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Greenhouse Gas Emission Accounting 2

Update including Second National Communications

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This research is part of the Global Emissions Inventory Activity (GEIA), a component of the International Global Atmospheric Chemistry (IGAC) Core Project of the International Geosphere-Biosphere Programme (IGBP).

Abstract

This study is the second in a series of studies on analysis of greenhouse gas emission estimates. The first report, 'Greenhouse Gas Emission Accounting', prepared as a background document for an IPCC Expert Meeting on *Inventory Data Quality* in Bilthoven, The Netherlands from 5-7 November 1997, laid down the methodology for comparison of emissions and concentration data, including a first analysis. In the study presented here a more detailed analysis is made of the differences between national emission estimates, including the second National Communications, and global inventories such as EDGAR 2.0 and atmospheric concentration data. This follow-up report provides background information on the greenhouse gases carbon dioxide, methane and nitrous oxide for IPCC expert meetings on *Good Practice Guidelines and Inventory Quality*. It also supports the review and synthesis process of national communications by the Climate Secretariat and the Subsidiary Body on Scientific and Technological Advice (SBSTA).

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Chemical compounds

CFCs	Chlorofluorocarbons
CF_4	Perfluoromethane (tetrafluoromethane)
C_2F_6	Perfluoroethane (hexafluoroethane)
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CTC	Carbon tetrachloride (tetrachloromethane)
FICs	Fluoroiodocarbons
HCFCs	Hydrochlorofluorocarbons
HFCs	Hydrofluorocarbons
HNO_3	Nitric acid
MCF	Methyl chloroform (1,1,1-Trichloroethane)
NO_x	Nitrogen oxide (NO and NO_2), expressed as NO_2
N_2O	Nitrous oxide
NMVOC	Non-Methane Volatile Organic Compounds
PFCs	Perfluorocarbons
SO_2	Sulphur dioxide
SF_6	Sulphur hexafluoride
VOC	Volatile Organic Compounds (may include or exclude methane)

Units

MJ	mega joule (10^6 J)
GJ	giga joule (10^9 J)
TJ	tera joule (10^{12} J)
PJ	peta joule (10^{15} J)

Mg	mega gramme (10^6 g)
Gg	giga gramme (10^9 g)
Tg	tera gramme (10^{12} g)
Pg	peta gramme (10^{15} g)

ton	metric ton (= 1 000 kilogramme = 1 Mg)
kton	kiloton (= 1 000 metric ton = 1 Gg)
Mton	megaton (= 1 000 000 metric ton = 1 Tg)

Conversion factors for emissions

From element basis to full molecular mass basis:	From full molecular mass to element:
$C \rightarrow CO_2$: x 44/12 = 3.67	$CO_2 \rightarrow C$: x 12/44 = 0.27
$C \rightarrow CH_4$: x 16/12 = 1.33	$CH_4 \rightarrow C$: x 12/16 = 0.75
$C \rightarrow CO$: x 28/12 = 2.33	$CO \rightarrow C$: x 12/28 = 0.43
$N \rightarrow N_2O$: x 44/28 = 1.57	$N_2O \rightarrow N$: x 28/44 = 0.64
$N \rightarrow NO$: x 30/14 = 2.14	$NO \rightarrow N$: x 14/30 = 0.47
$N \rightarrow NO_2$: x 46/14 = 3.29	$NO_2 \rightarrow N$: x 14/46 = 0.30
$N \rightarrow NH_3$: x 17/14 = 1.21	$NH_3 \rightarrow N$: x 14/17 = 0.82
$N \rightarrow HNO_3$: x 63/14 = 4.50	$HNO_3 \rightarrow N$: x 14/63 = 0.22
$S \rightarrow SO_2$: x 64/32 = 2.00	$SO_2 \rightarrow S$: x 32/64 = 0.50

Summary

This report is the second in a series on analysis of greenhouse gas emission estimates. It describes ways to assess the quality and uncertainty of national greenhouse gas emission inventories. This study is the second in a series of studies on analysis of greenhouse gas emission estimates. In the first report, 'Greenhouse Gas Emission Accounting' the methodology for comparison of emissions and concentration data was laid down and a first reconnaissance performed. It was prepared as a background document for an IPCC Expert Meeting on Inventory Data Quality in Bilthoven, The Netherlands from 5-7 November 1997. In this present study a more detailed analysis is made of differences between national emission estimates, including the second National Communications, and global inventories such as EDGAR 2.0 and atmospheric concentration data. This follow-up report provides background information for IPCC Expert Meetings on Good Practice Guidelines and Inventory Quality and supports the review and synthesis process of national communications by the Climate Secretariat and the Subsidiary Body on Scientific and Technological Advice (SBSTA). It covers the greenhouse gases: carbon dioxide, methane and nitrous oxide. Measuring greenhouse gas concentrations in the atmosphere is not the only independent method to verify inventories because measurements and atmospheric models also contain errors and uncertainties. Comparisons with (semi)-independent inventories at national, regional and global scales can provide more insight into the quality of the inventories. Specific conclusions from this study are:

- Our analysis showed that national annual inventories from *industrialised countries (Annex I countries)* as reported in National Communications are not transparent, comparable, complete and accurate enough to assess compliance of the Kyoto Protocol.
- Precise and complete information on emissions from *non-Annex I countries* is still missing. A lack of statistics on long term trends and a lack of country-specific emission factors make national inventories from these countries incomplete and inaccurate, especially for agriculture, forestry and land use change. Energy statistics are reasonably accurate but can be improved. This report based its analysis mainly on information from the Climate Secretariat, EDGAR and country studies for non-Annex I countries.
- Developing countries *lack adequate instruments* to develop their own country-specific information like basic statistics and emission factors. A more thorough analysis for developing countries is possible after the quality of national reports is improved and more country-specific emission factors have been developed.
- At this moment only *part of the global budget is addressed* by the National Communications that have been submitted by Annex I countries. The part covered by the National Communications is for CO_2 about 50%, for CH_4 about 30% and for N_2O about 25%. It is important to complete the inventory of Annex I countries and to establish the contribution on non-Annex I countries when they, in the course of time, participate in a protocol. The participation of countries should increase and the evaluation of the reported emissions should be more accurate in order to be certain that the entire anthropogenic part of greenhouse gas emissions is addressed by international climate policy.
- It is necessary to agree on a *level of detail and accuracy of reporting* the national inventories of countries. Transparency in reporting can be improved by the mandatory use of standard data tables for reporting emissions, activity data and aggregated emission factors for all sectors. A suggestion for the level of detail of such tables is given in this report (Table 5.2).
- A quantitative estimate of the *uncertainty in annual emissions* is required to determine in more detail whether differences found in comparisons as observed in this study are significant or not. A quantitative estimate of the *uncertainty in the emission trend* is required to assess compliance with the assigned emission reduction in the Kyoto Protocol.
- Accurate verification of national inventories through an analysis of *atmospheric concentrations and the use of transport models* is limited by a lack of detailed measurement data.

Samenvatting (Dutch)

Dit is het tweede rapport in een serie over analyses van emissieschattingen van broeikasgassen. Het beschrijft een aantal manieren om de kwaliteit en de onzekerheid van nationale emissie inventarisaties te schatten. In het eerste rapport 'Greenhouse Gas Emission Accounting' is de methodiek voor vergelijking van emissies en concentraties beschreven en is een eerste verkenning uitgevoerd. Het was geschreven als achtergronddocument voor een IPCC Expert Meeting over de kwaliteit van emissie-inventarisaties, die van 5 tot 7 november 1997 in Bilthoven gehouden is. In het voorliggende rapport wordt een meer gedetailleerde analyse gemaakt van geconstateerde verschillen tussen nationale emissieschattingen, inclusief die van de tweede *National Communications*, en mondiale inventarisaties zoals EDGAR 2.0 en atmosferische concentratiemetingen. Dit vervolgrapport geeft achtergrondinformatie voor IPCC Expert Meetings over *Good Practice Guidelines and Inventory Quality* en heeft tot doel het review- en synthese-proces van *National Communications* door het Klimaatsecretariaat en de *Subsidiary Body on Scientific and Technological Advice (SBSTA)* te ondersteunen. De analyse is gericht op kooldioxide, methaan en lachgas. Het analyseren van concentraties van broeikasgassen in de atmosfeer is niet de enige onafhankelijke manier om de inventarisaties te verifiëren omdat metingen en modelberekeningen ook fouten en onzekerheden bevatten. Vergelijkingen met semi-onafhankelijke inventarisaties op nationale, regionale en mondiale schaal kunnen meer inzicht geven in de kwaliteit van de inventarisaties. De belangrijkste conclusies van deze studie zijn:

- Onze analyse toont aan dat nationale emissie inventarisaties van de *(Annex I) industrielanden*, zoals gerapporteerd in National Communications, niet voldoende transparant, vergelijkbaar, compleet en nauwkeurig zijn om te kunnen beoordelen of een land voldoet aan de verplichtingen in het Kyoto Protocol.
- Complete en nauwkeurige informatie over emissies van *(niet-Annex I) ontwikkelingslanden* ontbreekt nog steeds. Een gebrek aan statistische informatie over langjarige trends en een gebrek aan landen-specifieke emissiefactoren maken nationale inventarisaties van deze landen incompleet en onnauwkeurig, vooral voor landbouw, bosbouw en landgebruikverandering. Energiestatistieken zouden ook nog aanzienlijk verbeterd kunnen worden. Dit rapport is voornamelijk gebaseerd op informatie van het Klimaatsecretariaat, EDGAR en landenstudies voor niet-Annex I landen.
- Op dit moment *ontbreekt het ontwikkelingslanden aan middelen* om eigen, landenspecifieke, informatie te verzamelen zoals basis-statistieken en emissiefactoren. Een meer diepgaande analyse voor ontwikkelingslanden is mogelijk nadat de kwaliteit van landenrapporten is verbeterd en meer landenspecifieke emissiefactoren zijn ontwikkeld.
- Op dit moment wordt maar een *deel van het mondiale budget gedekt* door de uitgebrachte National Communications van de Annex I landen, namelijk circa 50%, 30% en 25% voor respectievelijk CO_2, CH_4 en N_2O. Het is van belang om een complete inventarisatie van alle Annex I landen te hebben en om de bijdrage van niet-Annex I landen vast te stellen, als zij in de loop van de tijd in een protocol deelnemen. De deelname van landen moet groeien en de nauwkeurigheid van de gerapporteerde emissies moet verbeteren, teneinde te kunnen beoordelen of daadwerkelijk het complete antropogene deel van broeikasgas emissies wordt geadresseerd in het internationale klimaatbeleid.
- Het is van belang om overeenstemming te krijgen over het *detailniveau en de nauwkeurigheid van het rapporteren* van de emissie-inventarisaties van landen. De transparantie in rapportage kan worden verbeterd door gebruik van standaard tabellen voor het rapporteren van gegevens over emissies, activiteiten en geaggregeerde emissie factoren voor alle sectoren. In dit rapport wordt een voorstel gedaan voor het detail niveau voor dit soort tabellen (Tabel 5.2).
- Een kwantitatieve schatting van de *onzekerheid in de jaarlijkse emissies* is nodig om meer gedetailleerd te kunnen vaststellen of gevonden verschillen significant zijn of niet. Een kwantitatieve schatting van de *onzekerheid van de trend in emissies* is nodig om te kunnen beoordelen of de afgesproken emissiereductie voldoet aan de afspraken in het Kyoto Protocol.
- Op dit moment is het moeilijk om definitieve conclusies te trekken over de mogelijkheden van validatie van nationale emissies met behulp van *concentratiemetingen en atmosferische transportmodellen*. Het ontbreken van voldoende meetgegevens is hiervoor een belangrijke factor.

1. Introduction

1.1. Background

This report describes ways to assess the quality and uncertainty of national greenhouse gas emission inventories. It concludes that measuring greenhouse gas concentrations in the atmosphere is not the only way, because the measurements themselves are surrounded by uncertainties. Comparisons with semi-independent inventories at national, regional and global scales can give more insight into the quality of the inventories. This report concludes that new ways have to be found to assess emission reductions by countries for the Kyoto Protocol.

Because of the growing scientific and political concern about the possible effect of the build-up of greenhouse gas concentrations in the atmosphere, 154 Heads of State signed the *United Nations Framework Convention on Climate Change* (UNFCCC) in Rio de Janeiro in 1992. The same countries later ratified this Climate Convention. The overall objective of the Convention is to stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level is to be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner (UNFCCC, 1993). The greenhouse gas emissions, projections for 2000, 2010 (and beyond), and policy initiatives for the reduction of emissions are reported in National Communications to the Climate Convention Secretariat in Bonn. In addition to commitments related to the reduction of greenhouse gas emissions for the industrialised countries (countries listed in Annex 1 to the Convention), the Convention has provisions for the regular reporting of emissions and for review of the commitments. A common reporting format is used to allow a compilation and synthesis of emission data to be made regularly by the Climate Convention Secretariat. This study analyses these emissions.

This study is the second in a series on an analysis of greenhouse gas emission estimates and concentration data. In the first study, "Greenhouse Gas Emission Accounting" (Van Amstel et al., 1997) the methodology for comparison of emissions and concentrations data was laid down and a first reconnaissance performed. The study was prepared as a background document for an IPCC expert meeting on Inventory Data Quality in Bilthoven, the Netherlands from 5-7 November 1997 (Van Amstel et al.,1999). In the present study a more detailed analysis is made of reasons for differences between national and global emission estimates. National inventory data are compared with global inventories to reduce uncertainties and thereby improve the inventory quality. Prepared as a follow-up to the first report, this study is used as background for a number of IPCC Expert Meetings on 'Good Practice in Inventory Preparation', for example for the meeting on "Good Practice in Inventory Preparation: Agricultural sources of methane and nitrous oxide", held at the Wageningen Agricultural University, from 24-26 February 1999.

Inventory quality has become an issue since the adoption of legally binding emission reduction targets for a group of six gases in the Kyoto Protocol to the Climate Convention. Especially since uncertainties are large in some sectors, like land use and agriculture where carbon dioxide, methane and nitrous oxide are emitted and sequestered. This report, which also supports the review and synthesis process of national communications by the Climate Secretariat and the Subsidiary Body on Scientific and Technological Advice, will cover three of the six greenhouse gases: carbon dioxide, methane and nitrous oxide.

Carbon dioxide

Partitioning the anthropogenic flux of carbon dioxide from fossil fuel combustion, burning natural vegetation and deforestation over the most important sinks, i.e. the oceans and the biosphere is still unclear. The extra input of carbon dioxide from human activities is masked by the seasonal exchange between atmosphere and biosphere. Also, it is unclear how global warming will affect this partitioning over the reservoirs in the future. Warming due to a CO_2 increase may increase the fertilisation effect. It is unclear how the biosphere and the ocean uptake will be affected in such a scenario.

Methane

Although most biogenic sources are natural for methane, they are also enhanced by anthropogenic influence, e.g. by agricultural practices. So it is difficult to distinguish purely natural from purely anthropogenic sources. The fossil fuel methane input is poorly constrained because the emission of C isotopes from the nuclear energy sector seems to be higher than earlier assumed (Vermeulen *et al.* 1996). For Europe the validation of methane emission inventories has been performed by different research groups (Vermeulen et al., 1996; Zhang, 1996; Janssen et al., 1997; Van der Wal, 1997; Stijnen, 1997; Berdowski et al., 1998; Levin et al., 1999). Their experience will be used to develop an overall method for validating the IPCC methodology.

Nitrous oxide

Nitrous oxide is relatively inert in the troposphere, but the relatively large uncertainties in emission estimates and complicated reactions in the soil make it difficult to quantify individual sources. Annual variations in atmospheric concentrations are mainly caused by variation in emissions. We will compare the atmospheric model results with the national inventories. It is assumed that if the atmospheric model results are more precise than the national emission inventory results, a verification of emission estimates by atmospheric model results could lead to a reduction of uncertainties.

1.1.1 Kyoto Protocol

Reporting emissions and review/quality control of the emissions estimates will be essential for the success of the Kyoto Protocol, not only to check compliance, but also for the application of the flexible mechanisms, agreed to in the Protocol, like Joint Implementation, Emissions Trade and the Clean Development Mechanism. One of the agreements in the Kyoto Protocol is that countries will have to develop a 'National System' to allow for verification and checking of emissions (Article 5.1). The *IPCC 1996 Revised Guidelines for National Greenhouse Gas Inventories*, developed and published by the IPCC (IPCC/OECD/IEA, 1995) and later revised (IPCC/OECD/IEA, 1997), were adopted as the common methodology for reporting emissions and sinks to the Climate Convention Secretariat.

In the Convention it was agreed that the industrialised countries (listed in Annex 1 to the Convention) would stabilise their CO_2 emissions in 2000 at the 1990 level. In the Kyoto protocol (1997) targets were agreed for the period after 2000. A reduction level of an average of 5% between the base year and the budget period (2008 to 2012) was adopted for industrialised countries. The exact reduction targets per country can be found in Annex B to the Kyoto Protocol (UNFCCC, 1997). The reduction objective is related to six (groups of) gases: CO_2, CH_4, N_2O, HFCs, PFCs and SF_6. The Protocol will come into force when ratified by 55% of the countries, accounting for at least 55% of the total greenhouse gas emissions. The agreed emission reduction targets will then become mandatory for the countries that ratified the Protocol.

One of the provisions of the Protocol is that countries will have to prove their emissions do not exceed the agreed allowance in the budget period (2008-2012). A compliance regime for the Protocol will have to be further developed. A 5% reduction for OECD countries means a large total reduction of 15%, while emissions grew by 10% between 1990 and 1998. The European Union has offered a reduction of 8%, the USA 7% and Japan 6%. Through burden sharing within the EU, European countries have taken on different obligations. Some can even increase their emissions, while others will introduce stronger emission reductions. Verification of reductions will become essential with the adoption of this legally binding instrument. One of the approaches is comparison of emission estimates with independent or semi-independent global inventories or atmospheric concentration data.

1.1.2 Obligation of countries to report on sources and sinks of greenhouse gases

The OECD countries and Eastern Europe (as listed in Annex 1 to the Convention) have already reported emissions for the base year to 1996 in their first and second National Communications on Climate Policies. Several of the inventories in the second National Communication are based on the *IPCC 1996 Revised Guidelines*. Many countries have recalculated the base year emissions following these revised guidelines. To see the actual trends in the emissions and sinks, a second compilation and synthesis of data by the Climate Secretariat has been made. This report was based on all available Second National Communications (FCCC/CP/1998/11/Add.2). This compilation and synthesis was available at the fourth Conference of the Parties in Buenos Aires in November 1998. It was used as a basis for analysis in the present report.

Results between 1990 and 1995 show increasing emissions for carbon dioxide in industrialised countries, with the exception of Eastern European countries, including (Eastern) Germany. Results for methane between 1990 and 1995 show decreasing emissions, with some exceptions in which methane emissions are rising (like Canada, USA and some European countries). Nitrous oxide emissions rise between 1990 and 1995 in industrialised countries and fall in Eastern Europe (UNFCCC/CP/1998/11/Add.2). The emission estimates are characterised by uncertainties, which could affect the assessment of policies and measures.

The protocol prescribes the use of the IPCC 1996 Revised Guidelines to assess the emissions of greenhouse gases. These guidelines do not prescribe, however, the use of one single method to do so. Countries are encouraged to use best methodology and country-specific data on emission factors. In practice, this means that countries use all kinds of different methods and emission factors to report their emissions. A recent synthesis report of the Second National Communications of the Annex-1 countries (produced by the secretariat of the UNFCCC) shows that it is very difficult to inter-compare national reports of countries. To improve this comparability and the quality of emission inventories, it is very important to develop standard reporting formats for emissions, activity data and emission factors, as well as reporting guidelines for completeness, consistency, comparability, validation and transparency. The IPCC has been asked by the Subsidiary Body on Scientific and Technical Advice to the Convention (SBSTA) to advise on improvements in the reporting framework by developing "Good Practice Guidelines". Improvements are needed to be able to compare data across countries and to check compliance of the countries to their emission reduction target.

Table 1.1. Uncertainty estimates in the inventory of the Netherlands. (Source: Van Amstel et al., 1999c)

	(Mton CO -eq.)	(%)	(Mton CO -eq.)
CO_2 (carbon dioxide)			
Fossil combustion	149.7	2%	3.0
Industrial processes/Feedstocks	11.7	25%	2.9
[Land use (sinks)	(-1.5)	15%	
Subtotal	*161.4*	*3%*	*4.2*
CH_4 (methane)			
Energy	4.5	25%	1.1
Agriculture	10.6	25%	2.7
Waste	11.9	30%	3.6
Subtotal	*27.0*	*17%*	*4.6*
N_2O (nitrous oxide)			
Energy use	2.3	75%	1.7
Industrial processes	9.8	35%	3.4
Agriculture	6.9	75%	5.2
Subtotal	*19.0*	*34%*	*6.4*
HFC/SF_6			
Energy use	1.4	50%	0.7
Industrial processes	5.1	50%	2.6
Subtotal	*6.5*	*41%*	*2.6*
PFCs			
Industrial processes	2.4	100%	2.4
Subtotal	*2.4*	*100%*	*2.4*
Other sectors			
Other sectors	*1.0*	*50%*	*0.5*
Total emissions:	**218.8**	**4.4%**	**9.6**
Target 2008-2012:	206		

the square root of sums of squares of underlying sources.
(Strictly speaking this can only be done as uncertainties are: a) normal distributed, b) 2 sigma < 60%, c) sources and gases are independent).

1.1.3 Uncertainty

In addition to improvements in reporting emission inventory data by countries, it is important to work on the improvement of inventory quality itself. As a first step, the range of uncertainty related to the emission of greenhouse gases by the respective economic sectors should be made clear. Table 1.1 gives an example for the Netherlands. It shows that the overall uncertainty, if expressed as the square root of the sums of the squares of underlying sources, for the estimated total greenhouse gas emission in the Netherlands is only 4.4%. The uncertainty in the estimates for individual sources is larger. It should be noted however, that strictly speaking this type of uncertainty analysis only holds in case that the uncertainties are normally distributed, 2 sigma < 60% and sources and gases are independent. This is not the case in the Dutch inventory. To report the overall uncertainty is not only important for developing a better feeling for the quality of the inventories, but - in the end - will indicate whether countries will be complying to their commitments under the Kyoto Protocol. An analysis of uncertainties will also create an agenda for further work on the improvements of inventory quality, and prioritise the limited financial means for scientific research.

The uncertainties in emission estimates are related to the difficulty of extrapolating measurement results from experimental research to the national level (emission factors) and to uncertainties in the statistical information produced by a country (activity data). The uncertainty is considered lowest in carbon dioxide emission estimates from fossil fuel combustion. In most OECD countries this is the largest source, with a contribution of at least two thirds of the total emissions. In OECD countries the uncertainty in this source is considered relatively small (2-10%). This is because the carbon content of the fuels is relatively well known and the energy statistics are realistic. However, the uncertainties in estimates of carbon dioxide, methane and nitrous oxide emissions from other (mainly biogenic) sources are much higher. This is the result of the large spatial and temporal variability of these sources, making it difficult to extrapolate the measurement results to the national level. Further research may be needed to increase the accuracy of the methodology.

1.2. Purpose of this study

This study is meant as a contribution to inventory quality and uncertainty assessment and the international discussions on “Good Practice Guidelines”. At the request of the IPCC, the Wageningen Agricultural University organised an IPCC expert meeting on Good Practice in Greenhouse Gas Emission Inventory Preparation in Agriculture, held in Wageningen, from 24-26 February 1999. This report has been used for the preparation of the meeting.

The purpose of the study is to compare different types of emission inventories (e.g. National Communications, science-based (Bottom-Up) emission inventories and (Top-Down) budgets derived from atmospheric modelling) to improve inventory quality. This was carried out through the analysis of available information. The analysis is based on:

- The first and second National Communications of countries to the Climate Convention Secretariat;
- Emission inventories of other country studies;
- Global emission databases (like the results of a core project of the International Geosphere-Biosphere Programme. This is called the International Global Atmospheric Chemistry project, and includes its Global Emissions Inventory Activity and an Emissions Database for Global Atmospheric Research using sectoral and country total emissions (IGBP/IGAC; GEIA-EDGAR Version 2.0);
- Results of (inverse) modelling calculations and data assimilation studies (where measurement data are assimilated into atmospheric models to enhance their performance).

Bottom-up national inventories are defined here as all inventories based on a simple accounting method with an estimation of emissions from activity levels and emission factors. Top-down global or regional budget estimates are defined here as results of atmospheric models. Atmospheric transport and chemistry models calculate budgets using measurement data of atmospheric concentrations of greenhouse gases. (Some studies define bottom-up and top-down differently, 'bottom-up' referring to detailed methods within emission inventories, 'top-down' meaning more general methods for emission inventories based on more general statistics. These definitions are not adopted here).

In the project selected target areas are analysed to make recommendations for improvement of the IPCC methodology, reporting and Good Practice.

Questions that are answered in the present study:

1. What are the reasons for the differences encountered between first and second national inventories and EDGAR 2.0? (Chapter 3).
2. What are the results of a comparison of aggregated national inventories with regional and global atmospheric models? (Chapter 4)
3. Where can IPCC methodologies and reporting for national emission inventories be improved in the future? (Chapter 5)

1.3. Method

The present study is reporting on the following tree steps:

1. Presenting an in-depth comparison of EDGAR with national inventories based on an analysis of large differences in emissions in case studies from different world regions. (Chapter 3)
2. Presenting the results of comparisons of aggregated national inventories with global atmospheric modelling studies on latitudinal bands of 10 degrees. (Chapter 4)
3. Presenting lessons for reporting and the future development of the IPCC methodology. (Chapter 5)

Bottom –up comparison of national inventories with EDGAR (Chapter 3)
Official national communications and related background documents were used for a comparison of national inventories with semi-independent regional and global inventories. Results of the United States Country Studies Programme were included (as summarised by Braatz *et al.*, 1996), along with the IGBP/IGAC/GEIA/EDGAR data (Emission Database for Global Atmospheric Research) (Olivier *et al.*, 1996 and 1999). For the comparison with top-down budgets, aggregated national inventories supplemented with EDGAR emission inventory data, were used. Comparison with additional other data is also possible, e.g. CORINAIR inventories for the European Union (Jol, 1996), or e.g. a comparison with GEIA data (Global Emissions Inventory Activity of the IGAC/International Geosphere- Biosphere Programme). The last will be more difficult as often sector overviews and emission factors are not available in GEIA.

Comparison of EDGAR with national inventories is carried out to check the precision, consistency and accuracy of the national inventories and to analyse the uncertainties in different sources of emissions data. The comparison points out major areas of uncertainty and future possibilities for improving the IPCC Methodology. A comparison will be made of emission inventories for countries in different world regions: the European Union, 'Rest of OECD', Eastern Europe and the former Soviet Union, 'Rest of the World 1' (country studies available) and 'Rest of the World 2' (only EDGAR results available). The result of this comparison provides an insight into the reasons for different estimates.

Top-down comparison with atmospheric budgets (Chapter 4)
Working Group 1 of the IPCC published global budgets of greenhouse gases based on atmospheric concentration measurements and atmospheric modelling (IPCC, 1990; 1992; 1994; 1996). We note that the term "budget" used here is different from the use in the UNFCCC documents, where 'budget' means the total emissions to be reduced by a country in a certain period of time. The IPCC Second Assessment Report (1996) shows a range in sources and sinks of greenhouse gases, so the measurements and models are also characterised by uncertainties. Inverse modelling gives information on the emissions that explain a certain global concentration field. Atmospheric models are run with 'a

priori' emission estimates. Forward modelling can be done with national inventories as an 'update' of the 'a priori' emission estimates.

Different authors have published verification studies for carbon dioxide, methane and nitrous oxide (Fung et al., 1991; Ciais et al., 1997a,b; Hein et al., 1997; Kaminski et al., 1997; Hartley and Prinn, 1993; Bouwman and Taylor, 1996). However, these verifications were performed on a global scale and did not consider the level of detail contained in the national inventories as submitted to the Climate Convention Secretariat. Here we present a comparison of aggregated national inventories with global models. Comparison is done for latitudinal bands of 10 degrees.

Existing model exercises for carbon dioxide, methane and nitrous oxide will be evaluated in this report. National inventories present results as national yearly totals for economic sectors. The results of global models (in the reverse mode) offer different temporal and spatial resolution (e.g. total emission per month, per grid or latitudinal band, per source group). Measuring concentrations of isotopes may provide information on a split between different sources.

Before a comparison of top-down modelled emissions with data from bottom-up national inventories can be made, a compatible format must be obtained. Different spatial and temporal comparisons are possible:

- National totals per year could be compared with model results.
- National totals per month could be constructed from yearly totals if a comparison is made with monthly calculations from models.
- National totals per sector could be compared with model outcomes for groups of sources.
- National totals per sector per month could be compared with detailed model calculations.
- National totals per sector could be distributed at grid cell level, thereby providing a means to compare global 2-D distributions or 1-D latitudinal distributions with global results of inverse modelling.

The EDGAR software provides the unique facility of converting national totals of any data set per sector, e.g. official UNFCCC submissions, to a $1^0 x 1^0$ grid, which in turn provides the required format for comparison of bottom-up results with top-down results of inverse modelling, either one-dimensional or two-dimensional modelling (1-D, 2-D). In the previous study we explored the possibilities of developing standard methodology for top-down/bottom-up comparisons, and comparisons of emission inventories. In the present study we start with comparisons by the IPCC sectors. EDGAR sectors are sometimes combined and sometimes split up to make them comparable with IPCC sectors. The details for the comparison are comparable to the Summary Tables 7A and 7B from the *IPCC 1996 Revised Guidelines*, Volume 1: Reporting Instructions (IPCC/OECD/IEA, 1995; 1997).

1.4 Structure of the report

Chapter 2 explains the methodologies, while in Chapter 3, detailed comparisons are described between national inventories and EDGAR. In Chapter 4 atmospheric measurements and model results will be compared with the aggregated bottom-up national inventories. In Chapter 5 we give some lessons for improving the IPCC Reporting Guidelines for national GHG inventories. Chapter 6 comprises a discussion followed by several conclusions on greenhouse gas emissions accounting.

2. Assessment of the quality of emission inventories

2.1 Quality assessment

An IPCC Expert Meeting was organised in Bilthoven, the Netherlands, in November 1997, to discuss improvement of national emission inventory quality (Van Amstel et al., 1999). Four approaches were defined for improvement of inventories: 1. Quality assurance; 2. Comparison with model results; 3. Inventory comparisons; 4. Direct emission measurements. The following is based on the conclusions of that meeting and summarises how this report adds to the knowledge.

Before a comparison of inventories is carried out one has to make an assessment of the quality of the inventories to be compared. Relevant questions may be:

- *Are IPCC defaults or country specific data and emission factors used?*
- *If country specific data are used, are emission factors based on sound measurement programmes and how are measurements extrapolated to be valid for a whole country?*
- *How are emission factors derived?*
- *How are IPCC defaults derived?*
- *What is the uncertainty related to a set of emission factors?*

Evaluation of the quality may include: tracing the original sources of emission factors and testing the sample set for appropriateness, reproducibility, statistical variance; assessing the robustness of the survey techniques used for collecting activity data; identifying and evaluating the reliability of national and international sources of emission factors and activity data, and comparing independent sources of these data; assessing the algorithms used to prepare emission estimates. This approach can help identify systematic differences in data, and quantify uncertainties in emission estimates. Inventory quality can be defined according to several criteria. Important criteria are completeness, consistency, transparency, comparability and accuracy. Adequate quality depends on the purpose of the inventory, such as for analysis of trends of emissions and assessment of the effects of policies and measures. The quality of greenhouse gas emission estimates should be adequate for both purposes (Lim et al., 1999).

