & Salminen 1969). The inventory proceeds by region and the increment figures for the entire country come from different years. The inventory has lasted 5 to 10 years. The inventory results are updated only through field measurements, not e.g. with models and simulations. Modelling presumes annual increment variation measurements each year in the whole country. These are not carried at the moment. The trend-like changes in the stem volume growth are no longer as high as they were in the 1970s and 1980s, so the increments given in the Table E-2 are relatively up-to-date. The inventory years for the increment figures for 1995 and 1999 are, for example:

1995: 1989–1994,
1999: 1992–1999.

The drain figures correspond exactly to the given year. A small difference in C change between Table E-2 and that given by Karjalainen *et al.* (1996) is caused by the difference in the total increment; a slightly smaller increment figure has been used in this latter article.

The C- balance of 1990 is presented in two different ways (Table E-2). The first one is based on the same increment calculation method as for the years 1991–1999. The second one is based on a computational updating of the increment figures, i.e. on a forecast of the increment, carried out only once, so far, by the NFI. The real increment turned out to be smaller when the actual measurements were made. The reason for giving the 1990 figures based on the computational updating is that the corresponding $CO_2$ net emission has been reported by Karjalainen et al. (1996).

## 2.2 Estimation of annual drain

The total annual drain estimate of forests is based on the statistics of cutting removals reported by forest industry companies, the estimates of the household use of timber based on enquiries, the estimate of the cutting waste obtained from timber assortment quality requirements and taper curve models. The volume of natural losses has earlier been estimated using a study by Kuusela et al. (1986). The current estimate has been derived from the 3000 permanent field plots and is 2.5 $Mm^3$. An analytical expression for the reliability of the total drain is not available. The reported statistics of cutting removals are considered to be reliable.

*Table E-3. Calculation sheet for the estimation of the $CO_2$ removals from the forestry sector in Finland for the year 1999.*

| GREENHOUSE GAS SOURCE AND SINK CATEGORIES | | ACTIVITY DATA | | | | | IMPLIED EMISSION FACTORS | | ESTIMATES |
|---|---|---|---|---|---|---|---|---|---|
| | | **Area of forest/bio-mass stocks** | **Average annual growth rate** | | | | **Implied carbon uptake factor** | | **Carbon uptake increment** |
| | | [1000 ha] | Stemwood overbark [$m^3$/ha] | Expansion factor stemwood volume to total tree biomass | Conversion factor biomass volume to dry matter [t dm/$m^3$] | Total tree [t dm/ha] | Conversion factor dry matter to carbon [t C/ t dm] | [t C/ha] | [Gg C] |
| Managed Forest | Quercus | | | | | | | | |
| | Fagus | | | | | | | | |
| | other broadleaf [1] | | | | | | | | |
| | broadleaf total | 22943 | 0.76320 | 1.678 | 0.490 | 0.62751 | 0.505 | 0.31689 | 7270.52146 |
| | Pinus | 22943 | 1.49370 | 1.527 | 0.390 | 0.88954 | 0.519 | 0.46167 | 10592.17400 |
| | Picea | 22943 | 1.14458 | 1.859 | 0.385 | 0.81919 | 0.519 | 0.42516 | 9754.43679 |
| | Abies | | | | | | | | |
| | other coniferous [2] | | | | | | | | |
| | coniferous total | 22943 | 2.63828 | | | 1.70873 | | 0.88683 | 20346.61079 |
| | forest total [5] | 22943 | 3.40147 | | | 2.33625 | | 1.20373 | 27617.13225 |
| Plantations | Populus | | | | | | | | |
| | other [3] | | | | | | | | |
| | plantations total | | | | | | | | |
| Total annual growth increment [Gg C] | | | | | | | | | 27617.13225 |
| [Gg $CO_2$] | | | | | | | | | 101262.81826 |