2.1.1. Inventory quality assurance

Countries are encouraged to use best methodology available for the greenhouse gas emission inventories. IPCC tier 1 and tier 2 methodology, and country specific methodology are available. Criteria are needed for choosing the right methods and sources for activity data and emission factors. IPCC defaults are available for a country to be used in the absence of country specific data. Should a country use defaults from the IPCC Guidelines or should a country develop its own emission factors through measurement campaigns? This will be dependent on the available resources, manpower and capacity for measuring programs to implement the guidelines.

Inventory quality assurance and control is important for the sake of verifying compliance with the Kyoto protocol. Quality assurance can be done by countries themselves, but also international quality assurance programmes can be developed, possibly as part of the IPCC Guidelines Programme (Lim et al., 1999). At the moment country reviews are carried out by independent expert panels to evaluate the national emission inventories as part of the review process of the Climate Secretariat.

2.1.2. Comparison with atmospheric model results

"The only thing what matters at the end of the day is what the concentrations of greenhouse gases are" (Watson, 1998). The ultimate proof for the Kyoto Protocol in 2008/2012 that countries have fulfilled their obligations, and that greenhouse gas emissions are reduced is indeed in the measurements of atmospheric concentrations. Therefore, during the Kyoto meeting countries were encouraged to keep their monitoring stations up and running. But measurements alone are not sufficient for the evaluation of emissions from a country. Models are needed for an overall picture in time and space. Measurements are used to enhance the output of atmospheric chemistry and transport models that are capable of mapping concentrations in time and space. Both models and measurements suffer from uncertainties. Atmospheric models start with input data on the fluxes of greenhouse gases from sources at the earth's surface, then atmospheric processes and transport by wind result in concentration fields for a particular region, say western Europe. The first generation of these models used first approximations of these fluxes. Uncertainties were large. Now that we have detailed national inventories for the Climate Convention, a second generation of these models can use these national inventories as their input data. For methane emissions in Western Europe this exercise has been done to verify European greenhouse gas inventories (Berdowski et al., 1998; Levin et al., 1999). Results will be given in Chapter 4.

2.1.3. Inventory comparisons

The industrialised countries produce annual trend reports of greenhouse gas emissions and sinks for the Climate Convention. They have reported the greenhouse gas emissions to the Secretariat of the Climate Convention in their first and second National Communication on climate policies. The inventories are based on national and/or IPCC methodologies and reported according to IPCC guidelines. Overviews are made by the Climate Secretariat (e.g. FCCC/CP/1996/12/Add.2 and FCCC/SBI/1997/19/Add.1 and FCCC/CP/1998/11/Add.1 and 2). The IPCC methodology is published in *IPCC Guidelines* and *IPCC 1996 Revised Guidelines* (IPCC/OECD/IEA, 1995; 1997). Some developing countries have reported their greenhouse gas inventories unofficially in a book edited by Braatz et al. (1996). The database of UNFCCC was used to compare greenhouse gas inventories with EDGAR the emissions database for global atmospheric research developed at RIVM (Van Amstel et al., 1997).

The comparison of greenhouse gas emission estimates from National Communications and from EDGAR is carried out at the sector level of detail. The summary table 7A and 7B from the IPCC revised Guidelines was taken as a basis for the comparison. EDGAR sectors were mapped onto these tables in order to make this comparison possible. The comparison showed different things. First of all it showed gaps in reporting, secondly it showed large differences between official national estimates and EDGAR estimates for various sectors. The comparison showed sectors in which reporting is very scattered (e.g. biomass burning and land use change) and sectors with almost complete reporting (industry, agriculture). Once the large differences were found, a detailed investigation into the reasons for differences could be carried out. Three main reasons were found: the use of different emission factors, the use of different statistics for economic activities, and finally different methodology. The largest differences were mainly caused by the use of different emission factors. More detailed results will be given in Chapter 3.

2.1.4. Direct emission measurements

Measurements of greenhouse gas emissions are carried out at different scales. Direct emission measurements at a particular source are done with open or closed boxes, of e.g. one square meter. Measurements over larger areas of e.g. one hectare or more is carried out with measurement towers of about ten to twenty meters. An eddy correlation method is used to calculate the flux over this area. For larger areas, measurements can be carried out from aircraft or large towers of e.g. one or two hundred meters high. Greenhouse gas fluxes from different air masses with different origins can be calculated if at the same time mixing layer height, wind speed and direction is measured (Vermeulen et al., 1999). Small-scale direct emission measurements are used to estimate emission factors from one particular source. Larger scale measurements can be used to verify the emission estimate for a whole country or from a group of countries like the European Union. Different verification studies have been carried out for Western Europe. A review will be given later in this report. The uncertainty in the measurements as well as in the emission inventories is rather high. Extrapolation of measurements from one box to a whole country is very difficult and high uncertainties prevail. More details will be given in Chapter 4.

2.2 Methodology for inventory quality assurance

Countries can be asked to carry out quality assurance and control. These are techniques to ensure that fixed emissions inventory procedures have been followed. Quality assurance and control is linked to standard good laboratory practice. It is no guarantee for good data quality. It can be used to make uncertainties in different data sources explicit. Auditing is used to control if procedures of good practice are followed each year.

2.3 Methodology for comparison of inventories with model output

Two alternatives are possible. Models can be used in the forward mode and the reverse mode. In the forward mode 'a priori' geographical explicit estimates of emissions are used as input data. Second generation emission inventory data can be used as input for atmospheric chemistry and transport models. These data have to be geographically explicit. In the reverse mode measurements of greenhouse gas concentrations are used as input data to estimate the emissions of a certain area, be it a country or a continent. Data assimilation techniques are used to enhance the performance of models in the inverse mode using measurements of greenhouse gas concentrations. A review of recent papers on this subject will be given in Chapter 4.

2.4 Methodology for inventory comparison

In this paragraph methodologies will be described for the comparison of national inventories as reported to the Climate Convention Secretariat with the emission estimates made in EDGAR. For this kind of evaluation to be successful, the documentation of the inventories must be complete and transparent (Van Amstel, 1993). The data must be detailed enough to reconstruct the inventory. Background reports to the National Inventories should be available and data should be referenced. A first evaluation or in-depth review on draft inventories was carried out by IPCC/OECD/IEA in 1993 to evaluate draft IPCC methodology. For the Second Conference of the Parties to the Climate Convention the Climate Secretariat in 1996 published a second compilation and synthesis of 1990-1994 data of OECD and Eastern European countries (UNFCCC/CP/1996/12/Add.2, 2 July 1996). A first compilation and synthesis of second national communications was published in 1997 (UNFCCC/SBI/1997/19 and Addendum 1). In 1998, a second compilation and synthesis of second national communications was published (FCCC/CP/1998/11/Add.2). For the Conference of the Parties in Buenos Aires in November 1998 the Climate Secretariat published methodological issues identified during the processing of inventories (UNFCCC/SBSTA/1998/7 and 8). An overview of emissions, emission factors and activity data used in the inventories can be the basis for a thorough evaluation. Here a comparison with EDGAR is made. Emissions will be compared to search for big differences or omissions, then a more detailed analysis will take place using also information on emission factors and activity data.

The comparison methodology is based on the use of the same sources of emissions. The EDGAR sources were mapped on the IPCC Standard Reporting Tables 7A and 8A. When large differences were found an analysis took place for the reasons of these differences. We used background reports to the National Communications when available. More details will be given in Chapter 3.

3. Comparison of national inventories and EDGAR

In this chapter official national inventories as submitted to the Climate Secretariat of the UNFCCC will be compared with a semi-independent scientific database, EDGAR Version 2.0. Furthermore, inventories compiled as part of the Country Study Programme have been used for non-Annex I countries, where available. Three aspects will be considered in the analysis: 1) the methods for estimating the emissions, 2) the differences between the national communications and EDGAR and 3) the reasons for these differences. Three greenhouse gases, namely carbon dioxide, methane and nitrous oxide will be covered.

The comparison is aimed at:

1. Finding blanks, missing emissions or information gaps;
2. Flagging possible mistakes, for example, in allocation of emissions to source categories;
3. Finding systematic differences which could indicate differences in emission factors or activity data used in the sectors analysed;
4. Reducing uncertainties in the emission estimates;
5. Checking for systematic bias, i.e. if one of the databases in a significant source is consistently substantially lower or higher than the other, one of them being consistent with overall budget constraints. This points to possible systematic differences in methods or emission factors;
6. Drawing conclusions and offering recommendations for the improvement of the IPCC Guidelines and good practice in greenhouse gas inventory preparation.

The first four objectives refer to individual countries, whereas the last three refer to countries as well as to more generic aspects relevant for UNFCCC and the IPCC.

We compared emission estimates from official national greenhouse gas inventories (as reported in the first and second National Communications to the Climate Convention Secretariat) with emission estimates from EDGAR Version 2.0 (Emissions Database for Global Atmospheric Research developed by the National Institute for Public Health (RIVM) and the Environment and the Netherlands Organisation of Applied Scientific Research (TNO)). The national inventories and the EDGAR database were analysed to find out the reasons for the observed differences. Only the larger differences at country level were analysed: >10% difference between national communication and EDGAR estimates for carbon dioxide, methane and nitrous oxide. The national communications and background reports were analysed for the methodologies applied, emission factors and activity data used, allowing differences to be explained in terms of differences in: a) emission factors, b) activity data, or c) methodology.

Gaps in reporting are flagged but not further analysed. We assume that most gaps will be filled in the inventories in the near future. A short overview of the IPCC Guidelines and the EDGAR inventory methodologies follows.

In the comparisons all figures are for 1990, since EDGAR V2.0 only provides full datasets for this year. This also means that only for countries existing in 1990 can comparisons be made (therefore the new states in Eastern Europe and the former USSR for instance are excluded). We also note that the number of digits presented in all tables in this chapter does not represent the precision of the estimates, but is the direct result of the calculations. Table 3.1 provides an indication of the uncertainty of the emission estimates for the greenhouse gases CO_2, CH_4 and N_2O in the EDGAR V2.0 database (Olivier et al., 1996; 1999).

Table 3.1 Indication of uncertainty in sectoral estimates of emissions of CO_2, CH_4 and N_2O in EDGAR V2.0 (Source: Olivier et al., 1999)

Main source	Subcategory	Activity data	Emission factors			Total emissions		
			CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Fossil fuel use	Fossil fuel combustion	S	S	M	M	S	M	M
	Fossil fuel production	S	M	M-	-	M	M	-
Biofuel	Biofuel combustion	L	S	M	L	L	L	L
Industry/ solvent use	Iron & steel production	S	-	S		-	S	-
	Non-ferro production	S	-	S	L	-	S	-
	Chemicals production	S	-	S	L	-	S	M
	Cement production	S	S	-	-	S	-	-
	Solvent use	M	-	-	-	-	-	-
	Miscellaneous	V	-	-		-	-	
Landuse/ waste treatment	Agriculture	S	-	L	L	-	L	L
	Animals (excreta; ruminants)	S	-	M	M	-	M	M
	Biomass burning	L	S	M	L	L	L	L
	Landfills	L	-	M	-	-	L	-
	Agricultural waste burning	L	-	L	L	-	L	L
	Uncontrolled waste burning	L	-	-	-	-	-	-
Natural sources	Natural soils	M	-	L	-	-	L	L
	Grasslands	M	-	M	-	-	M	-
	Natural vegetation	M	-	M	-	-	M	-
	Oceans/wetlands	M	-	L	L	-	L	L
	Lightning	S	-	-	-	-	-	-
			CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
All sources		-	-	-	-	S	M	L

Notes:
S = small = +- 10%
M = medium = +- 50%
L = large = +-100%
V = very large = >100%
- = Not applicable.

3.1 Comparison for carbon dioxide

3.1.1. Differences between first and second national communication and EDGAR estimates

IPCC methodology for CO_2

The IPCC methodology recognises more than one level of detail. The easy to apply methodology is called Tier 1, the more detailed methodology Tier 2. The IPCC reference approach (Tier 1), as published in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC/OECD/IEA, 1997),* for CO_2 emissions from fossil fuel use is based on the carbon content of the fuels and the fuel supply to the national economy. Emissions are calculated using default IPCC emission factors for each fuel type and statistical information on the imports, exports and changes in stock of fossil fuels. Statistics on different economic sectors can be found in the energy balance of a country. The main source sectors for CO_2 emissions are power production, industry, space heating and (road) transport. The IEA published an overview of carbon dioxide emission estimates using this approach and the energy balances compiled by the OECD/IEA (OECD/IEA, 1998). More details about the methodology can be found in the *Revised 1996 IPCC Guidelines for National Inventories* (IPCC/OECD/IEA, 1997). Countries often use detailed emission factors for all different fuels in the economy and often a more detailed bottom-up demand-driven technical approach (Tier 2) is selected from which sectoral emissions can be calculated.

CO_2 process emissions from cement production and limestone use are minor sources of CO_2. The IPCC methodology for carbon dioxide from industrial processes is based on default emission factors for cement clinker production, limestone use and some other processes. The main sink for CO_2 is carbon sequestration by maturing forests. This sink is decreased by deforestation, notably in tropical countries and may be increased by afforestation. The methodology for carbon dioxide sources and sinks from landuse change and forestry is based on estimates of total stock changes of carbon stored in biomass within a country. However, the uncertainty in the national data required for this calculation is often very large. At present, this method is in revision and being studied by the IPCC to provide recommendations to the UNFCCC bodies. Therefore gaps are often found in the national reports on landuse.

EDGAR methodology for CO_2

The EDGAR methodology for carbon dioxide is essentially the same as the IPCC Tier 1 approach, however, using aggregated default emission factors for solid, liquid and gaseous fuels consumed in the various sectors, as described in the *Revised 1996 IPCC Guidelines* (see Table 3.2). These emission factors are similar to the global gridded CO_2 inventories of GEIA and per country estimates by CDIAC at ORNL (ORNL, 1998). These emission factors of EDGAR and GEIA are very similar to those recommended by the IPCC as defaults (Marland et al., 1999). In EDGAR, the IEA dataset is used for most of the energy calculations, while UN energy data are used for many smaller countries missing in the IEA dataset. EDGAR V2.0 used UN statistics on cement production, rather than clinker production because no comprehensive international statistics are available for the latter. More details on the construction of the fossil fuel data set are provided in Olivier et al. (1996; 1999).

Table 3.2 Global emission factors for CO_2, CH_4 and N_2O (g GJ^{-1} LHV) from fossil fuel combustion in EDGAR V2.0 (Source: Olivier et al., 1996; 1999)

Compound	Sector [a]	Fuel type		
		Solid	Liquid	Gaseous
CO_2 [a,c,d]	All sectors, except case below	93.5	70.62	56.1
CO_2	International marine bunkers (intern. shipping)	-	72.05	-
CH_4	Industry [a]	10	2	5
CH_4	Power generation [a]	1	3	1
CH_4	Total other sector [a]	300	10	-
CH_4	Road transport - gasoline, LPG	-	20	-
CH_4	Road transport - diesel	-	5	-
CH_4	Non-road surface transport [a]	10	50	-
N_2O	All sectors/countries, except cases specified below	1.4	0.6	0.1
N_2O	Air traffic	-	3.4	-
N_2O	Road transport 1990 - USA, Canada, Japan [b]	-	4.2	-
N_2O	Road transport 1990 - Australia, Germany (Fed. Rep.) [b]	-	1.8	-
N_2O	Road transport 1990 - Former DDR [b]	-	1.3	-
N_2O	Road transport 1990 - Netherlands [b]	-	1.1	-

[a] Industry : excluding the energy transformation sector; power generation: including autoproducers and cogeneration; total other sector: residential, commercial, other/non-specified; non-road surface transport: rail, inland water, other/non-specified

[b] Emission factor for N_2O from road transport per country is the weighted average of the emission factor used for cars equipped with catalytic converters (estimated at 7x0.6=4.2 g/GJ) and the emission factor for uncontrolled cars (0.6 g/GJ).

[c] Ignoring the unoxidised fraction from combustion. For liquid fuels we used the weighted average factor for gasoline and diesel, for marine bunker fuels this factor is 2% higher.

[d] For consumption of LPG, ethane as chemical feedstock and for other non-energy use of lubricants, naphtha and bitumen we used respectively 60%, 60%, 50%, 20% and 0% of the emission factor for liquid fuel; for consumption of gas as chemical feedstock and for other non-energy use we used 66% of the factor for gas. For feedstock use of other fuels (in chemical industry), an emission factor of 0 has been assumed, except for white spirit, paraffin waxes, petroleum coke and 'other petroleum products' as well as for liquid fuel for electricity output, where we assumed full oxidation.

Carbon dioxide: differences in emissions from fossil fuels and industrial processes

Table 3.3 provides an overview of total anthropogenic carbon dioxide emissions from fossil fuel use and industrial processes. Country-specific estimates were taken from the first and second National Communications (indicated by NC1 and NC2, respectively) as presented in addendum's to documents from the Climate Secretariat: FCCC/CP/1996/12/Add.2) and FCCC/CP/1998/11/Add.2 (UNFCCC, 1998). The differences are large for some countries. Differences larger than 10% of total emissions per gas in a country will be analysed in more detail in this section.

Differences of more than 10% between EDGAR and National Communication 1 (NC1) or National Communication 2 (NC2) were found in Bulgaria, Greece, Hungary, Iceland, Luxembourg, Netherlands, Norway, Poland and Portugal (see Table 3.3). Differences between NC1 and NC2 are not analysed in detail. Generally 1990 estimates in NC2 are updates of 1990 estimates in NC1. Those differences will be caused by improvements in methodology and/or statistics. In some cases (Bulgaria, Hungary and Poland) the differences are caused by selection of different base years in our analysis.

Large differences

Table 3.3 gives a comparison of national communications and EDGAR estimates of total CO_2 emissions for industrialised countries (Annex-1 countries in the Climate Convention). In Table 3.4 carbon dioxide emissions from combustion of fossil fuels from the national communications and EDGAR V2.0 are compared for countries with large differences. Table 3.5 compares CO_2 emissions from industrial processes (only for the countries with large differences).

Table 3.3 Total anthropogenic CO_2 emissions in Gg in 1990, (excluding land use change and forestry), from EDGAR 2.0 and the First and Second National Communications (NC1 and NC2)

Emission estimate 1990	NC1	NC2	EDGAR[1]	EDGAR-NC1	EDGAR-NC2
	Gg	Gg	Gg	difference (%)	Difference (%)
Australia	288965	273123	259807	-10	-5
Austria	59200	61880	57382	-3	-8
Belgium	114410	116090	108248	-5	-7
Bulgaria[a]	82990	96878	*71579*	-14	-35
Canada	462643	464000	431022	-7	-8
Czech Republic	165792	165490			
Denmark	52025	52277	51513	-1	-1
Estonia	37797	37797			
Finland	53900	53800	50541	-6	-6
France	366536	378379	352105	-4	-7
Germany	1014155	1014155	992478	-2	-2
Greece	82100	84575	73754	-10	-15
Hungary[b]	71673	83676	*65771*	-8	-27
Iceland	2172	2147	1905	-12	-13
Ireland	30719	30719	30242	-2	-2
Italy	428941	432150	404151	-6	-7
Japan	1155000	1124532	1071427	-7	-5
Latvia	22976	24771			
Lithuania		39535			
Luxembourg	11343	12750	10085	-11	-26
Monaco	71	71			
Netherlands	167600	167550	147138	-12	-14
New Zealand	25476	25476	25347	-1	-1
Norway	35514	35544	44764	26	21
Poland[a]	414930	476625	*362718*	-13	-31
Portugal	42148	47123	41810	-1	-13
Slovakia	58278	60032			
Slovenia		13935			
Spain	227322	226423	217746	-4	-4
Sweden	61256	55445	55576	-9	0
Switzerland	45070	45070	42602	-5	-6
Ukraine		700107			
United Kingdom	577012	583747	575640	0	-1
United States	4957022	4960432	4804805	-3	-3
Russian Federation	2388720	2372300			

[1] New European countries are missing in EDGAR V2.0

[a] Base year 1988 in NC2

[b] Base year is average of 1985-1987 in NC2

Table 3.4: Comparison of CO_2 emissions in Gg in 1990 from combustion of fossil fuels for countries with large differences. (Source EDGAR 2.0 and First and Second National Communications (NC1 and NC2).

Emission estimate 1990	NC1	NC2	EDGAR	EDGAR-NC1	EDGAR-NC2
	1990	1990	1990	Difference (%)	Difference (%)
Bulgaria	76535	*90327*[b]	69255	-10	-23
Greece	76210	76834	67197	-12	-13
Hungary	68105	*80089*[a]	*63664*	-7	-21
Iceland	1698	1674	1848	9	10
Luxembourg	10626	12133	*9768*	-8	-19
Netherlands	164800	164800	145124	-12	-12
Norway	27041	26938	28338	5	5
Poland	465229	*462998*[b]	356462	-23	-23
Portugal	38686	43281	38225	-1	-12

[a] Hungary average emission for 1985-1987

[b] Bulgaria and Poland emissions for 1988

In Table 3.5 carbon dioxide emissions from industrial processes of national communications and EDGAR are compared for countries with large differences.

Table 3.5. Comparison of CO_2 emissions in Gg in 1990 from industrial processes in countries with large differences. (Source EDGAR 2.0 and First and Second National Communications (NC1 and NC2).

Emission estimate 1990	NC1	NC2	EDGAR	EDGAR-NC1	EDGAR-NC2
	1990	1990	1990	Difference (%)	Difference (%)
Bulgaria	5680	*5890*[a]	2349	-59	-60
Greece	5890	7398	6552	11	-11
Hungary	3568	*3587*[b]	1951	-45	-46
Iceland	391	391	57	-85	-85
Luxembourg	585	585	317	-46	-46
Netherlands	1900	1850	1836	-3	-1
Norway	6514	6514	628	-90	-90
Poland	13599	*13574*[a]	6243	-54	-54
Portugal	3462	3421	3584	4	5

[a] Bulgaria and Poland emissions for 1988

[b] Hungary average emission for 1985-1987

3.1.2 Analysis of differences in carbon dioxide emissions

Base years

The differences for Bulgaria, Hungary and Poland in total CO_2 emissions are partly explained by the different base years (the differences with the NC1, which have the same reference year are about half of the emissions for Bulgaria and Hungary). Hungary took the average of 1985-1987 and Bulgaria and Poland used 1988. The emissions in those base years were higher because the economic collapse in these countries occurred after 1988. For Poland, however, this is not a relevant factor.

Origin of the activity data

The 1990 emission based on the reported national inventory in NC1 is given for comparison with EDGAR. The difference is partly explained by the fact that EDGAR energy data are based on IEA data. The IEA uses essentially national data provided by OECD countries to fit in their energy statistics database, whereas for non-OECD countries IEA uses information from country statistics provided by the UN Statistical Office combined with other data sources (OECD/IEA, 1998). In the case of Poland IEA statistics in terms of TJ appear to differ substantially from national energy statistics. This could be due to other conversion factors used for converting from physical units to energy units, in particular of coal. Possibly, also national estimates for the carbon content, notably of coal, differ from the IPCC defaults.

Sector definitions
In the process of dealing with statistics some categories may be defined and used differently by IEA. For example, energy use for electric power and industry are included in categories that differ from the national data. This applies especially to combined heat and power (CHP or 'cogeneration') and other energy transformation sectors. In national statistics CHP may be added to the industry sector by which it is operated unless the (public) power companies own the installation. Additional allocation questions rise when the CHP facility is a joint-venture of public utilities and private industry. Furthermore, differences occur when energy used for transformation of coal to coke and coke-oven gas, and coke to blast furnace gas, is treated differently in IEA and national statistics.

Netherlands: stored carbon
Another factor leading to differences is that in some countries the amount of carbon stored in products from fossil feedstock, like natural gas for plastic production, has been estimated to be lower than the EDGAR 2.0 (IPCC) defaults. The difference for the Netherlands can for example be totally explained by this low storage estimate in the National Communications. In the *update* of the Second National Communication of the Netherlands (VROM, 1998) the estimate of the stored carbon fraction in plastics and other products increased from 45% to 85%. The stored carbon fractions appear in general to be very uncertain or country-specific. The updated figures for the Netherlands had not yet been incorporated in the second compilation and synthesis document for COP4 in Buenos Aires (FCCC/CP/1998/11/Add.2) used for the comparison in this report.

Greece
The difference in the total estimate for carbon dioxide emissions for Greece can be explained by a large difference in the estimate for carbon dioxide from combustion (Table 3.4) but also by a larger estimate for CO_2 from industrial processes and CO_2 in agriculture in the second National Communication of Greece (Table 3.5). The activity data are different.

Norway
The difference between national inventories for Norway and EDGAR estimates can be partly explained by the fact that EDGAR used a high estimate for fugitive CO_2 emissions based on information on CO_2 rich natural gas. The estimates for carbon dioxide from combustion for Norway are closer to each other, with a difference of 5% (see Table 3.4). Process emissions in EDGAR are only 10% of the national estimate. Apparently many non-cement clinker processes accounted for in Norway's national inventory are not represented in EDGAR V2.0 (or a high fraction of clinker produced is exported, and so cannot be observed from cement production statistics).

Iceland
The difference between the national inventory and the EDGAR estimate for Iceland is explained by the fact that Iceland estimated an emission in industrial processes of 391 Gg versus 57 Gg in EDGAR. EDGAR obviously missed some activity (non-cement clinker processes).

Hungary
The difference for Hungary is partly explained by a higher estimate for carbon dioxide from combustion and partly by a higher estimate for carbon dioxide from industrial processes. EDGAR underestimated the industrial activity (see also Norway for remarks).

3.1.3 Conclusions on carbon dioxide

Differences between NC1 and NC2 are explained by updated estimates from improved methodology. For some European countries differences between national reports and EDGAR estimates are also caused by the use of different base years. For EDGAR estimates of carbon dioxide emissions to become comparable – for instance within 5% - to country emissions, the IEA energy data for many countries (including conversion factors) as well as country-specific emission factors need a thorough evaluation. The activity data for industrial processes in EDGAR also need improvement for some countries. Clearer definitions are needed for the allocation of emissions from combined heat and power. Should CHP be reported within industry or within power generation? The confusion about allocation to process emissions or combustion emissions of coking coal use in the iron and steel industry should be dealt with in order to make national inventories comparable at the sector level.

3.2 Comparison for methane

IPCC estimates for methane
A short description of total global emissions will be given in Table 3.6, followed by methodologies in IPCC and EDGAR and in the national inventories.

The main anthropogenic sources for methane emissions are:
- Ventilation of coal mines
- Leaks in the oil and gas production, transmission and distribution systems
- Venting from oil and gas production sites
- Combustion of fossil fuels
- Biomass burning
- Enteric fermentation (methane formation in ruminants, mainly cattle)
- Animal manure management
- Rice paddies
- Agricultural waste-burning in the fields
- Savanna burning
- Waste treatment (solid waste disposal on land and waste water treatment).

The main sink for methane is destruction in the atmosphere by OH radicals. A minor sink is consumption by methanotrophic bacteria in soils. Natural methane is formed by anaerobic methanogenic bacteria in wetlands, by termites and from natural seepage from oil and gas fields or methane hydrates from the bottom of the oceans where the right temperature and pressure conditions are found.

In Table 3.6 global totals of EDGAR are compared with IPCC estimates for these methane sources. For all sources the EDGAR emission estimates are lower than the IPCC estimates but still within the ranges given by IPCC (1994). If the EDGAR estimates for biomass burning, agricultural waste-burning, savannah burning and land use change are aggregated, the total is closer to the IPCC estimate for biomass burning.

The IPCC methodology for estimating national methane emissions is too detailed to describe here. It is documented in the *1995 IPCC Guidelines* and in the *Revised 1996 IPCC Guidelines* (IPCC/OECD/IEA, 1995, 1997). The *IPCC Guidelines* are used in compiling the first national communications. The *Revised 1996 IPCC Guidelines* are used in the second national communications. The methodology of IPCC is based on experimental research to find emission factors for all these sources. Measurement results are translated to the national level by up-scaling. Uncertainties are large in methane emission estimates because of the natural variability in space and time. Improvements in emission estimates can be expected as more detailed deterministic models are developed. In these kind of models methane formation is explained from variables like soil type, temperature, moisture and oxygen content.

Table 3.6 Total global methane emissions in Tg CH_4 per year for 1990, comparison of EDGAR and IPCC 1994

World 1990	EDGAR	IPCC	IPCC Range	EDGAR share
Sources				
Anthropogenic				
Fossil fuel combustion	5	10	1-30	0.47
Biomass burning	38	40	20-80	0.35
- Biofuel use	14			
- Agricultural waste burning	6			
- Savanna burning	12			
- Land use change	6			
Fugitive coal	38	30	15-45	1.27
Fugitive oil & gas	52	55		0.94
- Fugitive oil		15	5-30	
- Fugitive gas		40	25-50	
Industry	1			
Solvents	0			
Enteric fermentation	79	85	65-100	0.92
Manure	14	25	20-30	0.56
Rice	60	60	20-100	1.00
Soils	0			
Waste		65		
Landfills	36	40	20-70	0.89
Domestic sewage		25	15-80	
Total	**320**	**375**	**300-450**	**0.85**
Natural				
Wetlands	115	115	55-150	1.00
Termites	20	20	10-50	1.00
Oceans	10	10	5-50	1.00
Other	15	15	10-40	1.00
Total	**480**	**535**	**410-660**	**0.90**
Sinks				
Tropospheric OH		440	360-530	
Stratosphere		40	32-48	
Soils		30	15-45	
Atmospheric increase		**37**	**35-40**	

EDGAR methodology for methane

Fossil fuel

Fossil fuel use comprises production, transformation (i.e. production of secondary fuels such as coke and oil products) and combustion of fossil fuels. Process (i.e. non-combustion) emissions from coke ovens and refineries are also included here. The construction of the EDGAR energy production and consumption data sets is based on IEA statistics. For coal production, the 1990 data has been split into underground and surface mining, applying separate country specific assumptions to hard coal and brown coal. More details can be found in a description of EDGAR by Olivier et al. (1996; 1999). EDGAR data for fossil fuel, biofuel and industrial processes will be incorporated into version 1 of the Global Emissions Inventory Activity (GEIA) for methane.

Emission factors for fossil fuel production, transmission and handling

- Coal production

  The emission factors used in EDGAR to estimate CH_4 emissions from brown coal and hard coal mining have been taken from a literature study by Smith and Sloss (1992). When specified, emission factors for a given country, type of coal and mining depth were applied; in all other cases global default values given in this reference were used. The emission factors used in Version 2.0 are listed in Table 3.7.

- Crude oil production
  For crude oil production, the emission factors for CH_4 have been calculated from emission estimates by Little (1989), which is the same reference as used in the IPCC Tier 1 defaults (IPCC/OECD/IEA, 1997). The emissions have a geographical distribution according to the Oil and Gas Journal energy database (OGJ, 1991).
- Crude oil loading into marine tankers
  A minor part of the total crude oil production emission comprises emissions from oil loading into marine tankers. The magnitude of this part has been estimated with emission factors for oil loading taken from OLF (1993). The crude oil loading emissions have been distributed according to an inventory of oil loading facilities in OGJ (1989), International Petroleum Encyclopaedia. For this emission source category the general crude oil production profile has been assumed.
- Natural gas production and natural gas transport.
  The CH_4 emission factors for natural gas production and transport have been taken from Ebert et al. (1993), the same as the IPCC Tier 1 defaults.
- Crude oil refining and storage at refinery site.
  The emission factors for petroleum refining for CH_4, have been proposed by Veldt and Berdowski for the LOTOS database at TNO-MEP, Delft (Builtjes, 1992). These emission factors, expressed per unit of crude oil processed, account for all combustion and fugitive emissions occurring at the refinery site.

Table 3.7 Emission factors for methane emissions from underground and surface coal production in 1990 as used in EDGAR 2.0 (g CH_4/GJ coal) (Source: Olivier et al., 1996; 1999)

Hard coal Underground	E.F.	Hard coal Surface	E.F.	Brown coal Underground	E.F.	Brown coal Surface	E.F.
World	*835*	*World*	*77*	*World*	*24*	*World*	*24*
USA	815	USA	75	Afghanistan	39	Afghanistan	39
Former Czechoslov.	785	Australia	60	Romania	39	Brazil	39
Germany	675	UK	15	Vietnam	39	Colombia	39
Hungary	585			Australia	0.26	Former Czechoslov.	39
Poland	585			Thailand	0.26	Norway	39
Romania	585					Philippines	39
Former USSR	585					Portugal	39
UK	455					Romania	39
Australia	335					Vietnam	39
South Africa	270					Australia	0.26
China	325					Germany	0.26
Rest of World	325					Algeria	0.26
						Spain	0.26
						UK	0.26
						Ireland	0.26

For fossil fuel combustion a subdivision was made for industrial fuel use, fuel use for utilities and residential fuel use; each category and detailed fuel type has its own emission factor. EDGAR emission factors are taken from the LOTOS database on air pollution (Builtjes, 1992), which are assumed to be globally applicable. The reference for the emission profile for coke production is a report by Veldt (1994). For road transport and the evaporation of gasoline from automobiles the emission factors for CH_4 have been taken from Samaras (1991). The emission factor for CH_4 in air transport has been taken from Olivier (1995), in which the factor for methane had been derived from the total volatile organic carbons emission factor for the landing and take off cycle of aircraft and a percentage of 10% in total VOC emissions in the LTO cycle. For aircraft engines above 1 km methane emissions are assumed to be negligible. These emission factors represent the global aggregate of all air traffic, including military aircraft and general aviation. Aggregated emission factors applied only to scheduled civil air traffic may differ 10 to 50% from the global average. All other means of transport have been regarded as small industrial combustion units for which the appropriate emission factors have been taken from a database

(Builtjes, 1992). Olivier *et al.* (1996; 1999) show the calculated globally and regionally aggregated emission factors for fossil fuel combustion, both per main sector and fuel type. Again, we stress that the uncertainty in emission factors may be considerable (see Table 3.1).

Biofuel combustion

The total biofuel use estimates in Petajoules per fuel type per country are from Hall et al. (1994). The methane emission factors for biofuels are from Veldt and Berdowski (1995). For the USA, the emission estimates from the US-EPA inventory for biofuel combustion have been converted into the EDGAR processes and entered directly into the EDGAR database.

Table 3.8: EDGAR emission factors for CH_4 from industrial processes in 1990 (Source: Olivier et al., 1996; 1999)

Sector/product	Emission factor	Unit	Region	Reference
Ethene (ethylene)	247.5	g CH_4-C/ton	World	Builtjes, 1992 (LOTOS)
Styrene	22.5	g CH_4-C/ton	World	Builtjes, 1992 (LOTOS)
Coke production	13.171	kg CH_4-C/TJ	World	Builtjes, 1992 (LOTOS)
Sinter production	375.0	g CH_4-C/ton	World	Builtjes, 1992 (LOTOS)
Pig iron production (blast furnace)	675.0	g CH_4-C/ton	World	Builtjes, 1992 (LOTOS)

Industrial processes

For all countries, the default emission factors for CH_4 from industry from the LOTOS database have been used in EDGAR V2.0 (Builtjes, 1992) (see Table 3.8)

Land use and waste treatment

Land use and waste treatment sources in EDGAR include rice paddies (CH_4), fertiliser use (N_2O), animals (CH_4 and N_2O), biomass burning (all gases), agricultural waste burning and landfills (CH_4). Waste water and sewage treatment, which are considered to be sources of methane, are not included because to date no representative spatial emission estimates exist. Rice production levels and the area of arable land per country were taken from FAO (1991), combined with country-specific corrections for all arable land grid cells. For emissions from animals we used animal populations per country from FAO (1996), except for caribous which were defined as numbers per grid cell (Lerner et al., 1988). For agricultural waste burning in EDGAR we used estimates of carbon released per grid cell based on regional estimates of Andreae (1991) combined with the distribution of arable land according to Olson et al. (1983). More details on agricultural waste burning can be found in Bouwman et al. (1995). The landfilled amounts of waste are based on country-specific estimates of per capita waste production and the fraction of waste which is disposed of by landfilling as specified for the 13 regions in RIVM's climate model IMAGE 2 with data from the Stockholm Environment Institute (Subak et al., 1992) as described in Kreileman and Bouwman (1994). For rice cultivation the emission factor for CH_4 was taken from Kreileman and Bouwman (1994). Emission factors for landfills were derived from Subak et al. (1992). Factors for methane from enteric fermentation by ruminants were taken from Gibbs and Leng (1993). For biomass burning and agricultural waste burning, the CH_4 emission factors have been taken from Veldt and Berdowski (1995). The uncertainty of many methane sources is rather large, as indicated in Table 3.1.

3.2.1. Differences between national communications and EDGAR for methane

In the Tables 3.9 to 3.19 overviews are given for large world regions, for which regional totals are calculated from EDGAR V2.0 and from national reports. Later differences will be presented by country (Tables 3.20 to 3.45). In Table 3.9 in the first column the sources are listed. The fourth column gives the regional total according to EDGAR V2.0. However, since not all countries have reported officially, the country estimates from EDGAR 2.0 are aggregated in the fifth column that is comparable to the set of national reports available.

Table 3.9 Comparison of methane emissions in Gg/yr of CH_4 in 1990 for the European Union 15; comparison of EDGAR and national reports (NC1 and NC2) for the European Union with 15 members.

European Union 15	First National Communication	Second National Communication	EDGAR Total	EDGAR Comparable[1]	EDGAR-NC1 (%)	EDGAR-NC2 (%)
Fossil fuels	734		620	620		
Biomass burning	86		55	55		
Total Combustion	820	809	675	675	-18	-17
Fugitive coal	2854		3586	3586		
Fugitive oil & gas	1499		1139	1139		
Total Fugitive	4353	4497	4725	4725	8	5
Industry	23		151	151		
Solvents	0		0	0		
Enteric fermentation	6732		6996	6996		
Manure	2626		3070	3070		
Rice	102		169	169		
Soils	299		0	0		
Agr waste burning	0		0	0		
Savannah burning	146		967	967		
Total Agriculture	9906	9522	11181	11181	13	17
Land use change	14		0	0		
Total Waste	8054	7801	6101	6101	-24	-22
Total	23169	23076	22854	22854	-2	-1

[1] Comparable: only the countries included in the total of available national reports.

There is no difference between the fourth and fifth column in this table because the set of countries is the same in EDGAR and National Communications. Therefore the regional totals comprise all fifteen member states of the European Union 15. For the other regions, the aggregate of national communications is a subset of all existing countries in a region. More countries in the future will report their emission estimates. Then complete comparisons will be possible for the non-EU countries as well. In Table 3.9 the second column with the estimates from the first national communications has more detail because a detailed database from the UNFCCC secretariat could be used. For the Second National Communications at the time of analysis this was not possible. Instead, the more aggregated data tables from the compilation and synthesis report of the UNFCCC Secretariat were used (UNFCCC/CP/1998/11/Add.2).

In Table 3.9 it can be seen that for the 15 European Union countries the difference in the total is low (1-2%). This low difference, however, is a net effect, since differences for the different sectors can be large (>10%).

Table 3.10 Methane emissions in Gg/yr of CH_4 in 1990 for the Rest of OECD Europe (i.e. minus EU15); comparison of EDGAR and national reports for the rest of OECD Europe.

Rest OECD Europe	First National Communication	Second National Communication	EDGAR Total	EDGAR Comparable[1]	EDGAR -NC1 (%)	EDGAR -NC2 (%)
Fossil fuels	22	25	60	10	-58	-60
Biomass burning	3		129	2		
Fugitive coal	5		100	0		
Fugitive oil & gas	23	36	95	79	172	119
Industry	1		32	0		
Solvents	0		0	0		
Enteric fermentation	224		939	229		
Manure	93		174	88		
Rice	0		21	0		
Soils	25		0	0		
Agr waste burning	0		0	0		
Savannah burning	0		383	14		
Agriculture	342	254	1517	320	-6	26
Land use change	0		0	0		
Waste	247	373	724	187	-24	-50
Total	643	690	2655	609	-6	-12

In Table 3.10 the sector aggregates are given from the rest of OECD Europe consisting here of Iceland, Norway and Switzerland. The EDGAR total is different from the total of national communications because EDGAR estimates for Turkey were included. Differences are still large (>10%) if Turkey is excluded in the fifth column.

Table 3.11 Methane emissions in Gg/yr of CH_4 in 1990; comparison of EDGAR and national reports for Eastern Europe and the former Soviet Union.

Eastern Europe + former USSR	First National Communication	Second National Communication	EDGAR Total	EDGAR Comparable	EDGAR-NC1	EDGAR -NC2
	Gg/yr.	Gg/yr	Gg/yr.	Gg/yr.	%	%
Fossil fuels	102	448	1283	1281	1155	186
Biomass burning	23		36	35		
Fugitive coal	6495		8924	8924		
Fugitive oil & gas	21686		27402	27394		
Fugitive	28181	27852	36326	36318	29	30
Industry	6		218	218		
Solvents	0		0	0		
Enteric fermentation	6278		11420	11357		
Manure	350		2540	2527		
Rice	186		311	310		
Soils	0		0	0		
Agricultural waste burning	0		0	0		
Savannah burning	3		1376	1373		
Agriculture	6916	9479	15647	15567	125	64
Land use change	8		0	0		
Waste	4572	5346	4573	4534	-1	-15
Total	39709	43313	58083	57952	46	34

In Table 3.11 the comparison of EDGAR with national estimates for Eastern Europe and the former Soviet Union is hampered by the fact that in EDGAR some newly formed states are missing. So EDGAR estimates of total Eastern Europe and the former Soviet Union are compared with only that part reported to the Climate Convention, causing large differences to occur.

In Table 3.12 the difference between EDGAR estimates and national estimates for the United States and Canada is mainly caused by differences in fugitive methane emissions from coal and oil and gas. For agriculture and fossil fuels also differences were found, but these were smaller in absolute terms than the differences in fugitive methane emissions.

Table 3.12 Methane emissions in Gg/yr of CH_4 in 1990; comparison of EDGAR and national reports for OECD-North America.

OECD-North America	First National Communication	Second National Communication	EDGAR Total	EDGAR Comparable	EDGAR -NC1	EDGAR -NC2
	Gg/yr.	Gg/yr	Gg/yr.	Gg/yr.	%	%
Fossil fuels	655	1003	555	555	-15	-45
Biomass burning	772		395	395		
Fugitive coal	4491		12217	12217		
Fugitive oil & gas	4472		10804	10804		
Fugitive	8963	11293	23021	23021	157	104
Industry	0		65	65		
Solvents	0		0	0		
Enteric fermentation	6460		6353	6353		
Manure	2520		2289	2289		
Rice	429		520	520		
Soils	0		0	0		
Agr waste burning	0		0	0		
Savannah burning	79		1230	1230		
Agriculture	9488	9648	10392	10392	10	8
Land use change	38		0	0		
Waste	10945	10811	11053	11053	1	2
Total	30861	32778	45482	45482	47	39

Table 3.13 Methane emissions in Gg/yr of CH_4 in 1990; comparison of EDGAR and national reports for OECD-Pacific.

OECD-Pacific	First National Communication	Second National Communication	EDGAR Total	EDGAR Comparable	EDGAR -NC1	EDGAR -NC2
	Gg/yr.	Gg/yr	Gg/yr.	Gg/yr.	%	%
Fossil fuels	59	236	137	136	130	-42
Biomass burning	2		25	15		
Fugitive coal	854		1123	1123		
Fugitive oil & gas	296		765	765		
Fugitive	1150	1241	1888	1888	64	52
Industry	25		130	130		
Solvents	0		0	0		
Enteric fermentation	4768		3159	3132		
Manure	271		773	759		
Rice	271		997	991		
Soils	0		0	0		
Agr waste burning	370		0	0		
Savannah burning	22		172	172		
Agriculture	5702	5579	5101	5054	-11	-9
Land use change	379		0	0		
Waste	2294	1256	1754	1653	-28	32
Total	9611	8421	9034	8875	-8	5

In Table 3.13 for the OECD-Pacific, the main differences between EDGAR methane estimates and national communications are in coal mine emissions and enteric fermentation, manure, rice and waste emissions. Here OECD-Pacific countries are Australia, New Zealand and Japan. In the EDGAR total column other island states in the Pacific are also included, but are almost negligible (<2% in the total).

Table 3.14 Methane emissions in Gg/yr of CH_4 in 1990; comparison of EDGAR and national reports for Latin America.

Latin America	National Reports	EDGAR Total	EDGAR Comparable	Difference EDGAR-NR	Difference
	Gg/yr.	Gg/yr.	Gg/yr.	Gg/yr	%
Fossil fuels	260	126	59	-201	-77
Biomass burning	75	1077	354	279	372
Fugitive coal	73	417	151	78	107
Fugitive oil & gas	2820	2279	1518	-1302	-46
Industry	0	38	4	4	
Solvents	0	0	0	0	0
Enteric fermentation	3523	17537	3239	-284	-8
Manure	109	858	215	106	97
Rice	267	2398	225	-42	-16
Soils	0	0	0	0	0
Agr waste burning	238	1384	135	-103	-43
Savannah burning	16	1022	236	220	1375
Land use change	921	2617	794	-127	-14
Waste	908	2683	840	-68	-7
Total	9210	32436	7770	-1440	-16

In Table 3.14 for Latin America, the main difference in estimates for methane emissions are in fugitive oil & gas. Smaller but still significant differences can be found in many other sectors. Many countries in Latin America have not yet compiled official emission inventories, hence the large differences in the columns "EDGAR total" and "EDGAR comparable".

Table 3.15 Methane emissions in Gg/yr of CH_4 in 1990; comparison of EDGAR and national reports for Africa.

Africa	National Reports	EDGAR Total	EDGAR Comparable	Difference EDGAR-NR	Difference
	Gg/yr.		Gg/yr.	Gg/yr	%
Fossil fuels	594	81	64	-530	-89
Biomass burning	1374	3769	2062	688	50
Fugitive coal	1440	1324	1316	-124	-9
Fugitive oil & gas	217	1590	853	636	293
Industry	0	7	7	7	
Solvents	0	0	0	0	
Enteric fermentation	3275	9014	4239	964	29
Manure	301	393	178	-123	-41
Rice	854	1409	567	-287	-34
Soils	0	0	0	0	
Agr waste burning	1822	4293	1267	-555	-30
Savannah burning	349	1090	645	296	85
Land use change	221	1728	671	450	204
Waste	2562	1724	924	-1638	-64
Total	13009	26422	12794	-216	-2

In Table 3.15 for African countries, the main differences in methane emission estimates between EDGAR and national reports are found in biofuel burning, fugitive oil and gas, enteric fermentation, agricultural waste-burning and in solid waste disposal on land. Differences cancel each other out. The overall difference, as a result, is only 2%. The largest countries with emission inventories considered in this comparison with EDGAR are: Algeria, Morocco, Nigeria, South Africa, Tanzania, and Zimbabwe.

Table 3.16 Methane emissions in Gg/yr of CH_4 in 1990; comparison of EDGAR and national reports for the India region.

India region	National Reports	EDGAR Total	EDGAR Comparable	Difference EDGAR-NR	Difference
	Gg/yr.		Gg/yr.	Gg/yr	%
Fossil fuels	0	68	1	1	
Biomass burning	0	4021	312	312	
Fugitive coal	0	865	0	0	
Fugitive oil & gas	6	479	50	44	733
Industry	0	17	0	0	
Solvents	0	0	0	0	
Enteric fermentation	453	13547	806	353	78
Manure	0	1100	76	76	
Rice	439	24627	4131	3692	841
Soils	0	0	0	0	
Agr waste burning	0	23	0	0	
Savannah burning	0	2821	121	121	
Land use change	0	403	6	6	
Waste	76	1966	194	118	155
Total	974	49938	5696	4723	485

In Table 3.16 for the India region (India, Pakistan, Bangladesh, Sri Lanka), only Bangladesh estimates were available, taken from Braatz et al. (1996). Later we identified a report on India by Mitra and Battacharya (1998). This report was not included in the analysis. The main difference in Table 3.16 is in the rice estimate. EDGAR reported rice emissions for Bangladesh that were more than eight times higher, which may be due to the specific rice cultivation conditions, different from India. India rice conditions dominate the regional characterisation in EDGAR 2.0.

Table 3.17 Methane emissions in Gg/yr of CH_4 in 1990; comparison of EDGAR and national reports for the China region.

China region	National Reports	EDGAR Total	EDGAR Comparable	Difference EDGAR-NR	Difference
	Gg/yr.		Gg/yr.	Gg/yr	%
Fossil fuels	73	1552	1531	1458	1997
Biomass burning	2686	2776	2398	-288	-11
Fugitive coal	10656	9176	9057	-1599	-15
Fugitive oil & gas	387	644	635	248	64
Industry	0	106	100	100	
Solvents	0	0	0	0	
Enteric fermentation	5850	7125	6529	679	12
Manure	2850	2099	1986	-864	-30
Rice	11800	18922	14869	3069	26
Soils	0	0	0	0	
Agr waste burning	0	48	11	11	
Savannah burning	0	1461	1291	1291	
Land use change	0	252	67	67	
Waste	14	2571	2351	2337	16693
Total	34316	46732	40824	6509	19

In Table 3.17 for the China region (China, Mongolia, Vietnam, Kampuchea, Laos, North Korea) the main differences in methane emission estimates are for fossil fuel burning, coal mine ventilation, rice, savannah burning and waste. EDGAR 2.0 estimated lower methane emissions for biomass burning, coal mines and manure. The estimates in the other sectors were higher. In this table estimates from China and Mongolia are aggregated. Other countries in the region have not yet reported emission inventories.

Table 3.18 Methane emissions in Gg/yr of CH_4 in 1990; comparison of EDGAR and national reports for East Asia (Here only Philippines and Thailand)

East Asia	National Reports	EDGAR Total	EDGAR Comparable	Difference EDGAR-NR	Difference
	Gg/yr.		Gg/yr.	Gg/yr	%
Fossil fuels	12	188	16	4	33
Biomass burning	240	1600	321	81	34
Fugitive coal	7	194	11	4	57
Fugitive oil & gas	1	2091	71	70	7000
Industry	0	28	2	2	
Solvents	0	0	0	0	
Enteric fermentation	732	1288	609	-123	-17
Manure	109	564	195	86	79
Rice	6657	10037	5134	-1523	-23
Soils	0	0	0	0	
Agr waste burning	0	55	12	12	
Savannah burning	48	780	397	349	727
Land use change	223	570	172	-51	-23
Waste	0	1144	364	364	
Total	8029	18540	7306	-725	-9

In Table 3.18 for East Asia, the methane emission estimates in EDGAR 2.0 are lower than in national reports for enteric fermentation, rice and land use change. The most important difference is in methane emissions from rice cultivation, but these are still within the estimated uncertainty ranges as given in Table 3.1. Estimates from the Philippines and Thailand taken from Braatz et al. (1996) are aggregated in the second column (national reports) in this table. Other countries in the region were not yet included because of a lack of reports.

Table 3.19 Summary of methane emissions in Tg per year from different regions in 1990; comparison of EDGAR and national reports (National Communications and country studies).

	First National Reports	Second National Reports (when available)	EDGAR 2.0 Comparable
Annex I countries	**103.9**	**108.3**	**137.8**
of which:			
• European Union 15	23.2	23.1	22.8
• Other OECD-Europe	0.6	0.7	2.6
• Eastern Europe and former USSR	39.7	43.3	58
• OECD-North America	30.9	32.8	45.5
• OECD-Pacific	9.6	8.4	8.9
Non Annex I countries	**65.5**	**84.2**	**110.4**
if which:			
• Latin America	9.2	9.2	7.8
• Africa	13	13	12.8
• India region	1	19.6	41.7
• China region	34.3	34.3	40.8
• East Asia	8.0	8	7.3
Total of country reports	**169.5**	**192.5**	**248.2**
World			**320**

In Table 3.19 only a partial comparison was possible. The EDGAR comparable estimates for countries from a region are aggregated. The aggregated national reports represent subsets of countries from a region, because of lack of reports. From Table 3.19 it is clear that many

Non Annex I countries have not yet reported. About half of the IPCC (1994) estimate for anthropogenic emissions is covered in the second National Reports. The comparable EDGAR estimate of 248.2 is lower than the IPCC (1994) estimates for anthropogenic methane emissions (375 Tg).

Table 3.20 Methane emissions in Gg in 1990 for Annex-1 countries; comparison of EDGAR 2.0 with First and Second National Communications (NC1 and NC2).

	NC1	NC2	EDGAR	EDGAR-NC1	EDGAR-NC2
	Gg	Gg	Gg	difference	Difference
	1990	1990	1990	%	%
Australia	6243	5140	4476	-28	-13
Austria	603	587	452	-25	-23
Belgium		634	599		-6
Bulgaria	1370	1413	515	-62	-64
Canada	3088	3200	3851	25	20
Czech Republic	942	888			
Denmark	407	421	407	0	-3
Estonia	323	105			
Finland	252	246	264	5	7
France	2896	3017	3757	30	25
Germany	5682	5682	6136	8	8
Greece	343	443	426	24	-4
Hungary	545	664	708	30	7
Iceland	23	14	19	-17	36
Ireland	796	811	657	-17	-19
Italy	3901	2329	2388	-39	3
Japan	1382	1575	3336	141	112
Latvia	159	186			
Lithuania		378			
Luxembourg	24	24			
Monaco					
Netherlands	1060	1104	1002	-5	-9
New Zealand	1986	1706	1032	-48	-40
Norway	290	432	265	-9	-39
Poland	6100	3141	4619	-24	47
Portugal	226	809	421	86	-48
Slovakia	347	409			
Slovenia		176			
Spain	2151	2181	2027	-6	-7
Sweden	329	324	364	11	12
Switzerland	332	244	313	-6	28
Ukraine		9453			
United Kingdom	4531	4464	3868	-15	-13
United States	27000	29578	41512	54	40
Russian Federation	27000	26500			

3.2.1.1 Comparison by country versus EDGAR 2.0

In this section methane emission estimates are compared for the national level. In Table 3.20 the national total methane emissions from industrialised countries (as listed in Annex 1 to the Climate

Convention) are given according to the first and second National Communications (NC1 and NC2) and according to EDGAR. In the second national communications (NC2) some countries used improved methodology, leading to new estimates. When EDGAR is compared to NC2 estimates, large differences (>10%) are found for Australia, Austria, Bulgaria, Canada, France, Iceland, Ireland, Japan, New Zealand, Norway, Poland, Portugal, Sweden, Switzerland, United Kingdom, and the United States. For Hungary and Italy the difference between NC2 and EDGAR has decreased to less than 10% with the updated figure in the NC2. For Norway and Switzerland on the other hand, the difference between NC2 and EDGAR has increased to more than 10% with the updated NC2 estimate.

In Table 3.21 the methane emission estimates of some Non-Annex-I countries are given. Since these countries have not yet officially reported emission inventories through National Communications, EDGAR 2.0 cannot be compared with official country data for the Climate Convention. Instead, estimates are taken from Braatz et al. (1996) and from Mitra and Bhattacharya (1998) for India. Countries, where national estimates differ by more than 25% with EDGAR 2.0 estimates are Algeria, Bangladesh, Bolivia, Botswana, Ethiopia, India, Peru, Philippines, Thailand, Uganda, Venezuela and Zimbabwe.

Table 3.21 Total methane emissions in Gg/yr for 1990 for a selection of Non-Annex 1 countries; comparison of EDGAR 2.0 with data from Braatz et al. (1996) and Mitra and Battacharya (1998) for India.

	Country	EDGAR	Difference
	1990	1990	1990
	Gg	Gg	%
Latin-America			
Bolivia	600	757	26
Costa Rica	164	168	2
Mexico	3894	4192	8
Peru	1374	835	-39
Venezuela	3178	1818	-43
Africa			
Algeria	1370	757	-45
Botswana	537	366	-32
Cameroon	461	514	11
Cote d'Ivoire	717	586	-18
Ethiopia	1491	2003	34
Gambia	32	26	-19
Ghana	1078	347	-68
Morocco	443	378	-15
Nigeria	2692	3264	21
Senegal	306	258	-16
South Africa	2837	2334	-18
Tanzania	1303	1349	4
Uganda	1277	484	-62
Zimbabwe	381	501	31
Asia			
Bangladesh	974	5696	485
China	34287	40472	18
India	18672	35969	93
Mongolia	330	352	7
Philippines	1027	2241	118
Thailand	7002	5065	-28

In the following sections the differences are analysed for some important aggregated methane sources: fugitive fuel, agriculture and waste.

3.2.1.2 Methane from fugitive fuel emissions

Table 3.22 gives fugitive methane, (mainly from coal, oil and gas) levels for Annex-I countries. Differences between national communications and EDGAR 2.0 can be very high, even when the large uncertainty estimate for these sources is considered, in particular for oil and gas. Some are even increasing with updates in methodology, as can be seen in the difference EDGAR-NC1 compared with EDGAR-NC2. The EDGAR 2.0 estimates for Annex I countries are higher than the national estimates, with some exceptions.

Table 3.22 Methane from coal, oil and gas in Gg/yr for 1990 for Annex-1 countries; NC1 and NC2 compared with EDGAR 2.0

	NC1	NC2	EDGAR	EDGAR-NC1	EDGAR-NC2
	Gg	Gg	Gg	Difference	Difference
	1990	1990	1990	%	%
Australia	1026	1050	1140	11	9
Austria	92	4	21	-77	425
Belgium		53	57		8
Bulgaria	249	315	116	-53	-63
Canada	1322	1400	1622	23	16
Czech Republic	531	460	862	62	87
Denmark	11	12	12	9	0
Estonia	217				
Finland			9		
France	311	332	395	27	19
Germany	1549	1563	2260	46	45
Greece	39	44	2	-95	-95
Hungary	366	448	289	-21	-35
Iceland					
Ireland	10	10	20	100	100
Italy	348	309	163	-53	-47
Japan	100	166	672	572	305
Latvia	2	53			
Lithuania		26			
Luxembourg	2	2			
Monaco					
Netherlands	149	179	148	-1	-17
New Zealand	24	25	75	213	200
Norway	14	21	73	421	248
Poland	1222	1248	2895	137	132
Portugal	2	4	1	-50	-75
Slovakia	96	122			
Slovenia		51			
Spain	695	687	249	-64	-64
Sweden			4		
Switzerland	15	15	6	-60	-60
Ukraine		6229			
United Kingdom	1238	1298	1383	12	7
United States	7641	9893	21399	180	116
Russian Federation	19600	18900	31010	58	64

Table 3.23 gives fugitive methane emissions from coal, and from oil and gas, for some Non- Annex-I countries. Estimates taken from Braatz et al. (1996) are compared to EDGAR 2.0 (Olivier, 1996) estimates. The country with the highest emissions for coal, oil and gas is China, with about 11 Tg CH4/yr according to Braatz et al. EDGAR 2.0 estimated the emissions from coal mines to be 15% lower and the emissions from oil and gas 64% higher than Braatz et al. (1996). Other countries with important methane emissions from oil and gas are Mexico and Venezuela. EDGAR 2.0 estimated the oil and gas emissions to be lower than Braatz et al. (1996) for these countries. Methane emissions from coal mines in South Africa were estimated by EDGAR 13% lower than Braatz et al. (1996).

Table 3.23 Methane emissions in Gg/yr from coal, oil and gas in 1990 for a selection of Non-Annex-1 countries. Estimates from Braatz et al. (1996) compared with estimates EDGAR 2.0.

	Country 1990 Coal	Country 1990 Oil/Gas	EDGAR 1990 Coal	EDGAR 1990 Oil/Gas	Difference 1990 Coal %	Difference 1990 Oil/Gas %
Latin-America						
Bolivia	0	16	0	16	0	0
Costa Rica	0	0	0	0	0	0
Mexico	69	969	145	821	110	-15
Peru	1	12	0	29	-100	142
Venezuela	3	1823	6	651	100	-64
Africa						
Algeria	0	537	1	458	0	-15
Botswana	0	0	0	0	0	0
Cameroon	0	1	0	30	0	2900
Cote d'Ivoire	0	0	0	0	0	0
Ethiopia	0	0	0	0	0	0
Gambia	0	0	0	0	0	0
Ghana	0	0	0	0	0	0
Morocco	0	0	14	1	0	0
Nigeria	0	216	3	363	0	68
Senegal	0	0	0	0	0	0
South Africa	1425	0	1242	1	-13	0
Tanzania	2	0	0	0	-100	0
Uganda	0	0	0	0	0	0
Zimbabwe	13	0	56	0	331	0
Asia						
Bangladesh	0	6	0	50	0	733
China	10647	387	9051	635	-15	64
Mongolia	9	0	6	0	-33	0
Philippines	7	1	7	1	0	0
Thailand	0	0	5	69	100	100

3.2.1.3 Methane from agriculture

In Table 3.24 the methane emission estimates from agriculture in Annex-I countries are compared with EDGAR 2.0 estimates. EDGAR 2.0 estimates are sometimes higher and sometimes lower than those from the countries themselves because EDGAR 2.0 applies regional average emission factors to most agricultural sources. In most cases the same methodology is used. Large differences can occur when using fixed methane emission factors per animal for enteric fermentation, while countries used country-specific factors. Differences in methane from animal manure occur because in EDGAR 2.0 it was not possible to assess the manure management in each country. However, most differences are within 25%, comparing fairly well, with the exception of Finland, France, Japan and New Zealand.

Table 3.24 Methane from agriculture in Gg/yr for 1990 for Annex-1 countries; first and second national communications estimates compared with EDGAR.