| | | | Amount of biomass removed | | | | Carbon emission factor | | Carbon release |
|---|---|---|---|---|---|---|---|---|---|
| | | | Stemwood overbark [m³/ha] | Expansion factor stemwood volume to total tree biomass [4] | Conversion factor biomass volume to dry matter [t dm/m³] | [t dm/ha] | [t C/t dm] | | [Gg C] |
| Pinus | | | | | | | | | |
| Total biomass removed in Commercial harvest | | 22943 | 1.021 | 1.527 | 0.390 | 0.608 | 0.519 | 0.316 | 7239.58248 |
| Traditional Fuelwood Consumed | | 22943 | 0.035 | 1.527 | 0.390 | 0.021 | 0.519 | 0.011 | 247.57314 |
| Total Other Wood Use [6] | | 22943 | 0.074 | 1.527 | 0.390 | 0.044 | 0.519 | 0.023 | 522.65440 |
| Natural losses | | 22943 | 0.048 | 1.527 | 0.390 | 0.029 | 0.519 | 0.015 | 339.98808 |
| Total drain | | 22943 | 1.177 | 1.527 | 0.390 | 0.701 | 0.519 | 0.364 | 8349.79809 |
| Picea | | | | | | | | | |
| Total biomass removed in Commercial harvest | | 22943 | 1.135 | 1.859 | 0.385 | 0.812 | 0.519 | 0.422 | 9673.45937 |
| Traditional Fuelwood Consumed | | 22943 | 0.034 | 1.859 | 0.385 | 0.024 | 0.519 | 0.013 | 288.24992 |
| Total Other Wood Use [6] | | 22943 | 0.078 | 1.859 | 0.385 | 0.056 | 0.519 | 0.029 | 664.16348 |
| Natural losses | | 22943 | 0.023 | 1.859 | 0.385 | 0.016 | 0.519 | 0.008 | 193.15716 |
| Total drain | | 22943 | 1.269 | 1.859 | 0.385 | 0.909 | 0.519 | 0.472 | 10819.02993 |
| Other broadleaf [1] | | | | | | | | | |
| Total biomass removed in Commercial harvest | | 22943 | 0.297 | 1.678 | 0.490 | 0.244 | 0.505 | 0.123 | 2827.24047 |
| Traditional Fuelwood Consumed | | 22943 | 0.135 | 1.678 | 0.490 | 0.111 | 0.505 | 0.056 | 1281.78754 |
| Total Other Wood Use [6] | | 22943 | 0.106 | 1.678 | 0.490 | 0.087 | 0.505 | 0.044 | 1006.08073 |
| Natural losses | | 22943 | 0.040 | 1.678 | 0.490 | 0.033 | 0.505 | 0.017 | 382.00341 |
| Total drain | | 22943 | 0.577 | 1.678 | 0.490 | 0.474 | 0.505 | 0.240 | 5497.11214 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Forest total | | | | | | | | | |
| Total biomass removed in Commercial harvest | | | 2.453 | | | 1.664 | | 0.860 | 19740.28232 |
| Traditional Fuelwood Consumed | | | 0.203 | | | 0.156 | | 0.079 | 1817.61059 |
| Total Other Wood Use [6] | | | 0.257 | | | 0.187 | | 0.096 | 2192.89860 |
| Natural losses | | | 0.111 | | | 0.078 | | 0.040 | 915.14865 |
| Total drain | | | 3.024 | | | 2.084 | | 1.075 | 24665.94017 |
| Total Biomass Consumption from Stocks [Gg C] | | | | | | | | | 24665.94017 |
| [Gg $CO_2$] | | | | | | | | | 90441.78061 |
| | | | | | | | | | |
| Net annual carbon uptake (+) or release (-) [Gg C] | | | | | | | | | 2951.19209 |
| Net $CO_2$ emissions (+) or removals (-) [Gg $CO_2$] | | | | | | | | | -10821.03765 |

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# METHODOLOGY FOR ESTIMATING GREENHOUSE GAS EMISSIONS FROM THE WASTE SECTOR

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## 1 METHODOLOGY FOR ESTIMATING METHANE EMISSIONS FROM SOLID WASTE DISPOSAL ON LAND (LANDFILLS)

### 1.1 Methodology, emission factors and activity data

$CH_4$ emissions from solid waste disposal on land (SWDS) are estimated using the IPCC default method (Houghton et al. 1997). The default method is based on the equation:

$$Emissions\ (CH_4) = \sum_i (SW_i \times MCF \times DOC_i \times DOC_F \times F \times 16/12 - R) \times (1 - OX) \qquad (1)$$

Where:

| | | |
|---|---|---|
| SW | = | amount of waste disposed at solid waste disposal sites |
| MCF | = | methane correction factor (fraction) |
| DOC | = | degradable organic carbon (fraction) (kg C/ kg SW) |
| $DOC_F$ | = | fraction DOC dissimilated |
| F | = | fraction of $CH_4$ in landfill gas |
| R | = | recovered $CH_4$ (Gg/yr) |
| OX | = | oxidation factor (fraction) |
| i | = | type of waste (municipa solid waste, industrial solid waste, construction/demolition waste, municipal or industrial sludge) |