	NC1	NC2	EDGAR	EDGAR-NC1	EDGAR-NC2
	Gg	Gg	Gg	Difference	difference
	1990	1990	1990	%	%
Australia	3401	3223	2509	-26	-22
Austria	259	208	277	7	33
Belgium		388	336		-13
Bulgaria	307	307	316	3	3
Canada	892	890	1072	20	20
Czech Republic	195	204			
Denmark	263	329	316	20	-4
Estonia	60	60			
Finland	94	101	158	68	56
France	1649	1627	2326	41	43
Germany	2044	2044	2231	9	9
Greece	175	273	247	41	-10
Hungary	208	208	260	25	25
Iceland	12	12	14	17	17
Ireland	644	640	558	-13	-13
Italy	1860	909	1200	-35	32
Japan	797	843	1747	119	107
Latvia	111	111			
Lithuania		181			
Luxembourg	18	18			
Monaco					
Netherlands	500	505	584	17	16
New Zealand	1513	1513	798	-47	-47
Norway	91	91	118	30	30
Poland	863	863	1093	27	27
Portugal	176	211	243	38	15
Slovakia	172	187			
Slovenia		44			
Spain	887	926	1091	23	18
Sweden	196	200	205	5	2
Switzerland	239	151	188	-21	25
Ukraine		2254			
United Kingdom	1141	1143	1409	23	23
United States	8596	8758	9255	8	6
Russian Federation	5000	5060			

In Table 3.25 EDGAR Version 2.0 methane emission estimates from agriculture are compared with estimates from non-Annex-I countries using estimates from Braatz et al. (1996).

Table 3.25 Methane emissions from agriculture in Gg/yr for 1990 for a selection of Non-Annex-1 countries; comparison of EDGAR V2.0 with data from Braatz et al. (1996).

	Country	EDGAR	Difference
	1990	1990	1990
	Gg	Gg	%
Latin-America			
Bolivia	457	532	16
Costa Rica	126	122	-3
Mexico	1888	2167	15
Peru	721	416	-42
Venezuela	961	814	-15
Africa			
Algeria	0	201	100
Botswana	0	345	100
Cameroon	58	304	424
Cote d'Ivoire	311	301	-3
Ethiopia	1118	1622	45
Gambia	8	20	150
Ghana	42	156	271
Morocco	244	287	18
Nigeria	1527	1417	-7
Senegal	60	209	248
South Africa	853	806	-6
Tanzania	970	902	-7
Uganda	1192	328	-72
Zimbabwe	218	337	55
Asia			
Bangladesh	892	5133	475
China	20500	24352	19
Mongolia	0	334	100
Philippines	681	1715	152
Thailand	6865	4632	-33

There is no clear bias in the differences between estimates from Braatz et al. and EDGAR. The differences are partly due to the regional average emission factors being used in EDGAR V2.0, whereas some regions are very inhomogeneous in this respect. EDGAR 2.0 is either lower or higher than the country estimates. Some obvious gaps appear in this Table 3.25 where countries have not yet made an estimate for methane from agriculture (e.g. Algeria, Botswana, Mongolia) as a whole or from only one or more of the sub-sectors (e.g. Mexico, Cameroon, Senegal).

3.2.1.4 Methane from waste

In Table 3.26 for Annex-I countries methane emission estimates for waste from the national communications are compared with EDGAR 2.0. The main reason for the differences is the use of the

IPCC Tier 1 methodology in EDGAR, which tends to underestimate the emissions if compared to the IPCC Tier 2 method. If the national estimates are similar to the EDGAR 2.0 estimate, then Tier 1 is used in the national communication as well. If countries use the Tier 2 method, the national estimate could be about 40% higher. If national estimates are lower than EDGAR's Tier 1 estimate, we suspect underestimation by the countries, due to the use of a country-specific method.

Table 3.26 Methane from waste in Gg/yr for 1990 for Annex-1 countries; first and second national communications estimates (NC1 and NC2) compared with EDGAR 2.0 (Olivier et al. 1996; 1999).

	NC1	NC2	EDGAR	EDGAR-NC1	EDGAR-NC2
	Gg	Gg	Gg	Difference	Difference
	1990	1990	1990	%	%
Australia	1391	704	777	-44	10
Austria	228	227	129	-43	-43
Belgium		174	173		-1
Bulgaria	856	732	108	-87	-85
Canada	795	840	1093	37	30
Czech Republic	151	149			
Denmark	122	71	86	-30	21
Estonia	42	42			
Finland	139	126	83	-40	-34
France	749	800	941	26	18
Germany	1870	1870	1325	-29	-29
Greece	110	112	168	53	50
Hungary		257	125		-51
Iceland	11	2	4	-64	100
Ireland	136	136	58	-57	-57
Italy	1611	823	961	-40	17
Japan	470	397	721	53	82
Latvia	44	19			
Lithuania		166			
Luxembourg	4	4			
Monaco					
Netherlands	381	379	249	-35	-34
New Zealand	433	155	154	-64	-1
Norway	167	302	71	-57	-76
Poland	906	966	460	-49	-52
Portugal	35	578	171	389	-70
Slovakia	53	65			
Slovenia		76			
Spain	491	491	653	33	33
Sweden	100	85	143	43	68
Switzerland	69	69	112	62	62
Ukraine		934			
United Kingdom	2078	1925	961	-54	-50
United States	10150	9971	9960	-2	0
Russian Federation	2400	1940			

Table 3.27 Methane from waste in Gg/yr for 1990 for a selection of Non-Annex-1 countries; EDGAR V2.0 estimates from Braatz et al. (1996) compared to estimates from EDGAR 2.0 from Olivier et al. (1996; 1999).

	Country	EDGAR	Difference
	1990	1990	1990
	Gg	Gg	%
Latin America			
Bolivia	11	44	300
Costa Rica	21	18	-14
Mexico	526	531	1
Peru	129	129	0
Venezuela	221	118	-47
Africa			
Algeria	679	68	-90
Botswana	1	4	300
Cameroon	30	32	7
Cote d'Ivoire	279	33	-88
Ethiopia	58	135	133
Gambia	7	2	-71
Ghana	54	41	-24
Morocco	142	69	-51
Nigeria	577	297	-49
Senegal	84	20	-76
South Africa	510	97	-81
Tanzania	46	75	63
Uganda	4	51	1175
Zimbabwe	91	27	-70
Asia			
Bangladesh	76	194	155
China	0	2346	100
Mongolia	14	5	-64
Philippines	0	193	100
Thailand	0	172	100

In Table 3.27 the estimates from Braatz et al. (1996) for non-Annex-I countries are compared with estimates taken from EDGAR 2.0 (Olivier et al. 1996; 1999). The most striking difference is found for China. EDGAR assumes a large emission (2346 Gg) while the country estimated no emissions, assuming that all waste is used in small-scale digesters and that the methane released is used for energy. These systems will be leaky. Waste dumping in urban areas is not in digesters. So the truth will be somewhere in the middle. The comparison showed a clear bias in the estimates. EDGAR 2.0 estimates are based on IPCC Tier 1 methodology, which gives results about 50% lower than those from IPCC Tier 2 methodology. The Tier 2 methodology is a time dependent method. Nigeria and South Africa are countries with large waste emissions. They have higher estimates than EDGAR 2.0, indicating use of different statistics on waste disposal and/or different methodology.

3.2.2 Reasons for differences in methane estimates

3.2.2.1 Overview of large differences

High differences (>10%) are given and discussed below. Differences between national inventories and EDGAR estimates are given in absolute amounts (Gg or 10^9 g CH_4) and percentages, taking the official national total of all methane sources as 100%. Differences between official national totals and EDGAR were found to be large for methane emissions from fossil fuel combustion, traditional biofuel combustion, fugitive coal, fugitive oil and gas, enteric fermentation, manure management, landfills (solid waste disposal) and waste incineration. In this section the larger differences of all relevant sectors are given (>10% of the national total methane emissions from all sources, or large in absolute quantities) (Table 3.28). Most differences can be explained by:

1. *The use of different emission factors and activity data.*
2. *The methodology used in EDGAR*
   This is comparable to the Tier 1 methodology of the IPCC, whereas countries used IPCC Tier 2 or even more detailed methodology in their national inventories, with the different tiers providing incomparable figures.
3. *Differences in aggregation over sub-sectors (valid for some differences).*

Table 3.28 Overview of large differences between EDGAR V2.0 and national estimates of methane emissions from National Reports or Braatz et al. (1996) (in Gg/yr and as %).

	NC1	NC2	EDGAR	EDGAR-NC1	EDGAR-NC2
	Gg	Gg	Gg	%	%
Fugitives					
USA	7641	9893	21399	180	116
Bulgaria	249	315	116	-53	-63
Canada	1322	1400	1622	23	16
Germany	1549	1563	2260	46	45
Hungary	366	448	289	-21	-35
Japan	100	166	672	572	305
Poland	1222	1248	2895	137	132
Russian Federation	19600	18900	31010 1)	58	64
Coal					
European Union 15	2854		3586	26	
USA	4400	3557	11969	172	236
Russian Federation	1900		2)		
Ukraine	2784		2)		
former USSR	4684		5555	19	
Oil&Gas					
European Union 15	1499		1139	-24	
USA	3241	5790	9430	191	63
Mexico	969		821	-15	
Venezuela	1823		651	-64	
Russian Federation	17700		2)		
Ukraine	3435		2)		
former USSR	21135		25455	20	

Table 3.28 Overview of large differences between EDGAR V2.0 and national estimates of methane emissions from National Reports or Braatz et al. (1996) (in Gg/yr and as %). (continued).

	NC1	NC2	EDGAR	EDGAR-NC1	EDGAR-NC2
	Gg	Gg	Gg	%	%
Fossil combustion					
China	73		1529	1995	
Mexico	247		41	-83	
Algeria	537		6	-99	
Agriculture					
Australia	3401	3223	2509	-26	-22
France	1649	1627	2326	41	43
Italy	1860	909	1200	-35	32
Japan	797	843	1747	119	107
New Zealand	1513	1513	798	-47	-47
Poland	863	863	1093	27	27
Spain	887	926	1091	23	18
United Kingdom	1141	1143	1409	23	23
USA	8596	8758	9255	8	6
China	20500		24352	19	
Russian Federation	5000	5060	2)		
Ukraine		2254	2)		
former USSR		7314	11903		63
Enteric fermentation					
Eastern-Europe + former USSR	6278		11357	81	
OECD-Pacific	4768		3132	-34	
Africa	3275		4239	29	
Manure					
Eastern-Europe + former USSR	350		2527	622	
China	2850		1958	-31	
Rice					
Bangladesh	439		4131	841	
China	11800		14869	26	
Philippines	367		1314	258	
Thailand	6290		3820	-39	
Waste					
European Union 15	8052	7761	6101	-24	-21
Africa	2562		924	-64	
China	0		2346	100	

1) Including other former USSR countries

2) Not available in EDGAR 2.0

In the following sections the large differences from Table 3.28 will be explained.

3.2.2.2 Methane from coal

The total global methane emission from coal is estimated by IPCC at 30 (range 15-45) Tg CH_4/yr (IPCC, 1994).

USA

The USA estimate is about 7 Tg lower than the EDGAR estimate (Table 3.28). This difference is substantial on a world-wide scale. The reason for the difference is a different emission factor. The EDGAR emission factor for underground hard coal from the IEA study of Smith and Sloss (1992) was used. The IPCC default value is lower. Recently, in Smith (1997) an update was made of the IEA study on coal emission factors, but essentially most emission factors were not much changed.

3.2.2.3 Methane from oil and gas

The total global methane emission from oil and gas is estimated at 55 (range 30-80) Tg CH_4/yr (IPCC, 1994). For oil it is 15 (range 5-30) Tg and for natural gas, 40 (range 25-50) Tg.

USA

The USA estimate is 6 Tg lower than the EDGAR estimate (Table 3.28). This difference is substantial on a world-wide scale. The reason for the difference is a different emission factor. The EDGAR emission factors were taken from the study by Little (1989). The default emission factors recommended in the *IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1995) are low compared to Little's study. Some countries (Mexico and Venezuela) used emission factors that were even higher than from Little's study that was used in EDGAR. In the USA several estimates have been published of methane emissions from oil and gas production and transmission. Updated figures in new USA inventories are likely to be higher, thereby resulting in smaller differences between other scientific estimates such as EDGAR.

Eastern Europe and Russia

The difference between national data and EDGAR for Eastern Europe and Russia is about 6 Tg. This is substantial on a world-wide scale. Again the default emission factors recommended in the Guidelines are low compared to Little's study. The reason for differences for the countries in this region is various, e.g. some new independent states are missing in EDGAR 2.0.

Japan

The differences for Japan between national data and EDGAR is 672 Gg (Table 3.28). Japan estimated zero fugitive emissions from oil and gas in the NC1, and 59 Gg in the NC2. Apparently in their NC Japan assumes much lower methane leakage from pipelines than EDGAR. According to the Japan Gas Association, however, substantial quantities of cast iron pipelines still exist in Japan (see Table 3.29). An evaluation of the extent in which old lead-oakum joints are still used in the older parts of these pipelines, which are a major source of methane emissions, may be recommended..

Table 3.29 Length of gas distribution pipes in Japan (Source: Japan Gas Association)

	1990	1995
	km	km
Cast iron pipe	60715	66844
Steel pipe	113389	117213
Other	6702	14699
Total length	181306	198756

AFRICA

Algeria
In Algeria the reason for the difference presented in Table 3.28 may be a mistake or gap in reporting in the national report, or in an overestimation of EDGAR. We assume that in the national report fugitive emissions are reported under combustion emissions.

3.2.2.4 Methane from fossil fuel combustion

The total global methane emission from fossil fuel combustion is 15 (range 1-30) Tg CH_4/yr according to budget studies (IPCC, 1994).

China
China's estimate from Braatz et al. (1996) is 1.5 Tg lower than the EDGAR estimate. This is a substantial difference. The reason for the difference is the use of a different emission factor. The IPCC default for residential coal combustion used in Braatz et al. is 10 g/GJ, a factor from the RADIAN Corporation study used for boilers. EDGAR used 300 g/GJ for residential coal combustion, a factor from Berdowski et al. (1993).

Mexico and Algeria
Mexico used an even higher emission factor than the relatively high factor from Berdowski et al. (1993). Algeria may have erroneously reported leaks in the oil and gas system under this sector.

3.2.2.5 Methane from enteric fermentation and manure

The total global methane emission from enteric fermentation is 85 (range 65-100) Tg CH_4/yr according to budget studies (IPCC, 1994), and is in reasonable agreement with the total in EDGAR (80 Tg). The global total methane emission from animal manure is 25 (range 20-30) Tg CH_4/yr according to budget studies (IPCC, 1994), while the EDGAR estimate is 14 Tg.

EUROPE

Ireland
The first and second national communication (1994, 1997) estimated 551 Gg methane from enteric fermentation for 1990, while EDGAR estimated 427 Gg for Ireland in 1990. The first and second national communication estimated 52 Gg methane from manure, while EDGAR estimated 121 Gg. The fairly large differences may be caused by differences in the calculation methods and different emission factors. However, no details on the methodology were given in the national report.

Italy
The first national report estimated 654 Gg methane from enteric fermentation for 1990, while EDGAR estimated 685 Gg for Italy in 1990. The first national report estimated 887 Gg methane from manure for 1990, while EDGAR estimated 287 Gg. In the second national inventory methane from agriculture was less than half that of the NC1. No explanation was found in the NC2 for the difference. The reason that the EDGAR estimate is lower than the NC1 estimate for manure is the use of different calculation methods and emission factors.

EASTERN EUROPE

Eastern Europe and the former Soviet Union
The difference for Eastern Europe and the former Soviet Union between the national inventory and EDGAR for methane from enteric fermentation is 5 Tg. This is substantial. There are several reasons for this difference. First, some new independent states are missing in EDGAR. Second, emission factors and

activity data are different. Third, some have not yet been reported officially. So a complete comparison could not be made.

For Eastern Europe and Russia the difference between national estimates and EDGAR for methane emission estimates for manure systems is 2 Tg, this is large. This is caused by the Russian Federation not giving an estimate for manure.

AFRICA

The difference in Africa between US country study results and EDGAR for methane estimates from enteric fermentation is a substantial 1 Tg. The reason is that the African countries use lower emission factors than EDGAR. Actually, the difference is somewhat smaller. Some countries have given the total methane emission for enteric plus manure. These are not taken into account in the totals of each separate category: enteric and manure.

OECD PACIFIC

The EDGAR estimate for the OECD Pacific is 1.6 Tg lower than the total from the national communications. This is substantial. The difference is a result of different emission factors used: EDGAR uses a regional specific factor, while Japan, Australia and New Zealand use animal specific factors for their national communications.

Japan

For methane emissions from agriculture in Japan, many large differences were found between the first national communication (1994) and the EDGAR 2.0 database. With the second national communication (1997) these differences became even larger. In Tables 3.30 and 3.31 the methane emissions are summarised for NC1 and NC2 for 1990. These differences will be explained in the following sections.

Table 3.30. Methane emissions from agriculture in Japan in 1990 (Gg/yr) according to the national communication 1 and 2 and EDGAR V2.0.

Methane	Enteric	Manure	Rice	Soils	Agr. waste	Savanna	Land use change	Waste	Total
NC1	330	190	261	NE	6	NA	NE	465	1382
NC2	346	119	373	0	5	NA	3	397	1575
EDGAR	277	467	944	0	60			721	3367

NA = not applicable NE = not estimated

The differences between the national communications and EDGAR 2.0 for methane emissions from enteric fermentation and manure in Japan, are mainly due to different emission factors being used. Differences are also attributed to slightly different activity data from FAO. EDGAR used 1989 FAO data, while the national studies used fiscal year 1990 data, which represent the second half of 1989 plus the first half of 1990.

Table 3.31. Methane emissions in Gg/yr for 1990 from enteric fermentation and manure according to Japan's first national communication (NC1) and EDGAR V2.0.

	Number of animals NC1	Number of animals EDGAR	Emission factor NC1	Emission NC1	Emission factor NC1	Emission NC1	Emission factor EDGAR	Emission EDGAR	Emission factor EDGAR	Emission EDGAR
	Japan	FAO	Enteric		Manure		Enteric	Using National/FAO activity data	Manure	Using National/FAO activity data
	Fiscal 1990	1989	NC1		NC1		EDGAR		EDGAR	
	$(x10^3)$		kg/head/yr	Gg	kg/head/yr		kg/head/yr	Gg	kg/head/yr	Gg
Dairy cattle	2068	1570			19	39	54.2	112 / 85	82.8	171 / 130
Lactating cows	1082		109.5	120						
Dry	332		62.2	21						
Heifer	654		65.7	32						
Beef cattle	2805	3190			13	36	54.2	152 / 173	15.7	44 / 50
Dairy breed	1073		76.7	62						
Fattening one year and over	565		62.1	35						
Fattening under one year	453		43.8	9.9						
Breeding cows	714		51.1	36						
Sheep	30	27	4	0.12	0.28	0	8		0.4	
Goats	37	40	4	0.15	0.18	0	5		0.4	
Pigs	11335	11866	1	12	7	80	1.5	17 / 18	15.2	172 / 180
Horses	24	21	17	0.40	2.1	0.1	18		3.7	
Chickens	331526	330000	0		0.117	38.8			0.4	133 / 132
Total				330		190		281 / 276		520 / 492

ASIA

Bangladesh

The methane emission from enteric fermentation in Bangladesh, estimated at 453 Gg by Ahmed et al. (as cited in Braatz et al., 1996) is shown in Table 3.32.

Table 3.32 Methane emission from livestock in Bangladesh in 1990.

	Number (Million)			Emission factor	Emission
	Total	Local breeds	Improved Breeds	kg/head/yr	Gg
Dairy	4.52	4.20	0.32	17.80	80
Non-dairy	18.87	17.55	1.32	16.20	305
Buffalo	0.82	0.80	0.004	18.60	15
Sheep	1.00	0.74	0.003	2.00	2
Goats	27.49	24.55	0.032	1.80	49
Total					453

EDGAR estimated enteric fermentation at 806 Gg. The difference with the national report is caused by the use of different activity data and emission factors. EDGAR estimated 76 Gg methane from manure handling, while Ahmed et al. estimated zero methane emissions from manure.

China

For China the difference between the national report (as cited in Braatz et al., 1996) and EDGAR 2.0 for methane emissions from manure is nearly 1 Tg CH_4/yr. EDGAR is lower because other emission factors were used.

3.2.2.6 Methane emission from rice

The total global methane emission from rice is 60 (range 20-100) Tg CH_4/yr according to budget studies (IPCC, 1994). The EDGAR 2.0 total is 60 Tg. The total for national studies (national communications and national reports from Braatz) using EDGAR for missing countries is, however, lower than 60 Tg. Thus national studies tend to report lower estimates than EDGAR. A recent study by Neue and Sass (1998) concluded the global total emissions from rice to be only 41 Tg (range 33-49 Tg) based on new estimates on rice area and using emission factors from recent measurement studies, making the total rice emissions fairly uncertain, but still within the range set out by IPCC.

EUROPE

Italy

The first national communication estimated 64 Gg methane from rice for 1990; EDGAR estimated 97 Gg. The difference is caused by the use of different emission factors.

OECD-PACIFIC

Japan

The difference in the methane emission estimate for 1990 from rice between the first and second national communications and EDGAR is rather large. EDGAR estimates 916 Gg, the first national communication, 261 Gg, and the second national communication: 373 Gg. In Table 3.33 details are given on the calculation from the first national communication. Details on the calculation for the second national inventory were not published in the NC2.

Table 3.33 Some details on the estimation of methane emission from flooded rice cultivation in fiscal year 1990 according to the first National Communication of Japan of 1994

Soil type	Emission factor		Area under cultivation		Emission
	g CH_4 /m^2 /yr		10^7 m^2		Gg CH_4
Alluvial	13.4	(8 - 27)	1486	(72.3%)	199
Volcanic ash	5.9	(3.6 - 9.8)	245	(11.9%)	14
Peat	22.3	(13.3 – 44.8)	132	(6.4%)	29
Other	9.6	(5.9 - 18.4)	193	(9.4%)	19
Total			2055		261

In EDGAR 2.0 a global emission factor of 350 mg CH_4/m^2 per day is used with an inundated growing period of 130 days, resulting in 45.5 g/m^2 per year. This factor is corrected for the regional fraction of dryland rice of the total harvested area, to give the resulting emissions in the Table 3.34 below. The difference in methane emissions from wetland rice cultivation between the first national communication of Japan and EDGAR 2.0 is caused mainly by the difference in emission factors used.

Table 3.34 Methane emission from flooded rice cultivation according to EDGAR V2.0 (from Kreileman and Bouwman, 1994)

	Emission factor	Harvested Area 1990	Emission
	g CH_4 /m^2 /130 days/yr	1000 km^2	Gg CH_4
USA	45.5	11645	530
Latin America	45.5	53600	2439
Africa	45.5	30507	1388
OECD Europe	45.5	4056	185
Eastern Europe	45.5	1323	60
CIS	45.5	5050	230
Middle East	45.5	8942	407
India region	45.5	543641	24736
China region	45.5	404450	18405
East Asia	45.5	218626	9947
Pacific	45.5	1527	69
Japan	45.5	20129	916
Total	45.5	1303494	59309

N.B. Excluding dryland rice area.

ASIA

Bangladesh

The difference in Bangladesh between country study result and the EDGAR estimate for methane emission from rice is nearly 4 Tg. The reason is that EDGAR used a different regional emission factor dominated by Indian circumstances (notably the fraction of dryland rice) and different activity levels. The methane emissions from rice in Bangladesh are estimated by Ahmed et al. (as cited in Braatz et al., 1996), as given in Table 3.35.

In EDGAR 2.0 the methane emission from wetland rice in Bangladesh was estimated at 4131 Gg on the basis of wetland rice area and an emission factor of 45.5 g/m^2 over the season. The large difference between the national report and EDGAR is caused by the use of different activity levels and emission factors.

Table 3.35. Methane emission from wetland rice in Bangladesh in 1990 (Source: Ahmed et al., 1996).

Season/Varieties	Flooded rice areas (Mha)	Emission factor ($g/m^2/yr$)	Emission (Gg)
B Aus (local)	0.60	0	0
Aus (HYV)	0.31	5.29	16
B Aman (DWR)	0.90	0	0
Aman (local)	1.94	4.60	89
T Aman (HYV)	1.88	7.28	137
Boro (local)	0.25	5.04	13
Boro (HYV)	2.36	7.80	184
Total	8.28		439

HYV = high yielding variety
DWR = deep water rice variety
Local = local variety

China

The difference in China between the country study result and the EDGAR estimate for methane emissions from rice is 3 Tg CH_4/yr, the reason being that EDGAR used different emission factors and activity levels.

Philippines

The difference for the Philippines between the country study result from Braatz et al. (1996) and the EDGAR estimate for methane emissions from rice is about 1 Tg, because EDGAR used higher emission factors and other activity levels.

Thailand

Only for Thailand was the country study estimate from Braatz higher than the EDGAR estimate. The difference is about 2.5 Tg. Thailand used higher emission factors and activity levels.

3.2.2.7 Methane emissions from soils

The IPCC estimate for methane from agricultural soils is zero. From wetlands soils the estimate is 115 Tg CH_4/yr, but this is considered a natural emission (IPCC, 1994).

EUROPE

The national communications of France, Ireland, Italy, Spain and Switzerland estimated respectively, 19, 39/35 (NC1/NC2), 158, 83 and 25 Gg methane from soils. Different interpretations on the anthropogenic part of the emissions from soils may have been used. EDGAR 2.0 did not estimate methane emissions from soils.

3.2.2.8 Methane emissions from agricultural waste burning

The IPCC estimate for methane emissions from agricultural waste burning is unspecified. The IPCC total estimate for methane emissions from biomass burning is 40 Tg CH_4/yr (IPCC, 1994). The fraction of the amount of agricultural waste being burned annually may differ substantially between countries. EDGAR 2.0 uses regional average defaults to estimate the activity data for this source.

OECD-PACIFIC

Japan

The first and second national communications estimated about 6 Gg methane from the field burning of agricultural residues for 1990. EDGAR estimated 49.3 Gg. In Table 3.36 the estimate of methane emission from agricultural straw and chaff burning is given according to the Japan's first national report.

Table 3.36. Methane emissions from agricultural waste burning in Japan for 1990 (Japan's National Communication, 1996)

Type		Amount burned	Emission factor	Emission
		10^3 tonnes	kg CH_4/tonne	Gg CH_4
Wetland rice	Straw	438	4.13	1.8
	Chaff	710	5.25	3.7
Wheat etc.	Straw	54	4.13	0.2
Total				5.8

The IPCC Tier 1 method is followed in EDGAR 2.0. According to Crutzen and Andreae (1990) and others, about 4 promille (range 2-6) of the released carbon is emitted as methane during burning of biomass. In EDGAR the methane emissions are calculated from the area of agricultural land, using a region-specific amount of carbon burned. The calculation is given in Table 3.37 below. The calculation is as follows. The amount of carbon burned per hectare (A) is multiplied by the area to give total carbon burned. A fraction burned (not in table) multiplied with 4 promille escapes as carbon in methane. So, A x B x 0.004 x fraction burned each year x 16/14 (C to CH_4) gives the net methane emission.

Table 3.37 Methane emissions from agricultural waste burning according to EDGAR V2.0 (Kreileman and Bouwman, 1994)

	Amount of carbon burned	Area of agricultural land	Amount of carbon	Emission
	Tonne/ha	100000 ha	Gg C	Gg CH_4
	A	B	A x B	
Canada	0.87	1306	113622	151.5
USA	0.87	4144	360528	480.7
Latin America	1.12	3471	388752	518.3
Africa	1.05	3247	340935	454.6
OECD Europe	1.81	1703	308243	411.0
Eastern Europe	0.83	779	64657	86.2
CIS	0.83	2939	243937	325.2
Middle East	2.20	707	155540	207.4
India region	2.20	2739	602580	803.4
China region	2.20	2468	542960	723.9
East Asia	2.20	1591	350020	466.7
Oceania	0.38	1398	53124	70.8
Japan	2.20	168	36960	49.3
Total		26661		3954

Australia

Australia estimated 370 Gg methane from field burning of agricultural waste, while EDGAR estimated zero emission, the reason being that in EDGAR 2.0, activity data are missing for agricultural waste burning for OECD countries.

AFRICA

Botswana
The national report (as cited in Braatz et al., 1996) made no estimate for methane from agricultural waste burning, while EDGAR estimated 241 Gg, the reason being that the national report is not complete.

Cote d'Ivoire
The national report (as cited in Braatz et al., 1996) estimated only 1 Gg methane from agricultural waste burning. EDGAR estimated 101 Gg. The national report is probably not complete.

Nigeria
The national report (as cited in Braatz et al., 1996) estimated 17 Gg methane from agricultural waste burning. EDGAR estimated 130 Gg. The reason for the difference is the use of different activity data and emission factors.

South Africa
The national report (as cited in Braatz et al., 1996) estimated 6 Gg methane from agricultural waste burning. EDGAR estimated 62 Gg. The difference is explained by the use of different activity levels and emission factors.

Uganda
The national report (as cited in Braatz et al., 1996) estimated 4 Gg methane from agricultural waste burning. EDGAR estimated 79 Gg. The reason is the use of different activity data and emission factors.

3.2.2.9 Methane emissions from savanna burning

The IPCC made no separate estimate for savanna burning. The IPCC total estimate for biomass burning is 40 Tg CH_4/yr (IPCC, 1994).

LATIN AMERICA

Peru
The national report (as cited in Braatz et al., 1996) estimated 204 Gg methane from savanna burning. EDGAR estimated only 25 Gg, the reason being that EDGAR used a low estimate for the amount of savanna burned.

AFRICA

Nigeria
The national report (as cited in Braatz et al., 1996) estimated 297 Gg methane from savanna burning. EDGAR estimated 203 Gg. The difference is caused by the use of different activity levels and emission factors.

South Africa
The national report (as cited in Braatz et al., 1996) estimated 265 Gg methane from savanna burning. EDGAR estimated 83 Gg. The difference is caused by the use of different activity levels and emission factors.

Uganda
The national report (as cited in Braatz et al., 1996) estimated 960 Gg methane from savanna burning. EDGAR estimated 42 Gg. The difference is explained by the use of different activity levels and emission factors.

ASIA

Bangladesh
EDGAR estimated 121 Gg methane from savanna burning. Since the national study (as cited in Braatz et al. 1996) estimated zero methane emissions from savanna burning it may be not complete.

China
EDGAR estimated 1272 Gg methane from savanna burning. Since the national report (as cited in Braatz et al. 1996) estimated zero emissions from savanna burning, it may be not complete.

Philippines
EDGAR estimated 105 Gg methane from savanna burning. Since the national report (as cited in Braatz et al. 1996) estimated zero, it may be not complete.

Thailand
EDGAR estimated 292 Gg methane from savanna burning. The national report (as cited in Braatz et al., 1996) estimated 48 Gg. The difference is explained by the use of different activity levels and emission factors.

3.2.2.10 Methane emissions from land use change

Land use change emissions are defined in EDGAR 2.0 as biomass burning due to deforestation of which the magnitude per country is generally seen as very uncertain. The IPCC estimate for methane from biomass burning is 40 Tg CH_4/yr.

OECD-PACIFIC

Australia
The national report estimated 372 Gg methane from land use change. EDGAR estimated zero emissions. EDGAR made no estimates on activity levels for the OECD countries.

LATIN AMERICA

Mexico
The national report (as cited in Braatz et al., 1996) estimated 195 Gg methane emissions from land use change. EDGAR estimated 356 Gg. The estimate from EDGAR is higher because of higher activity levels.

Peru
The national report (as cited in Braatz et al., 1996) estimated 441 Gg methane emissions from land use change. EDGAR estimated 145 Gg. The activity level in EDGAR was lower.

AFRICA

Cote d'Ivoire
The national report (as cited in Braatz et al., 1996) estimated zero methane emissions from land use change, while EDGAR found 193 Gg. The national report is probably not complete.

Ghana

The national report (as cited in Braatz et al., 1996) estimated zero methane emissions from land use change, while EDGAR found 107 Gg. The national report is probably not complete.

Nigeria

The national report (as cited in Braatz et al., 1996) estimated 3 Gg methane emissions from land use change, while EDGAR found 163 Gg. The national report uses rather low activity levels.

3.2.2.11 Methane emission from solid waste

The total global methane emission from solid waste is 40 (range 20-70) Tg according to budget studies (IPCC, 1994).

EUROPE

The EDGAR estimate for the European Union is lower than the sum of national inventories: 6101 Gg vs. 8052 Gg. This difference of 2 Tg is considerable on a global scale. The difference for the region is 9%. The reasons for the differences are that EDGAR used a direct method and that national estimates are, in some cases (Netherlands, UK, Germany), based on first-order degradation models. EDGAR used different activity data and different emission factors. Differences totalled more than 10% in most European countries.

In the following Table 3.38 the methane emission estimates are given according to the first national communications of the United Kingdom, Finland, Austria, Portugal and Norway.

Table 3.38 Methane emissions from landfills according to the first national reports

	Population	Emission factor	Emission
	million	g CH_4/cap/yr	Gg CH_4
Austria	7.7	29610	228
Finland	5.0	27800	139
Norway	4.2	39762	167
Portugal	10.5	3333	35
United Kingdom	57.2	36329	2078

No information on the methodologies used can be found at the moment. Most are published in background documents that are not at hand. Table 3.39 gives the EDGAR 2.0 calculations.

Table 3.39 Methane emissions from landfills in 1990 according to EDGAR V2.0

	Population	Emission factor	Emission
	million	g CH_4/cap/yr	Gg CH_4
Austria	7.7	16674	128
Finland	5.0	16674	83
Norway	4.2	16674	70
Portugal	10.5	16674	175
United Kingdom	57.2	16674	953

AFRICA

The EDGAR estimate for methane from solid waste disposal in Africa is lower than the national totals for the region: 924 vs. 2562 Gg. This difference of 1.6 Tg is considerable on a global scale. The difference is 13%. EDGAR is consistently lower for the separate countries: i.e. 10 to 20%. Probably the national reports used the same method but different emission factors.

Algeria

The national study (as cited in Braatz et al., 1996) estimated methane emissions from landfills at 675 Gg and from municipal waste water at 4.1 Gg, based on IPCC default methodology (Khennas and Gaid, 1994). EDGAR estimated 68 Gg, based on an emission factor of 2.7 kg methane per capita for African countries.

Cote d'Ivoire

The national study (as cited in Braatz et al., 1996) estimated 266 Gg methane from landfills and 13 Gg from wastewater. No information is found on the emission factors used (Toure et al., 1996). EDGAR estimated 33 Gg methane from landfills, based on 2.7 kg methane per capita for African countries.

Ethiopia

The national study (Ethiopian Energy Authority, 1994) (as cited in Braatz et al. 1996) estimated 40.1 Gg methane from landfills and 10.2 Gg from industrial wastewater. We assume that this was based on IPCC default methodology; no details were given in Braatz et al. (1996). EDGAR estimated 135 Gg methane from landfills alone, based on 2.7 kg methane per capita for African countries.

Morocco

The national study (as cited in Braatz et al., 1996) estimated 142 Gg methane from landfills (Buret et al., 1994). No details were given in Braatz (1996). EDGAR estimated 69 Gg methane from landfills based on 2.7 kg methane per capita for African countries.

Nigeria

The national study (as cited in Braatz et al., 1996) estimated 520 Gg methane from landfills and 57 Gg from waste water based on IPCC default methodology (Obioh et al., 1996). EDGAR estimated 297 Gg methane from landfills, based on 2.7 kg methane per capita for African countries.

Senegal

The national study (as cited in Braatz et al., 1996) estimated 68.9 Gg methane from landfills and 14.8 Gg from industrial waste water, based on IPCC default methodology (GoS, 1994). EDGAR estimated 20 Gg methane from landfills based on 2.7 kg per capita for African countries.

South Africa

The national study (as cited in Braatz et al., 1996) estimated 510 Gg methane from landfills based on IPCC default methodology (Ngobese et al., 1994). EDGAR estimated 97 Gg based on 2.7 kg per capita for African countries.

Tanzania

The national study (as cited in Braatz et al., 1996) estimated 24.5 Gg methane from landfills and 22 Gg from waste water, mostly industrial. This was based on IPCC default methodology (CEEST, 1994). No details were given in Braatz et al. (1996). EDGAR estimated 75 Gg methane from landfills, based on 2.7 kg methane per capita for African countries.

Uganda

The national study (as cited in Braatz et al., 1996) estimated 2.5 Gg methane from landfills and 1.6 from municipal waste water, based on IPCC default methodology (MNR, 1994). No details were given in Braatz et al. (1996). EDGAR estimated 51 Gg methane from landfills, based on 2.7 kg per capita for African countries.

Zimbabwe

The national study (as cited in Braatz et al., 1996) estimated 91 Gg methane from landfills, based on IPCC default methods (Braatz et al., 1996). EDGAR made no estimate for methane from landfills.

OECD-PACIFIC

Japan

In the first national communication an estimate of methane emissions from landfills was made using Tier 1 methodology. In the Tables 3.40 to 3.42 the details are given for municipal and industrial waste. For methane emissions from landfills, EDGAR estimated 721 Gg for 1990. The first national communication estimated 450 Gg; the second national communication estimated 388 Gg for landfills for 1990.

Table 3.40 Methane emissions from municipal waste buried in landfills in Japan in 1990

Waste type	Emission factor	Amount buried	Emission
	kg CH_4 /tonne	10^3 tonne	Gg CH_4
Municipal waste			
Buried directly	59	5890	350
Buried after incineration	0.65	36680	24
Total			374

Table 3.41 Methane emissions from industrial waste buried in landfills in Japan in 1990.

Waste type	Carbon content	Water content	Emission factor	Final disposal	Emissions
	%	%	kg CH_4/tonne	10^3 tonne	Gg CH_4
Industrial waste					
Waste paper	45	8	151.8	86	13
Waste wood	45	38	102.3	562	57
Waste fibres	45	8	151.8	3	0.5
Animal and plant residues	42	80	30.8	168	5.2
Dead animals	42	80	30.8	11	0.3
Total					76

In 1992 the methane emissions were estimated per country by the Stockholm Environment Institute (Table 3.42) on the basis of the amount of waste produced by urban population, the organic matter content, the fraction landfilled and the maximum amount dissimilated (80%) (Subak et al., 1992).

Table 3.42 Methane release from landfills according to Stockholm Environment Institute (Source: Subak et al, 1992)

	Waste generated	Land filled	Degradable organic carbon DOC	Dissimi-lated amount	Urban population	Emission Factor	Emission
	kg/cap/day	%	%	%	Million	kg/urban capita	Tg CH_4
Canada and USA	1.6	80	21	80	210	52.4	11
Other OECD	1.0	66	19	80	380	23.7	9
CIS and Eastern Europe	0.6	87	17	80	250	16.0	4
Developing countries	0.5	80	13	80	1154	10.4	12
Total					1994	18.0	36

In EDGAR V2.0 these estimates from Subak et al. (1992) were used to make a global distribution using total population and density. The resulting emissions per capita are calculated using total population, not urban population only.

Table 3.43 Methane emissions from landfills for different world regions according to EDGAR V2.0.

Region	Methane emission	Population	Emission factor
	10^9 g CH_4 (SEI, 1992)	10^6 (World Bank, 1990)	g CH_4/capita/yr (EDGAR 2.0)
Canada	1093	26	41030
USA	9966	249	39866
Latin America	2684	448	5991
Africa	1758	642	2738
OECD Europe	6298	378	16674
Eastern Europe	1488	123	12059
CIS	3085	289	10662
Middle East	1915	203	9425
India region	1966	1171	1679
China region	2572	1248	2060
East Asia	1144	371	3086
Oceania	1037	23	45496
Japan	721	124	5836
Total	35727	5297	6745

The Japanese methane emissions from landfilled waste are 450 Gg. The difference in methane emissions from landfills between the National Communication and EDGAR/SEI is due to using different emission factors and activity levels. The national estimate is more detailed but used lower emission factors.

ASIA

Bangladesh

Methane emissions from urban landfill sites were estimated by Ahmed et al. (1996). Assumptions (as cited in Braatz et al., 1996) were as follows: 0.4 kg waste generated per capita, fraction landfilled = 0.26, degradable organic carbon = 0.26, released biogas = 0.77, fraction methane in biogas = 0.5, giving a methane emission factor of 5.066 kg methane per urban capita per year. (Table 3.42).

Table 3.42 Methane emissions from urban landfills in Bangladesh in 1990.

	Population	Emission factor	Emission
	(x million)	g/cap/yr	Gg
Dhaka	6	5066	30.4
Chittagong	3	5066	15.2
Khulna	2	5066	10.2
Rajshahi	1.5	5066	7.6
Sylhet	1	5066	5.1
Mymensingh	1	5066	5.1
Total			73.6

EDGAR estimated 194 Gg methane emissions from landfills in Bangladesh on the basis of a methane emission factor of 1.679 kg methane per capita for total Bangladesh.

China

The EDGAR estimate for methane from solid waste disposal in China is 2346 Gg in 1990, based on 2.06 kg methane per capita, while the national report (as cited in Braatz et al., 1996) shows zero emissions.

This difference of 2.3 Tg matters on a global scale. The difference between the estimates from EDGAR and China is 7% of the national Chinese methane emission. The reason for the difference is that China assumes total use of the methane from disposal as fuel.

Philippines

EDGAR estimated 193 Gg methane from landfills for the Philippines for 1990 based on 3.09 kg methane per capita. The national study (as cited in Braatz et al., 1996) estimated zero emissions, which is probably too low.

Thailand

EDGAR estimated 172 Gg methane emissions from landfills for Thailand for 1990, based on 3.09 kg methane per capita. The national study (as cited in Braatz et al., 1996) estimated zero emissions. This is probably too low.

3.2.2.12 Methane emissions from waste incineration

Japan

Methane from waste incineration is reported by Japan, using emission factors for different facilities, see Table 3.45. The methane emission is 12.8 Gg. EDGAR estimated zero emissions because of a lack of activity data.

Table 3.45 Methane emissions from incineration. In Japan in 1990 (Source: Japan's first national communication)

	Emission factor	Amount incinerated	Emission
	g CH_4/tonne	10^3 tonne	Gg CH_4
Municipal waste			
Facility type			
Continuous	29.7	26930	0.8
Semi-continuous	617	2960	1.8
Batch	742	6780	5.0
Industrial waste			
Paper	680	104	0.07
Wood	680	899	0.61
Sludge	680	4840	3.3
Oil	680	984	0.67
Plastics	680	753	0.51
Total			12.8

3.2.3 Discussion and conclusions for methane

National methane inventories as reported to the Climate Convention Secretariat and compiled by the Secretariat in tables (UNFCCC/CP/1996/12/Add.2 and UNFCCC/CP/1998/11/Add.2) and country results (as cited in Braatz et al., 1996) are compared with EDGAR 2.0 (Olivier et al., 1996; 1999) methane emission estimates. Relatively large differences were analysed. Eventually, this kind of comparison of semi-independent databases may contribute to the validation and verification of both national inventories, and EDGAR, and contribute to improvement of IPCC methodologies for estimating emissions.

Four types of differences were found when emission estimates from national inventories and EDGAR were compared:

1. Differences as a result of different emission factors
These differences can be relatively large, for instance, in the case of methane emissions from manure, rice and waste. Measurements may be needed to improve country-specific emission factors. This information may be needed for the development of new IPCC default emission factors.

2. Differences because of the use of different activity levels
These differences point to the fact that EDGAR uses internationally available activity data, which, in some cases, differ from national statistics. Also, in some cases EDGAR used available approximations instead of detailed country-specific statistics. For example, the methane emissions from rice are different because it is hard to find data on areas planted and flooded each year.

3. Differences due to gaps in national data or EDGAR
Various national communications and country study reports are not complete or not yet available. When compared with EDGAR these gaps are very distinct. Country studies were made for capacity-building and to learn about IPCC methodology. We expect a complete reporting when more official national communications come due. EDGAR showed gaps, for example, in methane emissions from waste water treatment. EDGAR missed some of the new independent states in Eastern Europe. National reports showed gaps as well. No comparison of methane emission estimates was possible for the following agriculture and land use sectors: agricultural waste burning, savanna burning, deforestation and biomass burning, because the reporting in the national estimates for these sectors is very scattered.

4. Differences due to different definitions on the anthropogenic part of emissions
These differences occur in estimates of methane from soil, wetlands and land use change. IPCC Guidelines should make these definitions clearer.

The analysis indicates that review and evaluation of emission inventories of greenhouse gases can be useful because:

1. The exchange, review and comparison of emission estimates promotes dialogue, the sharing of information and consensus about the emission estimates among scientists and policy-makers.

2. The comparison of national inventories with EDGAR estimates has identified potential areas for future improvement in the IPCC methodology to estimate emissions and has indicated areas for improvement of good practice in inventory compilation.

3. The comparison of national methane emissions with (semi)-independent scientific database results can contribute to validation of the emission inventories and to the reduction of the uncertainty in the emission estimates. This is especially important with respect to the flexible mechanisms that have been introduced in the Kyoto Protocol.

The national communications were not transparent. A third party could not recalculate the emissions. In the national communications only summaries of emissions are published. The transparency of the emissions inventory is reduced this way because not all data is available for a third party to review the inventory. Often a reference is made to a background report with the more complete emission inventory. These background documents are crucial in a review procedure but are not always readily available. Therefore it is important that emission inventories also be made readily available and become an official document in the Climate Convention. To make inventories more transparent, the UNFCCC is recommended to publish standard data tables in their Guidelines for reporting, and countries are advised to improve the detailed reporting on emission factors and activity data in the national inventory reports.

When comparing national inventories and EDGAR data for 1990, the net large differences are 30 Tg (Table 3.28). This may be interpreted as uncertainty of the methane emission inventories. The global total methane emissions estimated from national data, country studies and EDGAR data to fill in the missing countries, fall short of the middle estimate of the ranges in the IPCC budget as published in 1994

(Table 3.6). The aggregated world total anthropogenic methane emission of 320 Tg compares with the low end of the range of 300-450 Tg methane per year as published by IPCC (1994). This may indicate that IPCC default emission factors from the Guidelines and/or emission factors used in national communications are generally too low.

3.3 Comparison for nitrous oxide

3.3.1 Introduction

Nitrous oxide (N_2O) is one of the natural greenhouse gases in the earth's atmosphere. Most atmospheric N_2O is of biogenic origin and produced by bacteria in soils and aquatic systems. It is a by-product of nitrification and denitrification which, in turn, are essential steps in the natural nitrogen cycle. As a result of human activities global emissions of N_2O have increased by about 50% (Bouwman et al., 1995). Most important, biogenic emissions have increased as a result of disturbance of the natural nitrogen cycle through agricultural activities. In addition, human activities result in several abiogenic emissions resulting from, for instance, combustion processes and industry.

Mosier et al. (1998) and Kroeze et al. (1999) show that the global N_2O budget can be closed, and that agriculture is by far the most important anthropogenic source of N_2O on a global scale (6 Tg N y^{-1}, or 10 Tg N_2O yr^{-1}), while fossil fuel use, industry and biomass burning together contribute less than 2 Tg N yr^{-1} (or 3 Tg N_2O yr^{-1}). Emissions from traffic, however, may increase relatively fast as a result of the introduction of three-way catalysts. The methodology that Mosier et al. (1998) and Kroeze et al. (1999) use for estimating agricultural emissions was developed for the Revised 1996 IPCC Guidelines for National Greenhouse Gas inventories. This methodology differs from the 1995 National Greenhouse Gas inventory with respect to the number of sources included, as well as the emission factors used.

In the following sections national estimates of N_2O emission are analysed. We will compare estimates as presented in the first and second national communications (NC1 and NC2) with estimates from the Emission Database for Global Atmospheric Research (EDGAR). Relatively large differences will be further analyzed and if possible explained. In the following sections we will analyse emissions from agriculture, fuel combustion, transport and industry.

3.3.2 Differences between EDGAR 2.0 and National Communications

3.3.2.1 Total national emissions of nitrous oxide

Total emissions of N_2O as summarised in Table 3.46 range between 0.1 Gg N_2O y^{-1} for Luxembourg (EGDAR) to 225.7 Gg N_2O from the Russian Federation (second National Communication), indicating there is a wide range in emission estimates between countries. Most of the differences, however, can be explained through the size of the country and the number of inhabitants.

A comparison of estimates by EDGAR and the first National Communication (NC1) was made for 25 countries (Table 3.32). Of these, Greece, Hungary, Japan and the UK have reported NC1 emissions within 10% of the EDGAR estimate. For 13 countries, the EDGAR estimate is 30 - 75% lower than the NC1 reported emission, and for 8 countries the EDGAR estimate is 15 - 550% higher.

We have also compared EDGAR estimates to the second National Communications (NC2). For only nine countries is the difference between EDGAR and NC2 smaller than between EDGAR and NC1 (Table 3.46). This implies that most countries revised their estimates for total N_2O but that these revisions do not reduce the difference between EDGAR and the NC estimate. Most countries report higher emissions in NC2 than in NC1. For some of these countries this may have been caused by the use of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories,* which includes a new methodology for N_2O emissions from agriculture. Use of this default method instead of the *1995 IPCC*

Guidelines could considerably increase the national N_2O emission (Mosier et al., 1998). The reasons for the differences will be explored in the following sections.

Table 3.46 Nitrous oxide (N_2O) emissions in 1990 according to the EDGAR V2.0 database (Olivier et al., 1996; 1999) and as reported in the first (NC1) and second (NC2) national communications in Gg N_2O/yr as well as differences (EDGAR minus NC) expressed as a as percentage of the NC estimate.

	NC1	NC2	EDGAR	EDGAR-NC1	EDGAR-NC2
	Gg	Gg	Gg	difference (%)	difference (%)
Australia	60.1	79	59	-2	-25
Austria	4.1	11.6	7	71	-40
Belgium		30.8	15		-51
Bulgaria	22.5	30.8	16	-29	-48
Canada	95.5	86	80	-16	-7
Czech Republic	24	25.8			
Denmark	10.3	34	13	26	-62
Estonia	2.4	2.3			
Finland	22	18	70	-55	-45
France	176.7	181.7	126	-29	-31
Germany	211	226	126	-40	-44
Greece	13.7	17.3	13	-5	-25
Hungary	11.4	12.9	11	-4	-15
Iceland	0.6	0.4	0,2	-67	-50
Ireland	42.3	29.4	14	-67	-52
Italy	120.3	164.5	44	-63	-73
Japan	55.2	105.3	52	-6	-51
Latvia	2.4	22.5			
Lithuania		13.2			
Luxembourg	0.6	0.6	0,1	-83	-83
Monaco					
Netherlands	51.5	51.2	19	-63	-63
New Zealand	17.1	47.5	40	134	-16
Norway	15	15	21	40	40
Poland	156	70	82	-47	17
Portugal	10.5	14	8	-24	-43
Slovakia	16	12.5			
Slovenia		5.1			
Spain	93.9	94.2	39	-58	-59
Sweden	15.2	9.2	8	-47	-13
Switzerland	15.6	11.5	4	-74	-65
Ukraine		23.4			
United Kingdom	108.3	120	111	2	-8
United States	411.4	425	531	29	25
Russian Federation	89.6	225.7			

3.3.2.2 Nitrous oxide from agriculture

Both from EDGAR V2.0 and the National Communications it can be concluded that agriculture is the largest anthropogenic source of N_2O in most countries. This is in agreement with global analyses by Bouwman et al. (1995) and Kroeze et al. (1999). However, there are a number of differences between the estimates from EDGAR and the National Communications as discussed below.

As described earlier, the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* were published after the countries submitted their first National Communication. Although most countries also submitted their second National Communication before the revised Guidelines were available, some of these revised their national estimates based on draft versions of the new Guidelines that circulated for comments or that were in press. The result is that the estimates of N_2O emissions from agriculture 'changed' considerably for a number of countries.

The most important difference between EDGAR, the 1995 *IPCC Guidelines* (used by many countries for NC1) and the *Revised 1996 IPCC Guidelines* for N_2O from agriculture is caused by the number of sources included in the methodology (Table 3.48). In addition, the default emission factors differ.

Table 3.47 Nitrous oxide (N_2O) emissions from agriculture according to the EDGAR V2.0 database (Olivier et al., 1996; 1999) and as reported in the first (NC1) and second (NC2) national communications in Gg N_2O/yr, as well as differences (EDGAR minus NC) expressed as a as percentage of the NC estimate

	NC1	NC2	EDGAR	EDGAR-NC1	EDGAR-NC2
	Gg	Gg	Gg	difference	difference
	1990	1990	1990	%	%
Australia	52.4	68.2	55	5	-19
Austria	2	3.3	6	200	82
Belgium		10.9	8		-27
Bulgaria	8.2	13.4	14	71	4
Canada	10.7	11	24	124	118
Czech Republic	2	2.3			
Denmark	8.5	33	12	41	-64
Estonia	0.9	0.9			
Finland	12	10	6	-50	-40
France	61.3	54.5	78	27	43
Germany	81	96	62	-23	-35
Greece	7.5	8.4	12	60	43
Hungary	4.1	4.6	10	144	117
Iceland	0.5	0.2	0	-100	-100
Ireland	39.5	23.3	14	-65	-40
Italy	58.7	75.2	31	-47	-59
Japan	4.7	9.7	22	368	127
Latvia	1.4	22			
Lithuania		10.8			
Luxembourg	0.5	0.5	0	-100	-100
Monaco					
Netherlands	22.2	22.2	16	-28	-28
New Zealand	14.1	44.9	17	21	-62
Norway	6	6	4	-33	-33
Poland	31.5	43	29	-8	-33
Portugal	3.6	7.4	6	67	-19
Slovakia	8.8	9.5			
Slovenia		4.6			
Spain	63.4	63.5	36	-43	-43
Sweden	7.9	0.2	7	-11	3400
Switzerland	13.4	9.2	4	-70	-57
Ukraine		10.2			
United Kingdom	10.5	10.4	48	357	362
United States	187.9	196	313	67	60
Russian Federation	60	200			

The *Revised 1996 IPCC Guidelines* include three categories of N_2O sources: (i) direct soil emissions, (ii) animal production and (iii) indirect emissions. On a global scale each of these emissions amounted to 2.1 Tg N yr^{-1} (3.3. Tg N_2O yr^{-1}) in 1989 (Mosier et al., 1998). The direct soil emissions result from increased nitrification and denitrification rates as a result of nitrogen inputs. The nitrogen inputs can be fertilisers (both synthetic and animal waste), biological N_2 fixation and crop residues. In addition, cultivation of organic soils such as histosols contributes directly to soil emissions of N_2O. Animal waste management systems include the second source of N_2O. When manure is produced and stored in stables N_2O can be formed and emitted. The 1996 revised Guidelines distinguish between six animal waste management systems and indicate that the N_2O emissions per unit of animal waste may differ by a factor of 20. The third group of emissions are considered 'indirect' emissions. These are released after nitrogen is removed from the agricultural field through volatilisation (NO_x or NH_3), nitrogen leaching or as crop. After removal this nitrogen may give rise to N_2O formation in remote locations, for instance, in soils onto which the NO_x and NH_3 is deposited, and in groundwater or rivers after leaching of nitrogen or disposal of sewage.

EDGAR and the 1995 IPCC Guidelines do not include all these sources of N_2O (Table 3.48). Most important, the indirect emissions and emissions from stables are not included, which on a global scale account for about 40% of the total emissions. In addition, all default emission factors in the 1995 IPCC Guidelines and those for grazing animals in EDGAR are at least 50% lower than those in the revised 1996 IPCC Guidelines. Finally, a number of N inputs giving rise to direct soil emissions is not explicitly accounted for in EDGAR and the 1995 Guidelines.

Table 3.48 Agricultural sources that are (yes) or are not (no) included in the EDGAR V2.0 methodology, the 1995 IPCC Guidelines and the revised 1996 IPCC Guidelines; for EDGAR and IPCC 1995 it is indicated if emission factors are similar (same EF) or different (other EF) than the revised 1996 IPCC Guidelines

Source	EDGAR[1]	1995 IPCC Guidelines[2]	Revised 1996 IPCC Guidelines[3]
Direct soil emissions			
- synthetic fertiliser	yes, same EF	yes, other EF	Yes
- animal waste used as fertiliser	yes, other EF	yes, other EF	yes
- biological N_2 fixation	no	yes, other EF	yes
- crop residue	yes[6]	no	yes
- cultivated histosols	yes[6]	no	yes
Animal production			
- animal waste management systems	no	no	yes
- grazing animals[4]	yes, other EF	no	yes
Indirect emissions			
- atmospheric deposition	no	no	yes
- nitrogen leaching and runoff	no	no	yes
- sewage[5]	no	no	yes

[1] Olivier et al. (1996; 1999); [2] IPCC (1995); [3] IPCC (1997); [4] soil emission, [5] assigned to IPCC Sector 'Waste'; [6] included in background emission, see Section 3.3.3.1

Table 3.47 shows that for about two-thirds of the countries the EDGAR estimate for agricultural emissions of N_2O is lower than the estimate reported in the second National Communications. In addition, it is clear that most NC2 estimates are higher than NC1 estimates. Both are in line with the differences as outlined in Table 3.48. However, it should be noted that most Annex I countries do not use the IPCC Guidelines without modifications based on in-country data, so that further analysis is needed to explain the differences (see section 3.3.3). Table 3.47 also indicates that apparently one-third of all countries report emissions that do not exceed EDGAR, which could be an indication that these countries do not report all agricultural sources of N_2O.

3.3.2.3 Nitrous oxide from fuel combustion

Fuel use is a source of N_2O in (i) stationary combustion of fossil fuels and biofuels and (ii) mobile combustion. Stationary combustion includes mainly electricity generation and usually results in relatively low emissions of N_2O. In general, coal gives rise to higher emissions than oil, while natural gas shows the lowest emissions in stationary combustion. Mobile combustion is discussed in Section 3.3.2.4.

In 17 of the 25 countries analysed, the EDGAR estimate for N_2O from stationary combustion is lower than the estimate reported in the second National Communications (Table 3.49). For some other countries, however, the EDGAR estimate is considerably higher. The latter holds in particular for Australia, Canada, Finland, New Zealand, Norway and Sweden, where EDGAR estimates relatively high emissions from biofuel use. Thus the comparison indicates that the EDGAR estimates for fossil fuel combustion are relatively low, while the estimates for biofuel are relatively high when compared to the National Communications.

Table 3.49 Nitrous oxide (N_2O) emissions from fuel combustion (incl. biofuel) according to the EDGAR 2.0 database (Olivier et al., 1996; 1999), as reported in the first (NC1) and second (NC2) national communications in Gg N_2O/yr, as well as differences (EDGAR minus NC) expressed as a percentage of the NC estimate

	NC1	NC2	EDGAR	EDGAR-NC1	EDGAR-NC2
	Gg	Gg	Gg	difference	Difference
	1990	1990	1990	%	%
Australia	3.6	7.7	4	-11	-48
Austria	1.4	4.3	1	-29	-77
Belgium		7.7	1		-87
Bulgaria	4.6	7	1	-78	-86
Canada	44.5	36	7	-84	-80
Czech Republic	19	20			
Denmark	1.8	2	1	-44	-50
Estonia	1.4	1.4			
Finland	7	5	1	-86	-80
France	11.6	14.3	4	-66	-72
Germany	37	37	18	-51	-51
Greece	3.7	6.6	1	-73	-85
Hungary	7.3	8.4	1	-86	-88
Iceland	0	0	0		
Ireland	2.8	2.8	0	-100	-100
Italy	41.7	44.6	3	-93	-93
Japan	21.9	65.6	14	-36	-79
Latvia	1	0.3			
Lithuania		1			
Luxembourg	0.1	0.1	0,1	0	0
Monaco					
Netherlands	6.2	5.5	1	-84	-82
New Zealand	2.4	2.6	23	858	785
Norway	2	2	1	-50	-50
Poland	7.1	7	5	-30	-29
Portugal	5	1.8	9	80	400
Slovakia	3.8	0.6			
Slovenia		0.5			
Spain	20.1	20.2	2	-90	-90
Sweden	4.6	6.3	1	-78	-84
Switzerland	1.4	1.4	0	-100	-100
Ukraine		6.7			
United Kingdom	4.8	14.7	6	25	-59
United States	127.4	133	102	-20	-23
Russian Federation	26.3	17.4			

3.3.2.4 Nitrous oxide from transport

In mobile combustion N_2O formation can be considerable when 3-way catalytic converters are applied, which is the case in many Annex I countries (Table 3.50). Nitrous oxide emissions from cars without 3-way catalytic converters can, per kilometre, be 80% lower than from cars having old catalysts (Baas, 1991; 1994). New catalytic converters, however, show considerably lower emissions than older converters. Thus an estimate of N_2O emissions from traffic requires knowledge on the number of catalytic converters and their age in the car fleet of a country. This information is not always available. In addition, it is not easy to derive reliable emission factors for vehicles from laboratory experiments, since it is difficult to quantify the impact of driving behaviour and vehicle type on N_2O formation.

We compared N_2O emission estimates from traffic for 25 countries (Table 3.50). For all countries the EDGAR estimate for N_2O from traffic is lower than in the National Communications. The differences range between 40% and 100%. Since the countries investigated are all Annex-I countries where 3-way catalysts are widely used and with potentially good-quality in-country data, our results could be an indication that EDGAR systematically underestimates emissions from vehicles with old 3-way catalysts.

Table 3.50 Nitrous oxide (N_2O) emissions from transport according to the EDGAR 2.0 database (Olivier et al., 1996; 1999), as reported in the first (NC1) and second (NC2) National Communications in Gg N_2O/yr, as well as differences (EDGAR minus NC) expressed as a percentage of the NC estimate

	NC1	NC2	EDGAR	EDGAR-NC1	EDGAR-NC2
	Gg	Gg	Gg	difference	difference
	1990	1990	1990	%	%
Australia	2.3	5.2	1.2	-48	-77
Austria	0.5	3.1	0.1	-80	-97
Belgium		0.9	0.2		-78
Bulgaria	0.2	0.2	0	-100	-100
Canada	33.6	29	5	-85	-83
Czech Republic	1	0.8	0.1	-90	-88
Denmark	0.4	0.4	0.1	-75	-75
Estonia	0	0			
Finland	5	2	0.1	-98	-95
France	4.1	4	0.9	-78	-78
Germany	11	11	2	-82	-82
Greece	1.2	1.6	0.1	-92	-94
Hungary		0.8	0.1		-88
Iceland	0	0	0		
Ireland	0.2	0.2	0	-100	-100
Italy	3.5	3.6	0.8	-77	-78
Japan	13.2	12.9	7.1	-46	-45
Latvia	0.1	0.1			
Lithuania		0.2			
Luxembourg	0	0	0		
Monaco					
Netherlands	5	4.9	0.3	-94	-94
New Zealand	0.4	0.4	0	-100	-100
Norway	1	1	0.1	-90	-90
Poland	1.6	1	0.2	-88	-80
Portugal	0.4	0.5	0.1	-75	-80
Slovakia	0.2	0			
Slovenia		0.1			
Spain	2.1	2	0.5	-76	-75
Sweden	0.4	2.6	0.2	-50	-92
Switzerland	1.1	1.1	0	-100	-100
Ukraine					
United Kingdom	1.8	3.4	1	-44	-71
United States	92.3	98	60.7	-34	-38
Russian Federation	9.4				

3.3.2.5 Nitrous oxide from industrial processes

The most important industrial sources of N_2O are the production of nitric acid and adipic acid. Nitric acid is produced mainly as a basis for synthetic fertilisers, while adipic acid is produced for nylon 6.6. Both sources are included in EDGAR, as well as in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*. There may be other industrial, yet unidentified, industrial sources of N_2O that are not considered in EDGAR or the National Communications (Oonk and Kroeze, 1998). This makes it likely that all estimates presented in Table 3.51 systematically underestimate the contribution of industry to total N_2O emissions. The comparison presented in Table 3.51 reveals that for all countries considered, the EDGAR estimates are lower than the National Communication, indicating that the EDGAR estimates may be on the low side.