The parameters used in the calculation are mainly IPCC default values (see Table F-1). The use of other values than the IPCC default values are justified by international and national research. The IPCC default values generally overestimate the emissions and therefore a lower $DOC_F$ value (0.5), based on the outcomes of several expert meetings, has been chosen. This value is also consistent with the fact the conditions at most Finnish landfills are not optimal for methane generation. For instance, many of the landfills are shallow and the mean temperature has been found to be between 10–15 $^oC$

(Väisänen 1997). OX is chosen to be 10 % of the $CH_4$ generated at landfills based on international reserach (e.g. Oonk & Boom 1995). The choices of the parameter are in full agreement with information and data ranges given in the IPCC good practice report (Penman et al. 2000).

*Table F-1. Parameters used in the estimation of methane emissions from Finnish landfills.*

| | | |
|---|---|---|
| MCF | 0.7 | This value is based on the assumption that half of the waste goes to small landfills with MCF = 0.4 and half to larger landfills with MCF = 1 (Pipatti & Wihersaari 1998). |
| $DOC_F$ | 0.5 | A lower value than the IPCC default has been chosen based on the fact that conditions at most Finnish landfills are not optimal for degradation (e.g. mean temperature 10 -15 $^oC$, Väisänen 1997). |
| F | 0.5 | IPCC Default |
| R | varies from year to year | Based on data collected by the Finnish Biogas Association (Leinonen & Kuittinen 2000). |
| OX | 0.1 | Based on international literature, e.g. Oonk & Boom 1995. |

The DOC content of the waste is estimated for different types of waste based on the IPCC default values and national research data (see Table F-2). The DOC (degradable organic carbon) content for mixed municipal solid waste is based on research on the mean composition of waste in the beginning of the 1990s (see e.g. Pipatti et al. 1996 and Pipatti & Savolainen 1996).

*Table F-2. DOC values (kg C/kg wet or dry waste) used in the estimation of methane emissions from Finnish landfills (e.g. Bingemer & Crutzen 1987; Dahlbo et al. 2000 and Pipatti et al. 1996)***.**

| Waste type | DOC-fraction* | Assumed dry weight fraction |
|---|---|---|
| **Solid wastes** | | |
| mixed MSW | 0.197 | |
| paper | 0.40 | |
| cardboard | 0.40 | |
| wood, bark | 0.30 | |
| textiles | 0.40 | |
| oil and grease (MSW) | 0.16 | |
| kitchen and yard waste | 0.16 | |
| plastics | 0.00 | |
| other combustible | 0.10 | |
| glass | 0.00 | |
| metal | 0.00 | |
| electrical equipment | 0.00 | |
| other non-combustible | 0.00 | |
| de-inking waste | 0.10 | |
| organic waste (unspecified) | 0.16 | |
| oil and grease (industry) | 0.10 | |
| inert construction waste e.g. concrete | 0.00 | |
| asphalt | 0.10 | |
| sand, lime | 0.00 | |
| soda ash (from dry weight) | 0.02 | 50 |
| **Sludges** | | |
| ***Forest Industry (from dry weight)*** | | |
| sludge (unspecified) | 0.45 | 30 |
| de-inking sludge | 0.30 | 30 |
| fiber sludge | 0.30 | 30 |
| pasta sludge | 0.10 | 30 |
| ***Other industry (from dry weight)*** | 0.45 | 15 |
| ***Municipal sludge (from dry weight)*** | 0.50 | 15 |

* DOC fractions apply to wet weight unless otherwise stated.

The activity data used in the calculation is taken from the VAHTI register (see general description of the register in Annex B). VAHTI contains data on the total amounts of waste taken to landfills from the year 1997 onwards. Corresponding data for municipal solid waste (MSW) for the years 1992–1995 was collected to the Landfill Registry of the Finnish Environment Institute. The disposal of MSW for the year 1996 is interpolated based on the VAHTI data for the year 1997 and the data in the Landfill Registry for the year 1995. The activity data for MSW for the year 1990 is based on the estimates of the Advisory Board for Waste Managment (1992) for municipal solid waste generation and treatment in Finland in 1989. The disposal data (amount and composition) at the beginning of 1990s for industrial, construction and demolition waste are based on surveys and research by Statistics Finland (Vahvelainen & Isaksson 1992; Isaksson 1993; Puolamaa et al. 1995) and The Technical Research Centre of Finland (Perälä & Nippala 1998; Pipatti et al. 1996). The disposal data on industrial waste for the years 1993–1996 is estimated based on the data in the industrial waste statistics for the year 1992 (Puolamaa et al. 1995) and data in the VAHTI registry for the year 1997. The Waste and Sewage Works Register of the Finnish Environment Institute has provided the data on the disposal of sludges (domestic and industrial) at the beginning of the 1990s.