Table 3.51 Nitrous oxide (N_2O) emissions from industry according to the EDGAR V2.0 database (Olivier et al., 1996; 1999), as reported in the first (NC1) and second (NC2) National Communications in Gg N_2O/yr, as well as differences (EDGAR minus NC) expressed as a percentage of the NC estimate

	NC1	NC2	EDGAR	EDGAR-NC1	EDGAR-NC2
	Gg	Gg	Gg	difference	difference
	1990	1990	1990	%	%
Australia	0.8	1.6	0	-100	-100
Austria	0.6	0.6	0	-100	-100
Belgium		11.5	6		-48
Bulgaria	9.6	10.4	1	-90	-90
Canada	37.1	37	33	-11	-11
Czech Republic	3	3.3	1	-67	-70
Denmark	0	0	0		
Estonia	0	0			
Finland	3	3	0	-100	-100
France	102.5	90	44	-57	-51
Germany	83	83	46	-45	-45
Greece	2.4	2.3	0	-100	-100
Hungary		3.7	0		-100
Iceland		0.2	0		-100
Ireland		2.6	0		-100
Italy	14.8	23.5	10	-32	-57
Japan	22.7	23.8	16	-30	-33
Latvia					
Lithuania		1.4			
Luxembourg			0		
Monaco					
Netherlands	18.2	18.6	2	-89	-89
New Zealand			0		
Norway	7	7	1	-86	-86
Poland	20.3	20	48	136	140
Portugal	1.9	1.9	0	-100	-100
Slovakia	2.1	2.1			
Slovenia					
Spain	10.4	10.4	1	-90	-90
Sweden	2.7	2.7	0	-100	-100
Switzerland	0.3	0.3	0	-100	-100
Ukraine		6.2			
United Kingdom	93	94	57	-39	-39
United States	96.1	96	142	48	48
Russian Federation	3	3			

3.3.3 Reasons for differences in nitrous oxide estimates

3.3.3.1 Introduction

In the previous sections we compared N_2O emission estimates from EDGAR 2.0 to those from national communications. In the following we will focus on some of the observed differences in more detail. We will limit our discussion to N_2O emissions from agriculture because this is by far the most important source of anthropogenic N_2O on a global scale, and in most countries included in our analysis. In some cases we will focus on emissions from agricultural soils, since this is a source of N_2O for which most countries have in-country data available. Soil emissions could include both direct soil emissions and emissions from grazing animals (see Table 3.48). We will discuss the estimates for the Czech and Slovak Republics, Ireland, Spain, the UK and the USA.

Summary of methods for estimating N_2O emissions from agriculture

To facilitate the discussion we first summarise the methods for estimating N_2O emissions from agriculture, as presented in the 1995 *IPCC Guidelines* for National Greenhouse Gas Inventories and as used in EDGAR V2.0. Table 3.48 shows that each of these methods includes different sources. Here we will also discuss the different emission factors used.

1995 IPCC Guidelines for National Greenhouse Gas Inventories
The 1995 *IPCC Guidelines* include default emission factors for N_2O emissions from agricultural soils. The default emission factors are 0.36 (0.05 - 3.9)% of each kilo of nitrogen input to the soil, where the N input can be from synthetic fertilisers, animal waste or biological N_2 fixation.

Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories
The *Revised 1996 IPCC Guidelines* present a revised default emission factor for direct soil emissions: 1.25 (0.2 - 2.5)% of N inputs to soils, where N inputs can be from synthetic fertilisers, animal waste, biological N_2 fixation and crop residues. In addition, cultivation of histosols may result in 5 - 10 kg N_2O-N emitted per hectare. The revised Guidelines also provide default emission factors for animal waste management systems including grazing animals, ranging from 0.1 to 2% of the nitrogen in animal waste. Finally, indirect N_2O emissions are estimated of 1% of NH_3 and NO_x emissions, and 2.5% of N leaching.

EDGAR
In EDGAR, direct soil emissions are estimated as the sum of background emissions (1 kg N_2O-N per hectare) and fertiliser-induced emissions (1.25% of fertiliser N and 1% of N in animal waste). The N input from synthetic fertilisers is taken from FAO databases, while N in animal waste was estimated by Bouwman et al. (1995). The background emissions are considered to be enhanced in the EDGAR estimates as a result of long-term fertilisation and soil cultivation, these could be considered an equivalent for the N input from crop residues and cultivated histosols mentioned in the revised IPCC Guidelines. EDGAR furthermore includes N_2O emissions as a result of biomass burning and tropical forest conversion that could be assigned to agriculture, but do not occur in the countries investigated here.

3.3.3.2 Nitrous oxide from agriculture: differences explained for a selection of countries

Czech and Slovak Republics

The Slovak Republic reported 9.5 Gg N_2O from agricultural soils in 1990 and 5.4 Gg in 1994 in the National Communications. The Czech republic reported 2.3 Gg in 1990 and 1.8 Gg in 1994. These estimates are lower than the EDGAR estimate of 18 Gg for 1990 for the Slovak and Czech Republic together. The method used for the National Communications is explained in the Slovak report and presented in Table 3.52. This method is taken from the *1995 IPCC Guidelines for National Greenhouse Gas Inventories*, in which the default emission factors are lower than in the *Revised 1996 IPCC Guidelines*. Thus if the emissions were calculated following the *Revised 1996 IPCC Guidelines*, the estimates would be considerably higher as a result of (i) higher emission factors for soil emissions and (ii) including emissions from stables and indirect N_2O formation.

Table 3.52 Agricultural areas, fertiliser N use and related N_2O emissions (Gg N_2O/yr) in the Slovak Republic (Source: Second National Communications (NC2))

Year	Area	N input	N input	N input	Emission factor	Emission factor	Emission factor	Emission
		Synthetic fertiliser	Animal waste	Biogenic N_2	0.0005	0.0036	0.039	
		Mineral	Organic	Fixation	(Low)	(Medium)	(High)	Average
	1000 ha	kg N ha^{-1}	kg N ha^{-1}	kg N ha^{-1}	kg N_2O ha^{-1}	kg N_2O ha^{-1}	kg N_2O ha^{-1}	Gg N_2O
1990	2448	75.3	62.8	33	0.13	0.97	10.49	9.46
1991	2449	63.6	56.6	33	0.12	0.87	9.39	8.47
1992	2447	36.5	47.2	33	0.09	0.66	7.15	6.45
1993	2445	23.3	33.8	33	0.07	0.51	5.52	4.97
1994	2444	31.2	33.8	33	0.08	0.55	6.01	5.41

Ireland

The nitrous oxide emission from agricultural soils in Ireland in 1990 was estimated at 40 Gg N_2O in the first National Communication, which is considerably higher than the EDGAR estimate (14 Gg N_2O; Table 3.24). In the second National Communication the Irish estimate for N_2O from agricultural soils was revised to 23 Gg for 1990 and 19 Gg for 1993. In the first National Communications no details were given on the estimation method. The revised estimate for 1993 was based on Ryan et al. (1995), as presented in Table 3.39.

The reasons for the differences between EDGAR and the second National Communications are mainly resulting from different emission factors used. The emission factors presented in Table 353 (used for NC2) are on an area basis, while the EDGAR emission estimates are related to the amount of fertiliser use (see Section 3.3.3.1). Table 3.53 also shows that, like in EDGAR, emissions from stables (animal waste management systems other than grazing animals) and indirect N_2O emissions are not included in the Irish National Communication, indicating that 19 Tg N_2O is an underestimation of the actual emissions from agriculture in Ireland.

Table 3.53 Crop and grassland area (ha), N_2O emission factors used (Kg N_2O ha^{-1} yr^{-1}) and reported nitrous oxide (N_2O) emissions from soils in Ireland. Source: second National Communications (NC2)

	Area ha	Emission factor kg N_2O ha^{-1}	Emission Gg N_2O
Arable crops	404000	2.5	1.0
Grassland with fertiliser	3500700	5	17.5
Grassland without fertiliser	499700	1	0.5
Total			19.0

Spain

In the first National Communication of Spain the nitrous oxide emissions from agricultural soils for 1990 are estimated at 63 Gg N_2O. This estimate was based on the CORINAIR methodology. The much lower EDGAR estimate (36 Gg N_2O) is based on 1.25% of N-fertiliser use from FAO statistics and manure production, with a loss factor of 1%.

United Kingdom

The nitrous oxide emission in 1990 in the United Kingdom was estimated 11 Gg N_2O in the first National Communication. In the second National Communication it was revised to 10.1 Gg (6.6 Gg from agricultural soils and 3.5 Gg from manure management) in 1990 and 9.9 Gg (6.4 Gg from agricultural soils and 3.5 Gg from manure management) in 1994. The EDGAR estimate for 1990 was 48 Gg N_2O, assuming a 1.25% and 1% loss of fertiliser and manure N, respectively (see 3.3.3.1).

USA

The N_2O emissions from US agricultural soils were estimated at 188 Gg N_2O for 1990 in the first US National Communication. It was estimated at 217 Gg N_2O for 1995 in the second National Communication. Table 3.54 summarises several details of the estimates for 1995. The emission factor for synthetic fertilisers and animal wastes used in the National Communications (2% of the N input) is high compared to the default emission factors of the revised IPCC Guidelines (1.25% for fertilisers and 0.1 - 2% for animal waste) and those applied in EDGAR (1 - 1.25%). A higher emission factor for the US could be realistic, given the relatively high use of anhydrous ammonia as fertiliser, which is known to give rise to relatively high emissions of N_2O. The EDGAR estimate for the USA for 1990 is 313 Gg N_2O, indicating that the estimates for the amounts of fertiliser and manure may differ or that background emissions are treated differently. It should be noted that neither EDGAR nor the US National Communication takes into account emissions from stables and indirect sources of N_2O (see Table 3.54).

Table 3.54 Nitrogen in fertiliser and manure, N_2O emission factors used and reported nitrous oxide emissions (Gg N_2O/yr) in USA (Source: second National Communications (NC2))

Amount fertiliser and manure Tonnes N	Emission factor g N_2O/t N	Emission Gg N_2O
10632220	0.0204	217.1

3.3.4 Conclusions for nitrous oxide

National estimates of N_2O emission were analysed. We compared estimates as presented in the first (NC1) and second (NC2) National Communications with estimates from the Emission Database for Global Atmospheric Research (EDGAR). Clearly, agriculture is the most important anthropogenic source of N_2O on a global scale as well as in most country estimates. Fuel combustion, industry and biomass burning are less important sources of N_2O.

Of the 25 countries that were included in the analysis, four (Greece, Hungary, Japan and the UK) have reported NC1 emissions within 10% of the EDGAR estimate. For 13 countries, the EDGAR estimate is 30 - 75% lower than the NC1 reported emission, and for 8 countries the EDGAR estimate is 15 - 550% higher. A comparison of EDGAR estimates with the second national communications (NC2) reveals that for only nine countries is the difference between EDGAR and NC2 smaller than between EDGAR and NC1. While this implies that most countries revised their estimates for total N_2O, these revisions do not reduce the difference between EDGAR and the NC1 estimate.

For about two-thirds of the countries the EDGAR estimate for agricultural emissions of N_2O is lower than the estimate reported in the second national communications. In addition, it is clear that most NC2 estimates are higher than NC1 estimates. Both findings may be induced by the publication of the *Revised 1996 IPCC Guidelines*, which include more agricultural sources and revised (higher) emission factors than the *1995 Guidelines*. About one-third of all countries report agricultural emissions that do not exceed EDGAR, which could be an indication that these countries do not report all agricultural sources of N_2O. In-depth analysis of a number of countries shows that country estimates could increase considerably if emissions were estimated following the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories.*

For N_2O from fuel use the analysis indicates that the EDGAR estimates for fossil fuel combustion are relatively low, while the estimates for biofuel are relatively high when compared to the National Communications. In addition, the EDGAR estimate for N_2O from traffic is lower than in the National Communications in all countries studied. Furthermore, the comparison reveals that for all countries considered the EDGAR estimates are lower than the National Communication, indicating that the EDGAR estimates for industry may also be on the low side.

4. Results of atmospheric measurements and models

"The only thing that matters at the end of the day is what the concentrations of greenhouse gases are"; Robert Watson (Science, 24 July 1998, pp 504)

Introduction

The objective of climate policy is to reduce emissions of greenhouse gases in order to stabilise concentrations in the atmosphere (UNFCCC, 1992). Quantifying the emission of greenhouse gases by compiling emission inventories using statistical data alone is not sufficient to establish and evaluate climate policy. The accomplishment of climate policy and the effect and efficiency of emission reduction measures can only be judged by atmospheric measurements. Both sources and sinks determine the rate of increase of concentrations of greenhouse gases in the atmosphere. Sinks determine the required effort to be put in emission reduction measures to stabilise concentrations of greenhouse gases as the magnitude of the sink determines the fraction of a greenhouse gas which remains in the atmosphere after emission. Besides emissions also the remaining fraction in the atmosphere should be considered as a key factor in climate policy. An analysis of the growth of CO_2, CH_4 and N_2O concentrations in the atmosphere and calculations with climate and atmospheric transport models showed that about 50%, 10% and 50% of the yearly anthropogenic CO_2, CH_4 and N_2O emissions respectively, remain in the atmosphere and cause the steady increase of greenhouse gas concentrations (IPCC, 1995).

In the next, the trends in atmospheric concentrations of the main greenhouse gases CO_2, CH_4 and N_2O are discussed relative to the atmospheric budget and reported emissions. A comparison of bottom up (National Communications and EDGAR) and top down (derived from atmospheric measurements and model calculations) emissions data on large zonal bands is presented. The growth in the atmospheric concentrations of HFCs, PFCs and SF_6, man made greenhouse gases which are also incorporated in the Kyoto protocol, are reported elsewhere (RIVM 1997, RIVM 1998).

4.1. Carbon dioxide

4.1.1. Atmospheric concentrations, monitoring and trends

The global average CO_2 concentration in 1997 was 363.1 ppm and 1.1 ppm higher than in 1996 which is about the average growth rate of the last 10 years (RIVM, 1997). The highest concentrations are measured in the Northern Hemisphere. The concentration at Point Barrow, a global background station in Alaska in 1997 was 365.1 ppm and nearly 4 ppm higher than the CO_2 concentration at the South Pole, which was 361.25 ppmv. This zonal gradient is caused because the main sources of CO_2 are located in the Northern Hemisphere. Derwent et al. (1998) published an analysis of CO_2 measurements at Mace Head and reported an increase of the CO_2 concentration of about 2 ppm/yr between 1993 and 1996 and an elevation of 5-10 ppm compared with background air in case winds are blowing from source regions. The average CO_2 concentration in a source area in north-western Europe as measured in Kollummerwaard in 1997 was 370.6 ppm and over 5 ppm higher than measured in Point Barrow. Kollummerwaard is located very close to large source areas and because of the large yearly variability, no clear trend can be detected from the Kollummerwaard data (RIVM, 1997).

4.1.2. The global budget

"A major source of uncertainty in future trends of the main important greenhouse gases arises from uncertainties in the current budget (Rayner et al, 1996) "

The global budget

Figure 4.1 shows a steady increase of the atmospheric CO_2 concentrations. Using the conversion factor 1 ppm = 2.11 Gt C/yr (Enting et al., 1993) a global increase of the CO_2 mass in the atmosphere can be calculated. Assuming an average increase of 1.45 ppm CO_2/yr between 1980 and 1997 means an average increase in CO_2 mass in the atmosphere of about 3 Gt C/yr. The CO_2 emission by fossil fuel in that period (excluding CO_2 emission from land use change) was between 5.5 and 6 Gt C/yr which means that about 50% of the emitted fossil CO_2 has been absorbed by other reservoirs in the climate system by the biosphere and oceans. The partitioning of CO_2 fluxes between the different reservoirs ocean, forests and atmosphere is very complicated and varies in space and time. Table 4.1 shows the partitioning of the global budget by various authors for different periods.

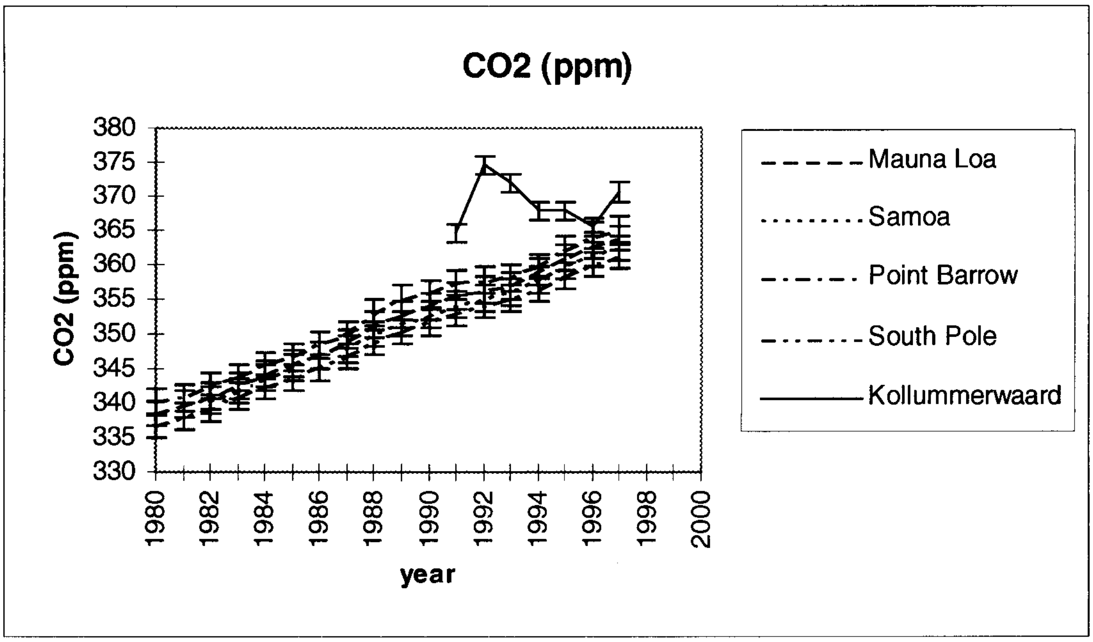

Figure 4.1 shows the course of yearly averaged CO_2 concentrations at four background stations and one station in a source area (Kollummerwaard).

Table 4.1 The global CO_2 budget as compiled by various authors.

	Period	1980-1989	1980-1989	1980-1989	1981-1987	1980-1987	1989-1990	1988-1992	1992	1991-1994
	Ref	IPCC 1994	IPCC1995	Houghton	Tans et al.	Enting et al.	Enting et al.	S. Fan et al.	Ciais et al.	Heimann
	year of publication	1994	1995	1996	1990	1993	1995	1998	1995	1996
1.	Fossil fuel and cement production	5.5 ± 0.5	5.5 ± 0.5	5.5 ± 0.5	5.3	5.39 ± 0.29	5.65 ± 0.29	5.9	6.1	6.1
2.	Atmospheric increase	3.2 ± 0.2	3.3 ± 0.2	3.2 ± 0.2	3	3.8	3.2	2.8	1.5	2.3
3.	CO oxidation					0.88 ± 0.2				
4.	Ocean uptake	2.0 ± 0.8	2.0 ± 0.8	2.0 ± 0.8	1 (0.6 - 1.4)	1.43 ± 0.97	1.67 ± 1.51	1.1 - 2.25	3.1 ± 1	2
	O_2/N_2 ratio trend 1989-1994	1.9 ± 0.8	1.9 ± 0.8							
	$^{13}C/^{12}C$ ratio	2.1 ± 1.5	2.1 ± 1.5							
5.	Net balance of terrestrial biosphere	0.3 ± 1.0	0.2 ± 1.0	0.3		2.18 ± 0.78	2.27 ± 1.27	1 - 2.2	1.5 ± 1	1.8 ± 1.1
	= (1+3)-(2+4)									(or 2.0)
6.	Land use change emissions	1.6 ± 1.0	1.6 ± 1.0	1.6 ± 1.0	0.4 - 2.6	1.14 ± 0.84	1.27 ± 1.27	2 ± 1	2 ± 1	
	(primarily tropics)									
7.	Net emissions from tropics									0
8.	Regrowth of temperate latitude forests	0.5 ± 0.5	0.5 ± 0.5	0.8 ± 0.4					3.5 ± 1	0
	(also based on forest statistics									
9.	CO_2 uptake by other terrestrial processes	1.4 ± 1.5	1.3 ± 1.5	1.1 ± 1.1	2.0 - 3.4					1.9 ± 1.5
	(o.a. fertilisation)									

The global trend

The ratio of fossil CO_2 emission and atmospheric increase of CO_2 is not constant and depends on various processes in the climate system as is shown in Figure 4.2[1].

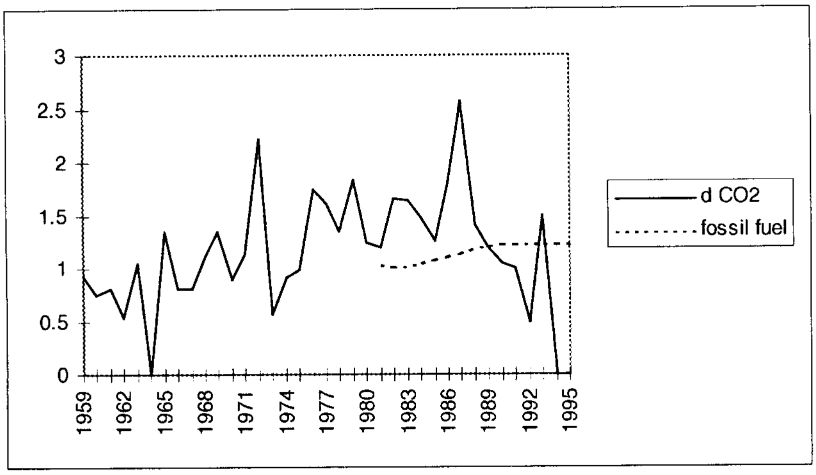

Figure 4.2 Yearly growth in CO_2 load (Gt C/yr) as derived from atmospheric measurements (CDIAC, 1998)

We may notice from Figure 4.2 that there is no fixed ratio between the CO_2 emission by fossil fuel and the increase of the CO_2 concentration in the atmosphere. The yearly variations in the increase of CO_2 mass in the atmosphere (1.5 - 3.8 Gt/yr) are much larger than the trend in the CO_2 emissions by the use of fossil fuel which is in the order of a few tens (0.1) Gt C/yr atmosphere.

Based on data from various authors, the ratio of atmospheric increase and fossil CO_2 emissions is calculated and shown in Table 4.2.

Table 4.2 Ratio of atmospheric increase and fossil fuel emission

Author	Period	Emission (Gt C)	Atmospheric increase (Gt C)	Ratio atmospheric increase/emission
IPCC 1994	1980-1989	5.5	3.2	0.58
IPCC1995	1980-1989	5.5	3.3	0.60
Houghton (1996)	1980-1989	5.5	3.2	0.58
Tans et al. (1990)	1981-1987	5.3	3	0.57
Enting et al. (1993)	1980-1987	6.13 (incl CO)	3.8	0.62
Enting et al. (1995)	1989-1990	6.5 (incl CO)	3	0.46
S. Fan et al. (1998)	1988-1992	5.9	2.8	0.47
Ciais et al. (1995)	1992	6.1	1.5	0.25
Heimann (1996)	1991-1994	6.1	2.3	0.38

We may conclude from Table 4.2 that the emission of 1 kg CO_2 leads to between 0.25 and 0.62 kg CO_2 in the atmosphere. As this ratio, due to natural variability varies from year to year, it may be possible to derive a best estimate of the effect of CO_2 emission on the atmospheric reservoir by averaging over a certain representative or typical period; and the definition of representative or typical to be established.[2]

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[1] 1998 Concentrations of CO_2 are substantially ($\approx$ 3 ppm) higher than in 1997 measured concentrations.

[2] The 1991 Mount Pinatubo eruption led to cooler, wetter conditions and a much higher global carbon uptake. We may conclude that in the period 1980-1987 the atmospheric increase/CO_2 emission ratio was substantially higher than in the period 1989-1992. The processes that cause of this difference are largely unknown.

Global CO_2 emission by fossil fuel burning

Atmospheric analysis - Top down

The uncertainty in the determination of the CO_2 emission based on atmospheric measurements is rather substantially and caused by:

- uncertainty in the trend caused by reporting of different figures by different authors, partly caused by the calculation of the global average based on a very limited number of measurements.
- inter-annual variability caused by various natural processes in the climate system.
- uncertainty in the partitioning of the CO_2 fluxes of the ocean and the biosphere.

Of the various components of the budget, only the atmospheric increase and the CO_2 emission by fossil fuel and cement production are considered to be accurately known. Ciais et al. (1995) reported an error in inferring global sources and sinks of the order of 1 Gt C/yr which agrees with uncertainties reported by the other authors. The main sources of uncertainty are the partitioning, the magnitude and the location of the ocean sink and/or the terrestrial biosphere. An uncertainty of 1 Gt C/yr is larger than the reported uncertainty in the calculated CO_2 emission by use of fossil fuel based on statistical methods, which is supposed to be about 10% or 0.6 Gt C/yr.

Emission inventory data - Bottom-up

Using national emissions, reported in the National Communications of Annex I countries, additional information by US countries studies and UNEP data and supplemented by EDGAR data for missing country data it is possible to establish a global (bottom-up) emission estimate based on statistical data which is shown in Table 4.3. This global total is in the range of the reported CO_2 emission by fossil fuel burning of the IPCC Working Group I. We therefore may assume that the global total of the CO_2 emissions by use of fossil fuel as compiled by Annex I countries and reported in their the National Communications is accurate within the uncertainty range of $\pm 10\%$. Is not possible to accurately validate the global total of the fossil CO_2 emission in inventories with measuring data and transport models because of the lesser accuracy of the latter.

Table 4.3 Global totals for 1990 carbon dioxide emission (Gt C/yr) by use of fossil fuel (adapted from Lim et al., 1999)

Source	Number of countries	Total emissions (Gt C/yr)		Global budget (Gt C/year) [a]
First National Communications	34	3.6		
Second National Communications	35		3.9[e]	-
Country studies [b]	31	1.6	1.6	-
Global database [c]	124	1.8	1.8	-
Total	190	7.0	7.3	7.1

a = IPCC Scientific Assessment 1995.

b = Braatz et al. (1996).

c = Olivier et al. (1996; 1999), only for those countries for which no National Communication or country-specific report is available.

4.1.3. The zonal budget

A next step is to increase the spatial resolution of the emission data from the global to the zonal scale in order to investigate whether emissions could be validated on a smaller scale. The purpose is to define that level of aggregation that enables a meaningful comparison of emissions estimates of different sources. The sources of information which are used are:

- a distribution of CO_2 emission by burning of fossil fuel as compiled by Marland et al. (1985),
- the EDGAR/GEIA database (Figure 4.3),
- National Communications,
- Results from atmospheric measurements and modelling.

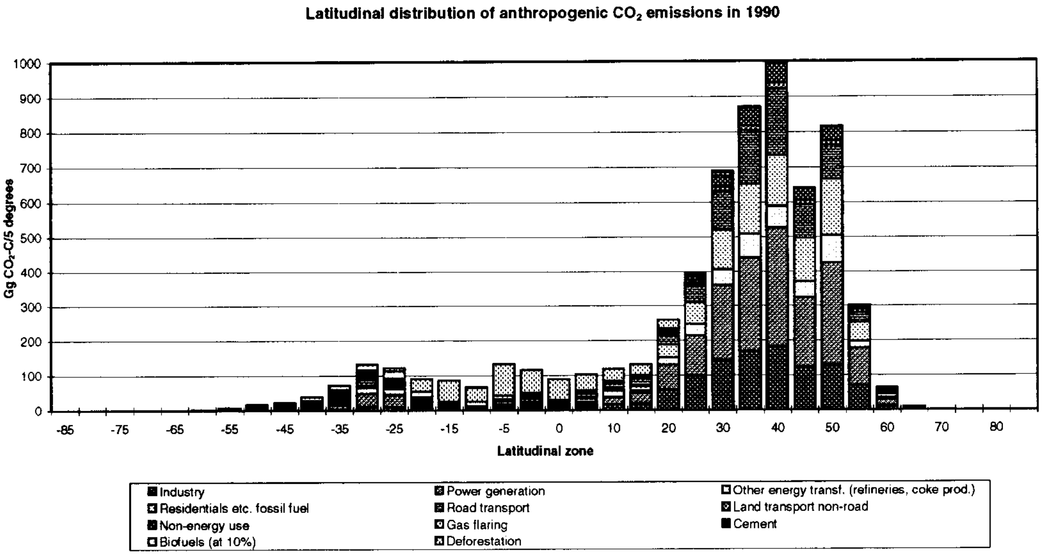

Figure 4.3 Zonal distribution of CO_2 emissions by fossil fuel burning as included in the EDGAR database (Olivier et al., 1996; 1999)

Division in regions

Because of the limited accuracy of atmospheric modelling and measurements rather broad zonal bands have been defined which also differentiate between mayor source areas. In order to be able to compare National Communications data with emission input from atmospheric and climate models a distribution of countries into zonal band has to be established, see Table 4.4 and Annex B.

Table 4.4 A zonal distribution of countries

NH high 50-70	NH mid 30-50	Tropics -20 to 30	SH mid -20 to -70
Canada	US	Mexico	Argentina
NW-Europe	S-Europe	Brasil	S-Africa
E-Europe	Middle East	Africa	Australia
Russia	N-China	Indonesia	
	Japan	India	
		Far East	

Next the national emissions have to be included into the corresponding zonal emission bands. We used the (bottom-up) NC data from Annex I countries, Country studies and UNEP data for the estimation of emissions from developing countries and EDGAR data for missing regions in order to be able to compile the global total. The result is shown in Table 4.5; see Annex B for more details.

Table 4.5 CO_2 emissions by fossil fuel burning on a zonal basis based on NC, EDGAR and Country Studies data

Region		Gt C
NH, high latitudes (NW/E-Europe, Russian Federation, Canada)	50 - 70^0 NH	≈ 2
NH, mid latitude (S. Europe, US, Japan, Middle East and China)	30 - 50^0 NH	≈ 2.5
Tropics (Mexico, Far East, Brazil, Africa, India, Indonesia)	-20 SH to 30 NH	≈ 0.7
SH mid (S. Africa, Venezuela, Argentina, Australia)	-20 to -50 SH	≈ 0.1
Total		≈ 5.3

The 5.3 Gt C about represents the global total of CO_2 emission by use of fossil fuel. The question is what part and what region is represented by the emissions reported in the National Communications.