In the VAHTI registry the waste amounts are registered according to the EWC (European Waste Catalogue) classification. Sampling routines have been developed to convert the classification of the VAHTI registry to the classification used in the emission estimations. The data in the VAHTI registry is considered more reliable than the data collected earlier in 1990s, especially as weighing of waste at the disposal sites has become more frequent during the last years.

The total amounts of municipal and industrial solid wastes and sludges, and construction/demolition waste, disposed of in Finnish landfills during 1990–1999, are given in Table F-3, where also the mean DOC-fractions for the the same waste categories are given. In Table F-4 detailed information on the estimated content of MSW is given.

*Table F-3. Solid waste disposal on land in Finland for the years 1990 and 1997 to 1998 (Dahlbo et al. 2000).*

| Waste category | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| MSW | 2 450 000 | 2 285 207 | 2 120 414 | 1 896 177 | 1 638 093 | 1 680 725 | 1 583 233 | 1 485 742 | 1 546 571 | 1 487 829 |
| Industrial SW | 2 617 844 | 2 562 172 | 2 506 500 | 2 400 000 | 2 100 000 | 1 800 000 | 1 500 000 | 1 238 569 | 1 457 930 | 2 479 333 |
| Construction/Demolition Waste | 1 262 400 | 1 110 000 | 781 000 | 666 650 | 639 450 | 637 200 | 566 500 | 553 100 | 465 429 | 457 005 |
| Municipal sludges (dry weight) | 61 500 | 61 500 | 61 500 | 50 000 | 40 000 | 30 000 | 20 000 | 10 915 | 7 108 | 6 905 |
| Industrial sludges (dry weight) | 210 000 | 210 000 | 210 000 | 205 000 | 195 000 | 195 000 | 195 000 | 189 034 | 154 074 | 134 981 |
| - unspecified | 174 000 | 174 000 | 174 000 | 165 000 | 155 000 | 145 000 | 135 000 | 126 570 | 104 572 | 92 201 |
| - de-inking | 36 000 | 36 000 | 36 000 | 40 000 | 40 000 | 50 000 | 60 000 | 62 465 | 49 503 | 42 781 |
| - fiber | | | | | | | | 4 802 | 3 520 | 3 366 |
| - pasta | | | | | | | | 16 633 | 14 026 | 13 305 |
| | | | | | | | | | | |
| **DOC** | | | | | | | | | | |
| MSW | 0.197 | 0.197 | 0.197 | 0.197 | 0.197 | 0.197 | 0.197 | 0.197 | 0.197 | 0.197 |
| Industrial SW | 0.0494 | 0.0474 | 0.0453 | 0.0360 | 0.0360 | 0.0360 | 0.0360 | 0.0360 | 0.0187 | 0.0096 |
| Construction/Demolition Waste | 0.0738 | 0.0713 | 0.0727 | 0.0722 | 0.0703 | 0.0672 | 0.0682 | 0.0680 | 0.0715 | 0.0690 |
| Municipal sludges (dry weight) | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Industrial sludges (dry weight) | | | | | | | | | | |
| - unspecified | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 |
| - de-inking | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| - fiber | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| - pasta | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |

*Table F-4. The estimated content of municipal waste disposed of in Finnish landfills in 1990–1999.*