This is shown in Table 4.6 together with results from atmospheric modelling adapted from Enting et al. (1995).

Table 4.6 A regional distribution of CO_2 sources and sinks (Gt C/yr) based on bottom-up data from Table 4.5, NC's and top-down atmospheric modelling and measurements (adapted from Enting et al.,1995)

	NH-high	NH-mid	Tropics	SH-mid	total
Fossil (bottom-up estimated global total) from Table 4.3	2	2.5	0.7	0.1	5.3
Fossil (bottom-up) 2nd NC	1.9	1.9		0.1	3.9
Biosphere	1 to 1.5	- 2.5 to -2	- 1.5 to 0.5		-1 to - 3
Ocean	- 1	-2	3 to 4	-2.0 to -2.5	-1 to -2
Atmosphere					1.3 to 3.8
Law et al. (1994) Net flux	1.5 to 4.8			- 1.2 to 1	0.7 to 4.3 = atmospheric increase

The conclusions are:

- A substantial amount of National Communication CO_2 emission data is lacking from countries in the Northern Hemisphere-midzone (0.6 Gt C) and in the Tropics (0.7 Gt C).
- It is not possible to validate CO_2 emissions on a zonal or smaller scale accurately using measurements and transport models (Hutjes et al., 1998; Anonymous, 1999). The question of a zonal CO_2 budget is complex and depends on analysed period, model, model and investigator.

4.1.4. The regional budget

Derwent et al. (1998) published time series the radiatively active trace gases: CO_2, CH_4, N_2O, O_3, HFCs and HCFCs measured at Mace Head. They analysed measured trends in atmospheric concentrations for several trace gases in terms of changes of emissions and comparisons with emission inventories. They reported an increase of the CO_2 concentration of about 2 ppm/yr between 1993 and 1996 and an elevation of 5-10 ppm compared with background air in the case winds were blowing from source regions. Because of complexity of the CO_2 budget, they did not quantify the CO_2 budget in terms of sources and sinks.

The conclusion is that the uncertainties in the magnitude of the regional natural sources and sinks is still that high that the relatively small discrepancies in the emission of CO_2 by fossil fuel burning cannot be resolved. A more accurate estimation of the global and regional CO_2 budget requires a more elaborated monitoring network.

4.1.5. Additional measurements; monitoring networks, regional analysis

The exist four main approaches for inferring fluxes of greenhouse gases such as CO_2, from measurements:

- sampling CO_2 levels in the air as is done in the SIO Air Sampling network, the NOAA/CMDL network and the ALE/GAGE network and use these data in inverse modelling studies (Enting et al., 1993, 1995; Ciais et al., 1995, 1997; Heimann, 1996);
- measuring carbon in forests and analysing human-altered landscapes (Phillips et al., 1998);
- erecting towers that that trace CO_2 fluxes between land and air (Martin, 1998);
- using satellites to estimate photosynthesis and thus CO_2 consumption - by plants - across ecosystems (Kaiser and Schmidt, 1998).

These approaches have been used in various monitoring programs.

Global monitoring programs

Besides global monitoring programs such as G3OS (Global Ocean Observing System; Global Terrestrial Observing System and Global Atmospheric Observing System = G3OS) and WMO Global

Atmospheric Watch (WMO-GAW) there exist a number of new initiatives to set up global and regional networks to evaluate regional and preferably national CO_2 budgets. These initiatives gained importance since the Kyoto protocol allowed to take sinks (i.e. forests) into account also. From the conclusion presented above it may be clear that the required accuracy is lacking to evaluate sinks as part of the Protocol.

At the moment a global network of CO_2 monitoring towers is erected consisting of 24 North American flux towers (Ameriflux), linked with the European Euroflux project and measuring towers in Japan, the Amazon, Australia, Siberia and Southeast Asia called Fluxnet, which is funded by NASA to use the data to calibrate an Earth observing satellite. These monitoring programs such as the European Eurofux project and likewise monitoring programs in North America are directed to determine the sink strength of regional forests directly from atmospheric measurements and models (Kaiser and Schmidt, 1998; Martin, 1998). Background information about the monitoring of the climate system and a framework for a Dutch contribution to such global monitoring programs is described by Van der Laan et al. (1998).

Network design

Analysis by Fan et al. (1998), Phillips et al. (1998), Tian et al. (1998) and Enting et al.(1993; 1995) are examples of attempts to evaluate the CO_2 budget at a smaller scale based on detailed results of CO_2 air sampling and monitoring networks. Preliminary results show that the results depend on the experimental set-up and very sensitive to the lay out of the monitoring network (Fan et al., 1998; Kaminski et al., 1997; Rayner et al., 1996). The conclusion is that the current network is not suitable to constrain both the global budget and the regional distribution of sources. Rayner et al. (1996) remark that a new network design requires clear criteria to what we wish to constrain:

- the contribution of individual sources which requires knowledge of the *total* variance;
- the global carbon cycle which requires knowledge of the global fluxes and the *global* variance.

The global variance may benefit from a correlation between sources and at the same time obscure the contribution of individual sources, decreasing the total variance. So there may exist some conflicting interests.

Modelling

All these measuring efforts require additional modelling efforts to do the necessary upscaling, interpolation and integration of the measuring results to the required spatial and temporal resolution. It appeared that the covariance between seasonal and daily exchange of CO_2 and CH_4 in the boundary layer and higher levels in the atmosphere increased the concentration gradients between the hemispheres known as the ‘rectifier effect’ (Law et al., 1996; Denning et al., 1996). This puts more emphasis on modelling emission and dispersion processes on smaller time scales and a good description of the boundary layer. However, at this moment the sparse density of the measuring network is the bottleneck for a more detailed analysis of the CO_2 budget.

4.2. Methane

4.2.1. Atmospheric concentrations, monitoring and trends

The global averaged methane concentration, as measured in the ALE/GAGE network at five background stations at different latitudes was 1743 ppb in 1997 which is somewhat more than 1 ppb below the average concentration in 1996. This recent decline as measured in the ALE/GAGE network, is caused by a decline of the average concentrations measured in the Northern Hemisphere. Concentrations at the Southern Hemisphere are still increasing, however at a lower rate compared with the average increase of over 10 ppb/yr at the end of the eighties. Dlugokenky et al. (1998) calculates for the global average CH_4 concentrations still a small increase of a few ppb, based on an

analysis of measurements from air samples at 29 land-based sites and 2 ship cruises in the Pacific Ocean of the NOAA/CMDL network.
The calculation of the global averaged CH_4 concentration is based on the assumption that the CH_4 measuring network is representative of the spatial distribution of the concentrations. As the global network for measuring concentrations of greenhouse gases is rather scarce, the calculated concentration field depends on the characteristics of the measuring locations and the interpolation method. This may cause differences between reported average concentrations by different authors.
Measurements in Kollummerwaard which are representative for methane concentrations in north-west Europe have been decreasing for some years and fit in the picture of decreasing concentrations in the Northern Hemisphere[3].

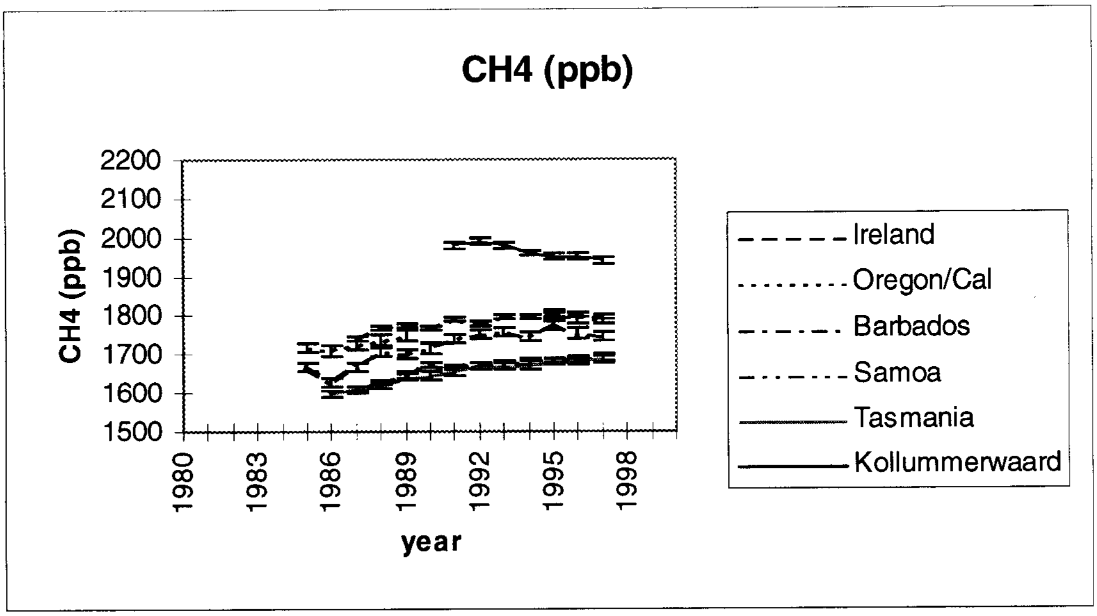

Figure 4.4 The course of the yearly averaged CH_4 concentration at five background stations and one station in a source area (Kollummerwaard)

The global trend

An analysis of the trend in the global average CH_4 concentrations by Dlugokencky et al. (1998) suggests that the diminishing growth rate over the past ten years is caused by about constant net CH_4 emissions in that period assuming the OH concentration has remained constant (see also footnote 1).

The Figure 4.5 from the Ozone Assessment Report (1998) and Figure 4.6 from Dlugokencky et al. (1998) show that:

- the yearly variations at the Northern and Southern Hemisphere may differ substantially;
- the eruption of the Pinatubo had a very large effect on the atmospheric concentration of CH_4 and may effect the trend substantially.

These variations obscure a clear separation of natural variations and a global trend caused by human activities.

Dlugokencky et al. (1998) calculate a annual global source CH_4 source between 449 and 580 Tg/yr depending on an atmospheric lifetime of CH_4 between 11 and 8.4 years respectively. This is in agreement with other model studies such as presented in Table 4.7.

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[3] The average concentrations of CH_4 in 1998 are substantially (≈ 5 ppb) higher than in 1997.

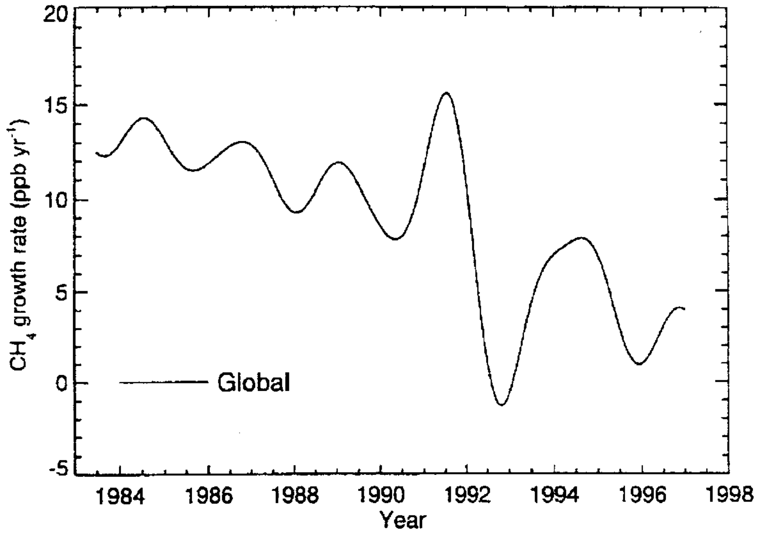

Figure 4.5 Instantaneous growth rate calculated as the deriviate of the long-term trend line shown for the NOAA/CMDL global CH_4 averages (1998 Ozone Assessment Report).

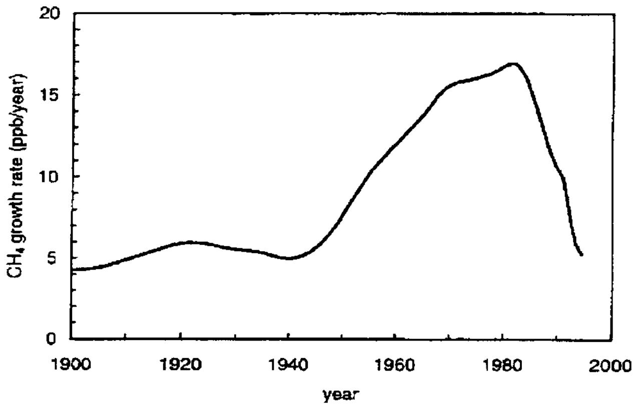

Figure 4.6 Instantaneous global CH_4 growth rate for the period 1900 to 1995 from Etheridge et al. (1997)

The global budget of methane

Between 0% and about 10% of the yearly CH_4 emission (of between 450 and 650 Tg CH_4/yr) remains in the atmosphere, i.e. between 0 and 65 Tg CH_4/yr (IPCC, 1995). Dlugokencky et al. (1998) reported a long-term trend of 8.9 ppb/yr over the period 1984-1996. Time series of CH_4 concentrations show that yearly variations of over 5 ppb occur corresponding with yearly variations in the atmospheric increase of over 20 Tg/yr. It is unknown whether changes in source strengths or changes in sinks caused these variations. It is therefore not possible to accurately estimate the global emission strength based on measurements of the atmospheric increase alone. This means that the global CH_4 emission can only accurately be determined:

- on a yearly basis if the modelling of the yearly variations is much approved (for instance by accurately modelling the OH concentration), or
- on a longer time scale of say 10 years if the a long term trend can be established above the background of the yearly natural variations.

Table 4.7 shows an overview of CH_4 emissions based on measurements and model calculations as compiled by several authors. The anthropogenic total ranges between 300 and 450 Tg/yr with an average of 375 Tg/yr.

Table 4.8 shows an estimate of the global total of anthropogenic emissions based on statistical data from bottom-up emission inventories by adding emission data from country studies and the EDGAR database to the data from the first and second National Communications.

Table 4.7 Global totals for methane (adapted from Lim et al., 1999)

Source	Number of countries	Total emissions (Tg/year)		Global budget (Tg/year)[a]
First National Communications[b]	33	104		
Second National Communications[b]	33	108		-
Country studies[c]	31	66	86	-
		(B'96)	(+MB)	
Global database[d]	125	121	121	-
Total	189	291	313	375 (300- 450)
		(1st)	(2nd)	

a = IPCC (1996).
b = UNFCCC (1997).
c = Braatz et al. (1996) and including Mitra and Battacharyra (1998), respectively.
d = Olivier et al. (1996; 1999).

This total of 291 Tg/yr (1st NC) and 313 Tg/yr (2nd NC) may be compared with the global budget of 375 Tg/yr derived from measurements and model calculations. The bottom-up estimate is substantially lower than the top-down estimate. The discrepancy between the global budget and the sum of national inventories is about 30% and is within the expected uncertainty range, however on the very low end.

The zonal distribution of sources

A next step is to investigate whether emissions could be validated on a smaller scale. The sources of information which are used are:

- the EDGAR/GEIA database;
- National Communications;
- results from atmospheric measurements and modelling.

Division in regions

In the same manner as has been done for CO_2, also for CH_4 rather broad zonal bands have been defined and a distribution of countries into those zonal band has to be established, see Table 4.5 and Annex B. Next the national emissions have to be included into the corresponding zonal emission bands. We used the (bottom-up) National Communication data from Annex I countries, country studies and UNEP data for the estimation of emissions from developing countries and EDGAR data for missing regions in order to be able to compile the global total. The result is shown in Table 4.9; see Annex B for more details.

Table 4.8 A global comparison of bottom-up and top-down emission estimates per source category (Tg $CH_{4/yr}$)

	Fung et al.	Taylor et al.				The et al.		Hein et al.		Saeki et al.	Lelieveld et al.	IPCC
Year of publication	1991	1991				1995		1997		1997	1998	1995
Period	1980-ties	1984				1990		1980-ties		1983-1994	1992	
Lifetime	10.1	8.3	10	8.5	10.2	10	8.2	8.3		9.1	7.9	8.6 +/- 1.6
Model emission input	Scenario 7	Source function 1		Source function 2				Crutzen (S1)	IPCC (S6)			
Uncertainties source categories	factor 2	factor 2									factor 2	
Wetlands	115			132.5		150		205-259	166-220		115-175	55-150
bogs	35(8)							36-52	33-49			
swamps	75 =60 (trop) + 15 (*)							163-213	127-179			
tundra	5											
Termites	20(*)			46.1							0-40	10-50
Oceans	10	11.5		11.5		10					5-15	5-50
Hydrates	5										5-15 (5)	
Other											0-30	10-40
Natural total (20)	**150**	**473(12)**		**190.1**		**160**		**205-259**	**166-220**	**336(18)**	**120-260**	**110-210**
Man-made:												
coal	35(9)					15		23-43	15-45		30-60	15-45
gas /oil prod	10					65 (14)		13-59	18-64		35-95	30-80
leakage	30					(15)		21-47	19-47			
subtotal	75					80						85 +
combustion												
industry												
Total fossil CH_4 (incl. hydrates) (19)	80 (10)	138.3 (13)		138.3		80		88-118	79-121	79.5	65-155(5)	70-120
Ruminants	80(11)	(12)		92.2		85		70-110	84-118		60-100	65-100
Rice	100(*)	(12)		126.8		75		46-92	42-86	(18)	30-130	20-100
biomass/waste				63.4				30-52	34-58		10-70	20-80
agric. waste		(12)								(18)		
biofuel												
Total biomass	55(*)					60		30-52	34-58	47.5	10-70	20-80
Landfills	40(*)	(13)				75		25-55	16-60	(18)	20-60	20-70
Animal waste		(13)								(18)	15-45	20-30
Sewage		(13)								(18)	15-40	15-80
Anthropogenic total	**350**			**420.7**		**375**					**300-450**	**300-450**
of which biogenic:												200-350
Total	**500**	**623.3**	**524**	**610.8**	**514**	**510(16)**	**610(17)**	**520-625**	**542**	**445-463**	**520-680**	**535 (410-660)**

Notes with Table 4.8:
The anthropogenic total ranges between 300 and 450 Tg/yr with an average of 375 Tg/yr. The global total CH_4 emission as estimated by Saeki et al. (445-463 Tg CH_4/yr) is the lowest and the global total as estimated by Taylor et al. (611-623 Tg CH_4/yr) is between the highest emissions. The assumed lifetime of CH_4 in the atmosphere is a very imported factor in the determination of the global total. The adopted lifetime of CH4 has undergone some changes in past years and ranged from about 8 years to over 10 years. This implies a change in the total source strength of CH_4 of about 20%.

The reported uncertainty ranges of the different emission estimates are summarised below per reference:

Fung et al.:
Uncertainty taken into account by modeling 7 emission input scenarios.
(7) The items 8); 9); 10) and 11 are kept fixed as considered known rather well.
(8) The individual contributions of sources labeled with an asterix (*) cannot be determined uniquely but total 295 Tg/yr.

Taylor et al.:
Uncertainty taken into account by modeling two source functions.
(12) Biogenic CH_4 excluding landfills and waste.
(13) Fossil CH_4 including landfills and waste.

The et al.:
Uncertainty discussed in a range of lifetimes (Δ= 20%) i.e. 20% of the total budget.
(14) Including leakage.
(15) Including in gas/oil production.
(16) ~100 Tg/yr.
(17) ~70 Tg/yr.

Hein et al.:
Uncertainty taken into account by evaluation of 8 emission input scenarios.

Saeki et al.:
Uncertainty expressed in the global total. Sensitivity studies of transport coefficients: K_{yy} and K_{xx}.
18) Bacterial processes
19) $^{14}CH_4$-free is 80-160 Tg/yr
20) CH_4 emissions by natural sources are included in the atmospheric modelling. These are of course an essential part of the total budget if calculated concentrations are to be compared with results of concentration measurements in the atmosphere. CH_4 emissions from natural sources are no part of the National Communications.

Table 4.9 Zonal/regional bottom-up and top-down comparison (only anthropogenic emissions) Tg $CH_{4/yr}$

	NH high 50-70	NH-mid 30-50	Tropics -20 to +30	SH -20 to -70	Tot
EDGAR [1)]	77	90	66	10	243
1st NC	59	69	27	14	170
2nd NC	65	70	46	13	195
Fung	29	116	128	17	332
Olivier [2)]	58	117	128	17	320
Hein	77	128	121	17.5	342
The	104.5	128	125	20.5	378
Taylor [3)]	76	176	177	6	435
Seaki [3)]	183	88	161	30	462

[1)] Data from first National Communications only supplemented with EDGAR data for missing countries. EDGAR (= Olivier) adds up to 320 Tg/yr. Differences of Olivier and EDGAR, which refer to the same data, are due to the coupling of EDGAR to a limited number of countries, those who submitted a NC, and next a distributions of the country emissions into zonal bands and to the division of the total gridded emission into zonal bands (Olivier)

[2)] EDGAR (= Olivier) adds up to 320 Tg/yr.

[3)] No clear division in anthropogenic and natural emissions can be made based on the definitions of source categories used.

The conclusions are:

- There are large differences between the emission estimates in the Northern Hemisphere.
- The bottom-up emission estimates (National Communications and EDGAR) are low compared with top-down estimates, especially for the Northern Hemisphere-midzone and the Tropics.
- The National Communications do not add up to the global total and a substantial amount of the anthropogenic CH_4 emission is not reported.

4.2.2 Regional emission estimates based on atmospheric measurements and models

Derwent et al. (1998) published time series the radiatively active trace gases: CO_2, CH_4, N_2O, O_3, HFCs and HCFCs measured at Mace Head. They measured trends in atmospheric concentrations for several trace gases for the 10 yr period from 1987-1997, and analysed them in terms of changes of emissions and comparisons with emission inventories. They reported annual increments in the methane concentrations of 10-40 ppb/yr between 1987 en 1989 en 1-8 ppb/yr at the end between 1994 and 1996. The mid-1996 methane concentration reached 1805.8 ± 0.1 ppb, the highest mid year value in the reported period which is about 80 ppb higher than the global average. If winds were blowing from source regions, the mean methane concentrations were about 100 ppb higher compared with background air. These data were used in atmospheric transport models to estimate the emission source strengths of the region closest to Ireland and which contains a population of 508 million and compared with the EU CORINAIR inventory of 29 European countries (McInnes, 1995). The average European methane source strength required to account for the observed methane concentrations in European polluted air masses was 32 ± 8 Mt/yr. The yearly results are shown in Table 4.10.

These results show that no clear trend in emissions based on model analysis and atmospheric measurements can be observed. Yearly variations up to 50% may occur as derived from model results. Differences between various estimates of the total CH_4 emission of West-European countries are between 20 and 35%.

Table 4.10 The CH_4 emissions of the region closest to Ireland which contain a population of 508 million, the EU CORINAIR inventory of 29 European countries and the results of national inventories (Derwent et al., 1998)

Year	Climatological model	Trajectory model	CORINAIR	National inventories
1987	47.9			
1988	22.6			
1989	22.7			
1990	31.5		45.6	
1991	35.2			
1992	31.0			
1993	23.6			
1994	40.9			
1995	30.5	57.1		
1996	34.5	49.5	31.8	38

The same analysis has been carried out by Stijnen et al. (1998) and Janssen et al. (1999) based on atmospheric measuring results at Kollummerwaard in the Netherlands and Mace Head in Ireland for 1995 using a Kalman smoother as an inverse modelling tool developed by Zhang et al. (1999). Figure 4.7 shows some results of calculations of the CH_4 concentration field in Europe using an atmospheric transport model and atmospheric measurements in a data-assimilation procedure. The gridded LOTOS database of CH_4 emissions was used as an 'a priori' emission estimate. Results of calculated and assimilated CH_4 concentrations are shown in Figure 4.7 below and show that the Kalman filter performs very well. The assimilated concentrations are generally somewhat higher than calculated concentrations, which are only based on the results of the Euros model, and the "a priori" emission data which indicate that 'a priori' emission estimates in that area might be to low.

Table 4.11 Results of emission inventories and inverse model calculations of the CH_4 budget of Western Europe (in Gg/yr)

	National Communications (1990)	LOTOS 'A priori' emission estimate (1990)	COMET Inverse (Vermeulen et al., 1999)	Roemer and Van Loon (in Berdowski et al., 1998)	Kalman smoother estimate [1]
Netherlands	1060	797	800	980	≈1000
Belgium	380	634	600	630	≈ 700
Denmark	407	310		350	≈ 450
Germany	5682	3806	3600	5730	≈ 4500
United Kingdom	4531	2289	4800	4900	≈ 5000
North Sea	-	270	500		600-1200 [2]
Italy	3902	1873			? [3]

[1] This update is based on the measuring period 1- 31 October 1995. A sensitivity analysis showed that these model results are very sensitive for the mixing heights in the model and the background concentrations at the boundaries of the model area (Vermeulen and Roemer, 1998). The background concentrations are taken from the TM-2 model (Houweling, 1998)

[2] The attribution of the concentration update in that area to the emission of specific sources is not accurate.

[3] No measuring data available for this area.

Nibet et al. (1998) used isotope measuring data and atmospheric modelling to validate national and regional inventory data notably the CORINAIR 1990 data. The measuring data have been elaborated by Vermeulen et al. (1999) who used the inverse of a Langrangian model to estimate CH_4 emissions in NW Europe. They used continuous concentration measurements at Cabauw, a meteorological tower of 200 m in the centre of the Netherlands. Because the air was sampled at 200 m, the contribution of local sources has been levelled off. These results are compared with results of other emission inventories and atmospheric transport model and shown in Table 4.11. This analysis shows that emission estimates for different countries may vary between about 15% up to a factor of 2. A sensitivity analysis showed that the results in Table 4.12 above are very sensitive for the assumed continental background concentration. These results show that if accurate measuring results are available atmospheric transport models can be used as independent tools to validate emission inventories, even at a regional scale.

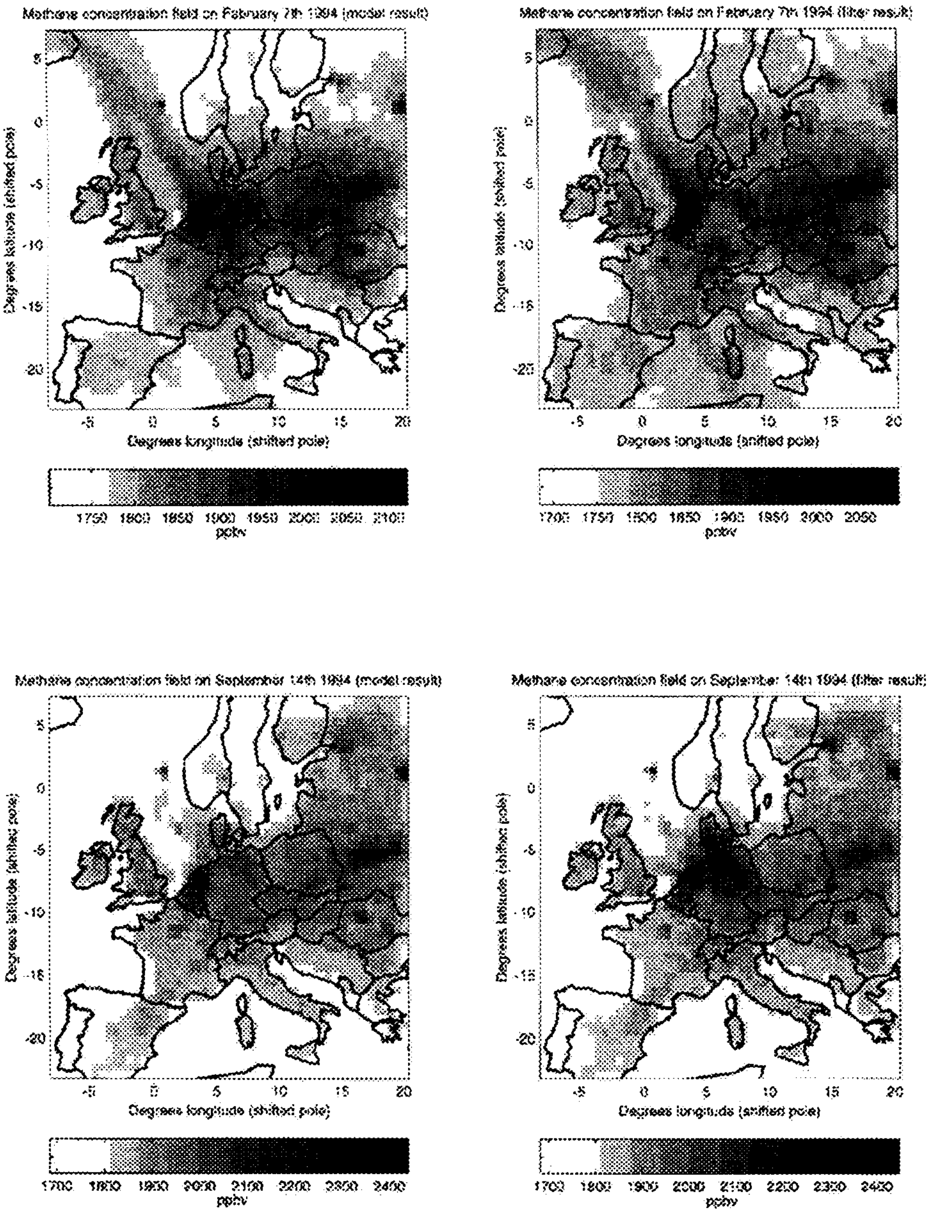

Figure 4.7 Results of calculations using only the Euros model (left) and results of the Euros model assimilated with measuring data of Kollummerwaard and the Kalman filter as a data assimilation tool (right).

4.3. Nitrous oxide

The average concentration in 1997 was 311.5 ppb and about 0.5 ppb higher than in 1996 (Figure 4.8). The global average of 1997 is between 312 ppm as measured at the Northern Hemisphere and 311 at the Southern Hemisphere (ALE/GAGE; RIVM, 1997)[4]. The pre-industrial concentration was about 275 ppb (IPCC, 1975).

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[4] The average N_2O concentration in 1998 was 312.1 ppb.

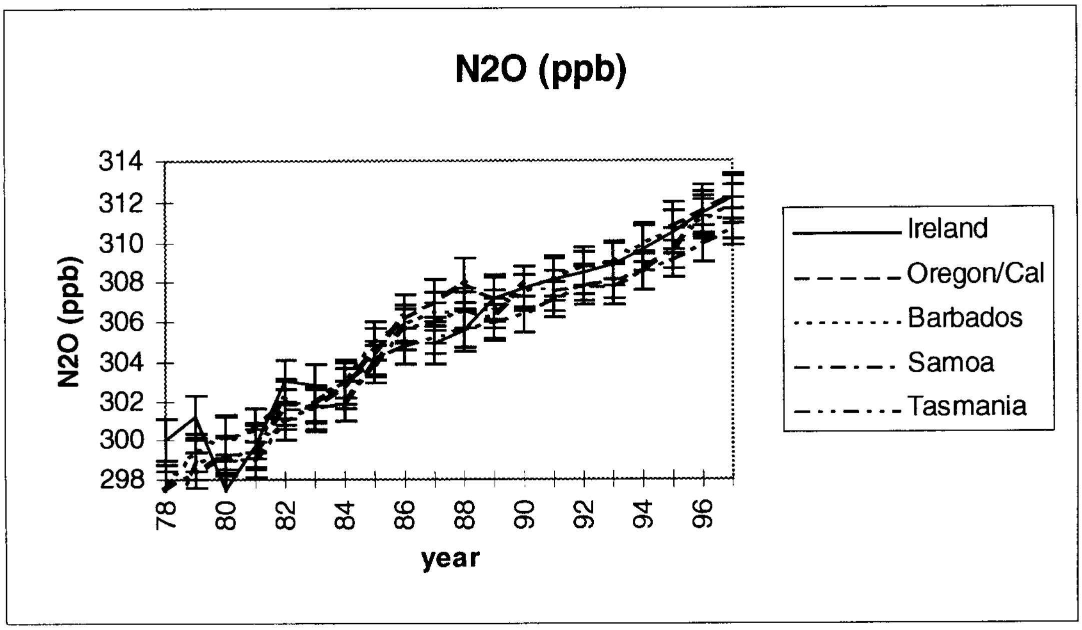

Figure 4.8 The course of the yearly averaged N_2O concentration at some background stations (ALE/GAGE).