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| MSW toal | 2 450 000 | 2 285 207 | 2 120 414 | 1 896 177 | 1 638 093 | 1 680 725 | 1 583 233 | 1 485 742 | 1 546 571 | 1 487 829 |
| -paper | 403 141 | 366 425 | 340 889 | 295 334 | 254 921 | 260 765 | 245 435 | 228 214 | 237 916 | 231 292 |
| -cardboard | 229 058 | 232 260 | 224 076 | 207 560 | 178 651 | 182 535 | 171 922 | 162 551 | 169 461 | 164 279 |
| -liquid cardboard | 22 906 | 21 115 | 19 485 | 17 297 | 14 888 | 15 211 | 14 327 | 13 546 | 14 122 | 13 690 |
| -wood | 159 424 | 123 168 | 89 074 | 77 448 | 64 131 | 63 742 | 58 247 | 55 102 | 57 444 | 54 730 |
| -textiles | 30 541 | 29 326 | 27 836 | 25 816 | 22 904 | 24 145 | 23 487 | 22 959 | 23 935 | 23 591 |
| -oil and grease | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -kitchen waste | 717 408 | 680 943 | 646 341 | 585 504 | 507 094 | 521 529 | 488 287 | 450 974 | 468 531 | 439 495 |
| -yard waste | 183 246 | 175 954 | 167 013 | 154 895 | 137 424 | 144 869 | 140 920 | 137 755 | 143 611 | 135 883 |
| -plastics | 137 435 | 131 966 | 125 260 | 116 171 | 103 068 | 108 652 | 105 690 | 103 316 | 107 708 | 106 158 |
| -other combustible | 175 916 | 168 916 | 160 333 | 136 308 | 120 933 | 127 485 | 124 009 | 110 204 | 114 889 | 113 235 |
| -glass | 82 461 | 74 781 | 68 475 | 60 409 | 50 847 | 50 704 | 46 504 | 42 704 | 43 801 | 43 171 |
| -metal | 73 298 | 70 382 | 66 805 | 61 958 | 54 970 | 57 948 | 56 368 | 53 724 | 56 008 | 55 202 |
| -electrical equipment | 51 920 | 48 681 | 45 650 | 41 305 | 36 646 | 38 632 | 37 579 | 35 816 | 37 339 | 36 330 |
| -other non-combustible | 183 246 | 161 291 | 139 178 | 116 171 | 91 616 | 84 507 | 70 460 | 68 877 | 71 805 | 70 772 |

# 2 METHODOLOGY FOR ESTIMATING METHANE AND NITROUS OXIDE EMISSIONS FROM WASTEWATER TREATMENT

$CH_4$ emissions from domestic (not including uncollected domestic wastewaters) and industrial waste water treatment have been estimated using a national method which is consistent with the IPCC methodology.

$$\textit{Emissions } (CH_4) = \textit{Organic load in wastewaters x } B_o \textit{ x MCF} \qquad (2)$$

The organic load in wastewater is the BOD load in domestic wasterwaters and the COD load in industrial wastewaters. The data on the BOD of domestic wastewaters is based on the VAHTI registry and the Waste and Sewage Works Register. The value for the maximum methane producing capacity used in the calculation is $B_o$ = 0.25 kg $CH_4$/kg BOD or COD (IPCC default value). The methane conversion factor (MCF) for domestic wastewaters is 0.025 and for industrial wastewaters 0.005. The values are based on expert judgement.

The assessed $N_2O$ emissions cover the only the emissions caused by the nitrogen load to waterways. In addition to the emissions caused by the nitrogen load of domestic and industrial wastewaters also the emissions caused by the nitrogen load of fish farming have been estimated. The estimation methodology is consistent with the IPCC method for leaching/runoff of agricultural nitrogen to waterways:

$$\textit{Emissions } (N_2O) = \textit{Nitrogen load in wastewaters x } EF_{N2O\ leaching/runoff} \qquad (3)$$

The nitrogen loads are obtained from the VAHTI registry and the Waste and Sewage Works Register. The $N_2O$ emission factor is 0.025 kg $N_2O$-N/kg N load to the waterways (IPCC default).

The activity data used in the calculation of the greenhouse gas emissions from wastewater treatment and fish farming are given in Table F-5.

*Table F-5. BOD, COD and nitrogen in wastewaters and the discharge to waterways in Finland in 1990–1999.*

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Sewage COD (kg)** | | | | | | | | | | |
| - metal | 80 880 | 83 623 | 90 405 | 90 098 | 111 510 | 87 982 | 85 790 | 100 180 | 110 812 | 118 128 |
| - chem. forestry | 814 362 276 | 720 367 453 | 706 167 533 | 736 591 613 | 780 545 408 | 777 731 740 | 774 012 145 | 741 319 016 | 746 716 704 | 758 043 987 |
| - food | 3 687 895 | 2 985 035 | 2 778 046 | 15 503 085 | 2 972 347 | 1 900 932 | 1 762 224 | 1 569 767 | 1 496 832 | 1 498 179 |
| - chemical | 16 335 524 | 14 753 625 | 14 820 327 | 15 120 512 | 16 168 053 | 16 889 038 | 16 264 663 | 16 437 226 | 16 422 423 | 12 750 381 |
| - mech. forestry | 9 161 411 | 7 138 282 | 8 660 644 | 9 445 132 | 15 801 316 | 8 456 730 | 7 133 016 | 6 535 957 | 5 491 224 | 4 115 712 |
| - other | 7 662 212 | 6 505 245 | 7 104 779 | 6 589 904 | 11 758 155 | 9 377 482 | 4 993 282 | 3 397 000 | 2 088 809 | 2 068 077 |
| **Total** | **851 290 198** | **751 833 263** | **739 621 735** | **783 340 344** | **827 356 790** | **814 443 905** | **804 251 120** | **769 359 148** | **772 326 805** | **778 594 464** |
| | | | | | | | | | | |
| **BOD7 ATU (kg)** | | | | | | | | | | |
| Sewage | 120 850 000 | 117 603 000 | 107 185 000 | 109 027 000 | 110 150 000 | 113 134 000 | 110 463 000 | 111 738 000 | 117 475 000 | 118 201 000 |
| Discharge to waterways | 11 250 000 | 9 580 000 | 9 995 000 | 9 517 000 | 10 285 000 | 8 434 000 | 7 538 000 | 6 576 000 | 7 099 000 | 6 593 000 |
| **BOD 5 (kg)** | | | | | | | | | | |
| Sewage | 103 290 598 | 100 515 385 | 91 611 111 | 93 185 470 | 94 145 299 | 96 695 726 | 94 412 821 | 95 502 564 | 100 405 983 | 101 026 496 |
| Discharge to waterways | 9 615 385 | 8 188 034 | 8 542 735 | 8 134 188 | 8 790 598 | 7 208 547 | 6 442 735 | 5 620 513 | 6 067 521 | 5 635 043 |
| | | | | | | | | | | |
| **Total nitrogen (kg)** | | | | | | | | | | |
| Sewage (municipal) | 22 254 000 | 21 733 000 | 20 862 000 | 21 290 000 | 21 974 000 | 21 115 000 | 20 893 000 | 21 183 799 | 22 288 083 | 21 827 000 |
| Discharge to waterways (municipal) | 15 374 000 | 14 646 000 | 14 428 000 | 14 338 000 | 14 592 000 | 14 570 000 | 14 380 000 | 14 000 516 | 12 753 282 | 12 198 000 |
| Discharge to waterways (industrial) | 5 671 000 | 5 462 000 | 5 025 000 | 4 562 000 | 4 515 000 | 4 333 000 | 3 780 000 | 3 875 275 | 4 132 596 | 3 945 000 |
| Discharge to waterways (fish farming) | 1 712 000 | 1 780 000 | 1 640 000 | 1 406 000 | 1 186 000 | 1 211 000 | 1 180 000 | 1 058 000 | 1 008 000 | 948 000 |

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# Greenhouse gas emissions and removals in Finland

Abstract

This report is part of Finland's National Inventory report to the United Nations' Framework Convention on Climate Change (UNFCCC). The report presents the methodologies, activity data and emission factors used in the compilation of the Finnish inventories for the years 1990–1999, as well as the estimated emissions for those years. A preliminary identification of the key sources in the Finnish inventory for the year 1999 is also given.

The total Finnish anthropogenic greenhouse gas emissions in 1999 were about 76.2 Tg $CO_2$ equivalents, which is about 1 % lower than in 1990. The most important source of the emissions is fuel combustion, which causes about 80 % of the emissions. The emissions from fuel combustion have grown with more than 6 % since 1990. Agriculture is also an important source of greenhouse gas emissions in Finland and contributed about 10 % to the total greenhouse gas emissions in Finland in 1999. The agricultural emissions have declined approximately 25 % since 1990. The importance of the waste sector as a contributor to Finnish greenhouse gas emissions has also declined much during the 1990s (1990: 5 % and 1999: 2 % of the total emissions). The Land-use change and forestry (removals) sector has constituted at net sink during the whole 1990s. In 1999 this sink was estimated to be about 10.8 Tg $CO_2$.

Identification of the so-called key sources of the Finnish inventory is preliminary and will be improved in the coming years. In the improvement of the accuracy of the inventory the key sources should be prioritised. Most of the 26 identified key sources are energy related, but also 5 agricultural, 2 industrial, 1 waste and 1 other key source were identified.

The methodologies used in the compilation of the Finnish inventory are largely consistent with the IPCC Guidelines and good practice guidance. Some needs to improve the methodologies, have, however, been identified. Continuous improvement of the activity and emission factor data is also seen as important.

Keywords
greenhouse gases, emissions, reduction, Finland, energy production, process industry, agriculture, forestry, waste disposal, waste water treatment, nitrous oxide, methane, carbon dioxide, fluorine compounds, manure, land use

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