4.3.1. The global budget

N_2O is one of the natural components of the earth's atmosphere. Global budget studies show that it is difficult to explain the observed increase in atmospheric nitrous oxide. It appears to be a mayor problem to quantify natural and (notably the biogenic part of) anthropogenic sources of N_2O and their changes over time as the N_2O budget is not well constrained. At the moment it is assumed that both natural and anthropogenic N_2O emissions stem to a large extent from biogenic sources. Using the revised IPCC Guidelines for agricultural emissions as developed by Mosier et al. it appeared to be possible to derive a closed global N_2O budget. Recently, Kroeze et al. (1999) presented an evaluation of the N_2O budget using an atmospheric box model. They show that increases in atmospheric N_2O could be primarily attributed to changes in food production systems. They proposed a budget for 1994 shown in Table 4.12. As can be noted from this table, we estimate that a fraction of about 4/8 ≈ 0.5 of the total anthropogenic N_2O emissions remains in the atmosphere.

Table 4.12 Global budget for N_2O for the year 1994 as compiled by Kroeze et al. (1999)

Source	Source strength (Tg N/yr)
Energy	0.9
Industry	0.3
Biomass burning	0.6
Agricultural	6.2
Total anthropogenic	**8**
Natural	9.6
Total global	**17.7**
Atmospheric increase	4

Comparison with inventory data

The global total has been established by adding Country studies data and EDGAR data to the emission data from the 1st and 2nd National Communications as previously has been done for CO_2 and CH_4, see also Appendix B. We conclude that for N_2O, the sum of inventories is far off the global budget (Table 4.13). However, the bottom-up estimates of total emissions were based on the previous IPCC method for N_2O (IPCC, 1995). If the current *Revised 1996 IPCC Guidelines* (IPCC, 1997), are used the global emission estimate will be higher. Mosier et al. (1999) estimated global N_2O emissions by agriculture alone of 6.2 Tg N/yr. This is in the range required to close the global budget giving confidence in the *Revised 1996 IPCC Guidelines*. The conclusion is that N_2O emission estimated with the methods prescribed in the 1995 IPCC Guidelines are probably too low. The revised Guidelines may give an improved description of the emission.

Table 4.13 Global totals for nitrous oxide (adapted from Lim et al., 1999)

Source	Number of countries	Total anthropogenic emissions (Tg N/year)		Global budget (Tg N/year) [a]
First National Communications [b]	33	2.0		-
Secondnd National Nommunications [b]	33	2.2		
Country studies [c]	31	0.1		-
Global database [d]	125	2.8		-
Total	189	4.9 (1st NC)	5.1 (2nd NC)	8 (5-13)

a = Kroeze et al. (1999).
b =UNFCCC (1997) and 1995 IPCC Guidelines.
c = Braatz et al. (1996).
d = Olivier et al. (1996; 1999).

4.3.2. The zonal budget

Bouwman and Taylor (1996) and Prinn et al (1990) derived zonal distributions of sources and sinks of N_2O. Due to the rather homogeneous distribution of sources and the long lifetime of N_2O in the atmosphere (over 100 years), the spatial gradients are very small (about 1 ppb, or about 0.3%). This hampers the establishment of a detailed spatial distribution of sources based on atmospheric measurements (Janssen et al., 1997). A more detailed bottom-up emission inventory based on statistical data is prepared by Olivier et al.; the EDGAR/GEIA database (Olivier and Bouwman (1997) and Olivier et al. (1996; 1999).

In order to be able to compare these national emission inventories with results of atmospheric models the country emissions have been distributed into zonal bands as is shown in Table 4.14.

Table 4.14 Zonal distribution of N_2O emissions based on national emission inventories (Tg N/yr)

	NH high 50-70	NH-mid 30-50	Tropics -20 to +30	SH -20 to -70	Total
EDGAR 1)	1.1	0.7	0	0.1	1.9
1st NC	1.2	0.7	0	0.1	1.9
2nd NC	1.3	0.4	0	0.1	1.8
Prinn et al. (anthropogenic emissions) 2)	1.6	2.1	1.6	0.5	6.0

1) Data from first National Communications only supplemented with EDGAR data for missing countries. EDGAR adds up to 3.6 Tg N/yr. Differences are due to the coupling of EDGAR to a limited number of countries, those who submitted a NC, and next a distributions of the country emissions into zonal bands and to the division of the total gridded emission into zonal bands.

2) Elaborated in Janssen (1997). This estimate is somewhat lower than estimated by Kroeze et al. (1999).

From this comparison it can be concluded that:

- A substantial part of the anthropogenic N_2O emission is missing, which is due to:
  - a number of countries (non-Annex I) has not yet reported their emissions;
  - countries have used the original *IPCC 1995 Guidelines* in their National Communication; using the *Revised IPCC 1996 Guidelines* will increase the reported emissions.
- An analysis of Mosier indicated that by using the revised guidelines the reported emissions may approach the global budget as calculated by Kroeze et al. (1999).
- The anthropogenic N_2O emission as estimated by Prinn et al. (1990) based on measurements and model calculations, is somewhat lower than estimated by Kroeze et al. (1999).

5. Lessons for the IPCC guidelines: Reporting of emissions

5.1 Introduction

Many industrialised countries have reported their emissions in their First and Second National Communications to the Climate Secretariat in Bonn. A wealth of experience has been developed over the last ten years on emission inventories. Developing countries are in the process of capacity building for inventory work. Many started to use the IPCC methodology in 1994 and reported their emissions unofficially through country studies programmes financed by UNEP, various Annex-1 countries and the Global Environment Facility. In this process they developed expertise in the preparation of emission inventories. In many cases they also started research to develop their own country-specific emission factors.

5.2 Good practice guidelines in the perspective of the Kyoto Protocol

It is vital to guide these developments well. For example, criteria for good practice could be developed for reporting. For this reason, the IPCC Guidelines Programme wants to bring experts from these countries together to start developing good practice guidelines. In 1999/2000 seven expert meetings on this subject were to be organised:

1. Industry/New Gases in January 1999 in Washington, USA
2. Agriculture/Methane and Nitrous oxide in February 1999 in Wageningen, the Netherlands
3. Energy, Transport and Fugitive emissions from Oil & Gas in April 1999 in Prague in the Czech Republic
4. Waste/Methane and Nitrous Oxide in July 1999 in Sao Paolo, Brazil
5. Cross-Sectoral Methodologies for Uncertainty Estimation and Inventory Quality in October 1999 in London, UK, organised to develop the general chapters for the draft IPCC report on "Good Practice Guidelines"
6. In February 2000, a final Expert Meeting will be held, in which the comments from government and expert review of the draft IPCC Report on Good Practice in Inventory Preparation will be evaluated.

For the workshop in Wageningen in February 1999 the most important agricultural sources and sinks of methane and nitrous oxide were covered to allow the exchange of experience between experts in preparing emission inventories. A draft of this comparison study was one of the building blocks in preparation of the meeting.

5.3 Common reporting format for estimating emissions and evaluating uncertainty

A common reporting format is needed for the review of country inventories. It allows assessment of the consistency, accuracy, transparency, uncertainty and validity of estimates. It allows common reporting of key issues involved in estimating uncertainties in annual emission inventories and in emission trends for individual countries. Emission inventories for greenhouse gases may contain parts showing considerable uncertainties, in particular for non-fossil fuel sources. It is vital to report on the overall effect of these uncertainties on the uncertainty of reported trends in greenhouse gas emissions. However, this should not pose a problem as long as the emission factors used are comparable with those used by other countries - within the uncertainty ranges - or can be justified by special national circumstances. This flags the need for reporting emission factors at an appropriate level, as well as estimating and reporting the uncertainty in factors contributing to sectoral emission estimates.

As the art of estimating country emissions and their associated uncertainty is developed at different levels of sophistication in different countries, a so-called 'tiered approach' aiming at quantified uncertainty estimates may be the most appropriate. Tier I is a simplified method for estimating the uncertainty quantitatively e.g. based on expert judgement, whereas subsequent Tiers use more detailed, data-intensive methods for the uncertainty estimates.

Such an approach will provide a means for generating comparable figures for many countries on the short term. In addition, it will allow reported levels of uncertainty to be evaluated soon in a more comprehensive way and assessments of uncertainties in a broader context. For example, it will allow uncertainties to be evaluated in regional or sectoral comparisons and 'chain calculations' from emissions to climate change, which address uncertainty in all elements of the chain in a harmonised way, e.g. through the use of uncertainty factors. In summary, it will facilitate:

- cross-border comparison for all countries where inventories are available (for checking comparability, inadvertent errors or identifying highly deviating emission factors and/or apparent country specific circumstances);
- uncertainty estimates for global regions (e.g. Annex I countries to the UNFCCC);
- uncertainty estimates for the world (by extrapolation, if required);
- insight into the robustness of reported emission trends for 1990 to 2012;
- comparison with reference inventories developed by other authoritative sources (for checking completeness, consistency, correct source allocation, and for inadvertent errors, which are also aspects of uncertainty within inventories that can only be evaluated using this method);
- comparison with independent top-down estimates by reverse modelling of atmospheric concentration measurements (for checking for possible biases in country totals or global or regional sectoral totals).

5.3.1. UNFCCC/Kyoto requirements

CO_2 emissions from fossil fuel use are, in general, known quite accurately. Therefore, generally speaking, uncertainty in greenhouse gas emissions is only relevant for non-CO_2 gases, which contribute only about 1/4 to 1/3 to total CO_2-eq. emissions of a country. So why are uncertainties then relevant for climate policies in contrast with, for instance, the ECE protocols on the reduction of acidifying compounds? Possibly because in contrast with other emission control policies where a number of technological measures can reduce emissions considerably, mitigation of greenhouse gases appears to be much harder to achieve. For example, this is because almost all measures have only a limited effect and many are needed. If, in addition, the practically feasible reduction potential in CO_2-eq. is the largest for the non-CO_2 gases - since the energy-related CO_2 emission is much harder to control - the robustness of the national policy mix of measures for achieving emission reduction targets is to a large extent dependent on the degree of uncertainty in emissions of sectors that are supposed to contribute substantially to the overall reduction target. However, this picture may change considerably when annual emissions or trends in emissions appear to be much lower (or higher) than the current estimate. A sector contributing, for instance, 10% to the national reduction target, may in fact contribute only 5% (or 15%) if its annual emissions appear to be 50% lower (or 50% higher).

This effect can be even larger when uncertainties in long-range trends are included (see Fig. 5.1).

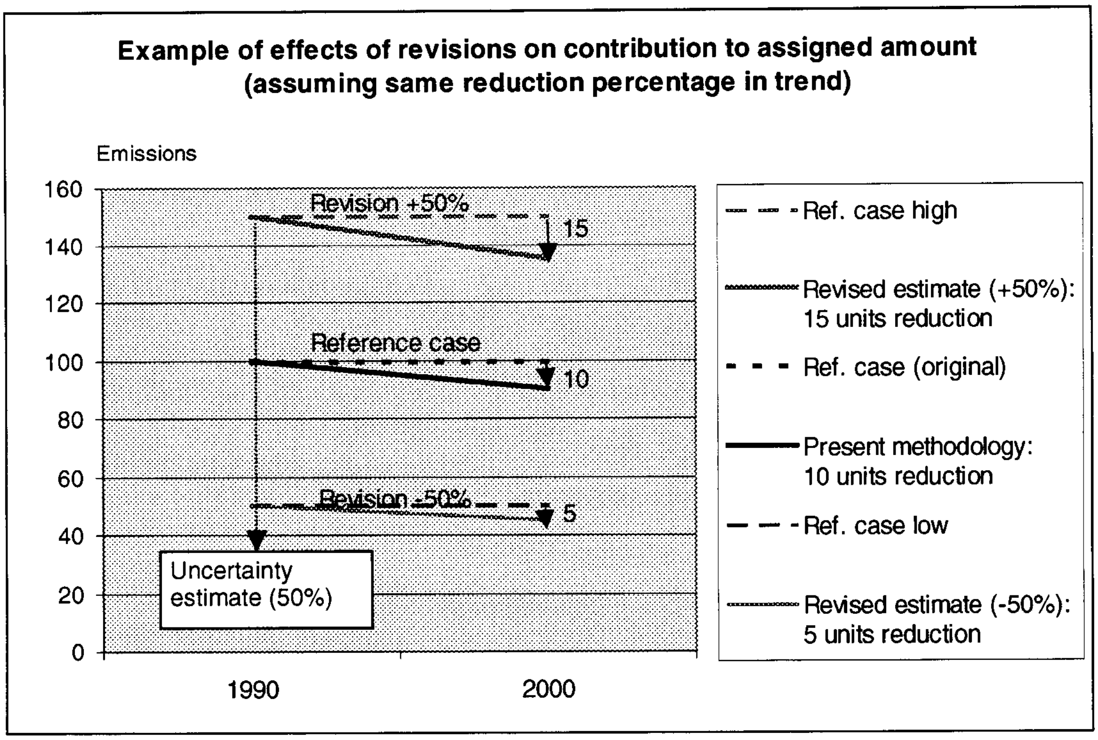

Fig. 5.1 Effects on reduction targets when uncertainties in long-range trends are included.

Thus, from the perspective of the UNFCCC the following aspects would appear to be relevant:

1. Uncertainty in annual inventories
This uncertainty is relevant because large uncertainties are identified, thus indicating areas of possible significant future changes in emissions due to improvement in methods/data. This also assists in setting priorities for improved monitoring and provides guidance on which parts in the inventory need the best verification or QA procedures. In addition, absolute annual emissions may be relevant for burden-sharing within a group of countries of agreed emission reduction objectives (e.g. the Brazilian proposal or the EU burden differentiation, but also for JI and emission trading between countries).

2. Uncertainty in emission trends for subsequent years
This uncertainty is highly relevant for checking compliance with agreed reduction targets expressed as a percentage of base year emissions (e.g. Kyoto Protocol for 6 (groups of) gases for Annex I countries).

3. Uncertainty in geographic detail in spatially and temporally resolved annual inventories
This uncertainty refers to allocating national emissions to a finer grid and into monthly, weekly or diurnal emission distributions, often required for comparison with back-calculated emissions from atmospheric concentration measurements. This is a truly independent verification procedure for regions or sectors feasible for application at country level when sufficient measurement data are available.

5.3.2. Sources and types of uncertainty relevant for greenhouse gases

Emission estimates for specific source categories are usually based on national activity data and emission factors, the latter representing the emission rate per unit of activity concerned. In some cases the emissions depend on other factors as well, for example time-delayed emissions from landfills or refrigerators or climate dependent emissions from natural sources. Subsequently, national total figures may be spatially distributed on a grid using geographical information on the exact location of the sources or gridded using thematic maps as a surrogate for distribution on a grid within a country. When a finer temporal resolution is required, standard procedure is to split up the annual data by using so-called time profiles defined per emission source.

A specific uncertainty that may occur in greenhouse gas inventories prepared according to the *IPCC Guidelines* is due to the different emission figures that may result from the use of tiers that refer to very different methodologies. This may be the case when the *IPCC Guidelines* propose to use a tiered approach dependent on data availability, but when these tiers refer to very different methodologies. For example including or not including time delays in emissions like in methane from landfills. This type of uncertainty can be studied by countries with sufficient data by comparing the results of using the different tiers; even better would be to resolve this discrepancy between tiers. However, we will not address this issue further in this paper.

Uncertainties in national emissions can therefore be traced back to the uncertainty in (1) activity data and (2) emission factors. For more detailed inventories in space and time, uncertainty is subsequently added by step (3) distribution of national totals to the grid and (4) distribution over time. We will proceed to discuss variables (1) and (2), which in practice are interrelated:

(1) Activity data
For application of emission factors, a source category is preferably split into subcategories that have distinctly different emission factors, but which can be considered more or less homogeneous with respect to emission factors within these subcategories. When activity data are determined for these subcategories as part of the regular national statistics, standard statistical procedures on data collection should be able to provide numerical estimates of the associated uncertainty unless data are required on sub-activities that are not part of the regular data collection process. If the case of the latter, the uncertainty is further determined on top of the statistical uncertainty in the activity regularly monitored at a higher aggregation level. This is done by the data quality or estimate of the shares of the sub-activities used for the emission calculation.

(2) Emission factors
Except for a few cases where emission factors are constant in time (e.g. CO_2 per unit of fuel) or continuous emissions occur, most emission factors will be generalisations of specific emission factors. Emission factors are related to either emissions measurements - but usually not covering the full time period during which the source is emitting, in other words not covering all operating conditions - or to specific operating conditions. This means that ultimately the selection of a representative emission factor implies the selection of an emission factor thought by experts to be representative of the overall time-averaged and source-characteristic-averaged emission rate. In doing so, the uncertainty refers to the knowledge on in-homogeneity in source conditions influencing the emission rates.

Recognising that the application of emission factors depends both on the level of aggregation for which homogeneous emission factors exist and the level of aggregation for which activity data are collected on a routine basis, compromises may, in practice, have to be made since these levels do not always match. In the next sections we will give some examples to clarify this principle.

5.3.3. Determination of relevant activity data and emission factors

Coal production statistics are generally available by coal type. However, the methane emission factor is a function of different variables, a key one being the depth of the coal seam that is being excavated. Suppose a number of emission measurements have been taken for various coal types and mining depths, then the question is how to generalise the emission factors for specific measured locations to other coal seams at the same and at other depths. One approach is to distinguish, per coal type, between underground mining and surface mining, since there appears to be a large difference in emission factor values for these two distinct different types of mining. Then one considers coal production per type of mining as the activity data and the emission factor for each type to use in the calculation. Per mining type this is either a weighted average of emission factors for all mining basins (if determined in some way) or the experts judgement of the average emission factor per type, taking into account the characteristics of the mining influencing the emission rate and the specific circumstances for which the measured emission factors apply. Alternatively, one could consider the total coal production of both surface and underground mining as the activity data, since this is easily available in statistics and derives an average, aggregated emission factor from the weighted average of assumed emission factors for each mining type.

Another similar example concerns emissions from passenger cars. Here activity data may be defined as total fuel consumption by this transport category. Alternatively, one may distinguish between fuel consumption of cars with and without a catalytic converter, or even fuel consumption in different operating modes (cold start, urban, rural and highway driving). Each of these types of cars and driving conditions may have specific emission factors. So if detailed information on fuel consumption at this level is available, the estimation of the applicable fleet-averaged (i.e. for all car types, with a mix of maintenance levels and age classes) emission factors can be done at a lower level. However, this still requires the expert judgement of the average emission factor per type, taking into account the characteristics of the whole fleet in relation to available measured or elsewhere reported emission factors.

These examples clearly show that in general:

- Emission factors used in emission estimates depend on the level of detail for which activity data exist but also on the level of (sub)activities, which have markedly different emission factors.
- Highly aggregated activity data may be readily available from the statistical offices, in contrast with the more detailed subtypes of activity for which data are often more difficult to obtain, their levels less accurately monitored (e.g. by mining type or by type of driving mode) and sometimes also less well-defined.
- Emission factors, whatever their level of aggregation, will in almost all cases represent a selection of values which, according to expert judgement, are representative for the country-wide averaged source strength.
- The definition of activity level, emission factor and aggregated emission factor for a specific source category is not obvious. The best level for estimating total emissions will depend on the levels on which activity data are available and measured, or on which reported emission factors are assumed to be applicable. In some cases this may be mine by mine, individual production plants or make of car, in other cases more aggregate levels seem to be more sensible to use.
- The long-range trend in emission factors may be dependent on the development of the mix of sub-activities, each with a distinct emission factor value as well as on the trend in intrinsic emission factors for a subcategory (e.g. through technological development like the effectiveness of catalytic converters).

From the examples discussed, we can conclude that the aggregation level used for the emission calculation may differ from country to country. This suggests that a common reporting format at meaningful levels of aggregation will be indispensable for evaluating comparability of inventories. It is also clear that statistics of whatever quality are used as activity, and sub-activity levels when required. Furthermore the selection or adjustment of emission factors is ultimately dependent on the expert judgement of its representativeness of the whole ensemble of sources.

5.3.4. Uncertainties related to the selected aggregation levels

Thus the uncertainty in calculating annual national emissions is the accumulated uncertainty in:

1. activity data based on regular (i.e. annual) national statistics,
2. emission factors, be it specific, generalised or aggregated, and, possibly,
3. sub-activity data needed to connect the available emission factors with the available regularly collected activity data.

Guidelines should provide instructions on how the scores for each of these elements should be combined to get the overall uncertainty in the resulting emissions. This aspect will not be discussed here further.

When calculating emissions for a series of years, on top of changing high level activity data, one could assume changes in emission factors, e.g. due to technological developments, and in the mix of sub-activities (with distinct different emission factors), used for calculating emissions. Therefore, uncertainty in national emission *trends* is further determined by:

- the derivation of *trends* in emission factors (only if changes in time are assumed, not so much the value itself);
- *changes* in the mix of sub-activities combined to calculate the aggregate emission factor for the higher activity data (only if changes the shares are assumed, not so much the value itself).

For verification of emission *trends* as reported under the UNFCCC, it would be sufficient to know the uncertainty in:

1. high level activity data;
2. assumed changes in emission factors, if any;
3. changes in the shares of sub-activity levels, if any.

5.3.5. Reporting format for assessing uncertainty in annual inventories

Keeping in mind the level of reporting required for a useful comparison of aggregated emission factors with other reported values (e.g. to be determined by sectoral exports), the (aggregated) emission factor in one inventory can be compared with the group of other inventories available to check for comparability or large deviations or a possible bias. It seems reasonable that in the latter cases a justification for large deviations is provided unless the value is within two standard deviations from the group average. A similar case would be for signalling large deviations from the emission factors in a reference dataset, outside of their estimated uncertainties, provided that the reference emission factors comply with sectoral emission rates determined or otherwise linked.

In order to analyse the annual emissions reported by countries using various levels of detail as illustrated above, one would need the following information:

- high level activity data: data (value and uncertainty) and definition of the level of data used;
- emission factors: level of sub-activities for which emission factors are used and the uncertainty in these emission factors;
- the mix of sub-activities used for the calculation, when applicable: data (value and uncertainty).

Obviously, here input will be needed from both statisticians and emission experts involved in the emission calculations.

5.3.6. Reporting format for assessing uncertainty in trends

In order to analyse the reported *trends* by countries using various levels of detail, in an ideal situation one would like the following information:

1. high level activity data: data (value and uncertainty) and definition of the level of data used;

2. emission factors: level of sub-activities for which emission factors are used and uncertainty found in these emission factors (for one year);
3. justification of assumed changes in emission factors, if any;
4. uncertainty in the mix of sub-activities, when applicable;
5. justification of assumed changes in the shares, if any.

This means that on top of the requirements for estimating uncertainty in *annual* emissions (1, 2 and 4) one needs a justification of assumed changes in parameters that are not always monitored annually and the related uncertainty in these changes. In particular, the input is needed here from emission experts involved in the emission calculations.

5.3.7. Tiered approach for assessing uncertainties

As discussed earlier, there is an urgent need for quantitative assessments of uncertainties, but also a varying degree of sophistication in compiling national emission inventories. Therefore it is recommended that national teams follow a tiered approach, so that at least a first quantitative evaluation for all reporting countries will be possible. A full scientific evaluation in all details at the national level will require time and man power, which may not be available. In parallel, countries with more detailed datasets and more capacity may pursue a more detailed scientific assessment of their reported uncertainties.

For annual inventories all tiers should ask for one common format e.g. as specified below, for providing of the following information based on either calculation or expert judgement (or both):

1. *Activity data for regularly monitored data*
   - specify level of uncertainty
   - specify basis, either calculated or estimated (expert judgement)
2. *Sub-activity data* for which specific emission factors were applied at a level meaningful for the purpose of comparison with other datasets (to be determined in reporting instructions)
   - specify (sub)activity level(s) used for the calculation
   - specify level of uncertainty
   - specify basis, either calculated or estimated (expert judgement)
3. *Emission factors used in the basic calculation*
   - specify (sub)activity level used for the calculation
   - specify level of uncertainty
   - specify basis, either calculated or estimated (expert judgement).

In addition, for estimating *trends* in emissions, Tier I requires uncertainty information on:

4. *Changes in time of the emission factors,* if applicable, e.g. based on expert judgement
5. *Changes in the mix of sub-activities,* if applicable, e.g. based on expert judgement.

In conjunction with the uncertainty in annual emissions, the uncertainty in changes encountered in emission factors and shares of sub-activities determines the robustness of reported emissions trends.

Tier 1

A simple approach, which should be feasible for parties with limited resources. It would also help them in identifying priority areas for improving their inventories. It would be just to rely on expert judgement for uncertainty estimates in activity data and emission factors. An exception could be made for cases where better information is readily available. Here a clear need is reflected for a classification of uncertainties to be agreed upon by a group of experts beforehand, e.g. as in Table 5.1.

For greenhouse gases, guidance could be sought from the qualifications and values already used in UNFCCC submissions, e.g. as reported in FCCC/SBSTA/1998/7, Table 14 (p. 36-37). Perhaps the Data Attribute Rating System of US-EPA (DARS) can be tied in here to derive quantitative uncertainty estimates (Beck, 1998). One also needs to decide which definition on uncertainty to use, e.g. absolute ranges or assumed standard deviation (1 standard deviation ~ 68% confidence interval;

two standard deviations ~ 95% confidence interval). According to the Annex I of the Reporting Instructions in the *Revised IPCC Guidelines*, the definition with two standard deviations should be used.

Table 5.1: Example of a classification of uncertainties

Range(±)	Uncertainty (±%)	Uncertainty Factor*	Confidence	Qualitative description
2-10%	5%	1.05	High	very small
5-20%	10%	1.1	High	small
10-50%	25%	1.25	Medium (High)	medium
20-100%	50%	1.5	Medium (Low)	large
50-150%	100%	2.	Low	very large
100-400%	200%	3.	Low	extremely large

* An uncertainty factor UF corresponds with the following range around the emissions level EM: from EM/UF to EM*UF.

To reduce the burden for countries, the uncertainty assessment in Tier 1 could be limited to sectors contributing substantially to either annual emissions or trends in annual emissions or to the emission reduction objective. This could be either per gas or in CO_2-eq., as well as cut-off percentages to be determined by an Expert Group and the UNFCCC bodies.

Tier 2

If a more elaborate emission calculation scheme is used, more detailed activity data collected regularly, and/or more local information on specific emission factors used if available, the uncertainty information as described above can be calculated instead of estimated by whole or partial expert judgement, from the more detailed datasets, using standard statistical methods. However, some expert judgement must always be used to determine if the sample is representative of the true population.

5.3.8. Advantages of reporting at fixed sectoral aggregation levels

When reporting instructions would include the provision of sectoral Standard Data Tables (also similar ones for reporting of uncertainties) the aggregated emission factors (and their estimated uncertainty) provided could be compared both with the average group value and with a reference dataset for checking for possible biases in sectoral estimates, like the sectoral Standard Data Tables in the first *1995 IPCC Guidelines for Greenhouse Gas Inventories*. These tables should be modified by sector experts in view of their usefulness for checking comparability. This check can be done by individual countries in subsequent releases of their annual inventory. Further possible inadvertent errors can be removed or large deviations from a group average can be traced and then explained and justified. Alternatively, emission experts may perform analysis on the data submitted by the countries, e.g. as part of comparability assessment for the UNFCCC or for the IPCC Greenhouse Gas Inventory Programme, with the aim of improving the guidelines or the default emission factors listed in them.

In summary, a tiered approach can be recommended for providing comparable quantitative uncertainty information (including use of expert judgement), based on the observation that many variables used in emission calculations are ultimately based on expert judgement. If in conjunction, Standard Data Tables with meaningful aggregated emission factors are provided for all sectors, these will give added value to the group of emission factors reported by other countries. Provision of these emission factor tables will also allow for self-checks of a country in subsequent releases of its inventory, as well as independent checks of the information provided in the national inventory. In particular, checks of large deviations of sectors contributing substantially to either annual emissions or trends in annual emissions. To this end, both a range of uncertainty classifications and a useful format for reporting sectoral data should be determined, e.g. by a group of experts.

In parallel, countries with sufficient detailed data may pursue and communicate a more elaborate estimate of the uncertainty in emissions. This will provide a sounder basis for improvement of emission factors currently based on expert judgement.

5.4 Example for improved reporting

The national inventories in the second National Communications are not transparent. This means that emissions cannot be recalculated by a third party, using only information from the National Communication. Reporting has to be improved. In the *Revised 1996 IPCC Guidelines* countries are asked to provide summary tables for the emissions and detailed tables for each sector on the calculation and emission factors used. These detailed tables are not always available, and/or activity data and emission factors are not included. This means that information on the activity data and emission factors is missing in many second National Communications, reducing the transparency compared to the first National Communications. As countries hesitate to give aggregated emission factors, as was asked in the first National Communications, we suggest a new reporting format that is one level more detailed. This could be a new Standard Reporting Format on the level of Sector Tables 1 to 6 of the Reporting Instructions of the *Revised 1996 IPCC Guidelines*, but with more detail, such as using three fuels in energy and other amendments (see Table 5.2 for an example). This new Standard Reporting Format should be made mandatory and should include activity data and aggregated emission factors. The suggested new table is given below. In principle, this table is applicable to all greenhouse gases, so includes the other greenhouse gases HFCs, PFCs and SF_6. It can also be used for reporting ozone precursors like NO_x, CO and NMVOC. It is suggested to choose a format so that trend reports can be made of emissions, activity data and emission factors. This approach should improve comparability across countries.

Table 5.2. Draft for New IPCC Standard Reporting Format (for reports 1990-2012) at sector level: for consideration by UNFCCC Secretariat and IPCC/OECD/IEA Guidelines Programme, and for inclusion in Good Practice Guidelines and UNFCCC Guidelines for annual reporting of Annex-I countries to the Kyoto Protocol. Format for trend reports 1990 to 2012.

Greenhouse gas source and sink categories	Activity			Emission			Implied emission factor		
(for carbon dioxide, methane, nitrous oxide; separately for HFCs, PFCs and SF$_6$)	1990	1991	1992	1990	1991	1992	1990	1991	1992
Total national emissions and removals									
1 All Energy (combustion and fugitive)									
Solid fuels									
Liquid fuels									
Gaseous fuels									
1A fuel combustion									
Solid fuels									
Liquid fuels									
Gaseous fuels									
1A1 Energy and transformation industries									
a Electricity and heat production									
Solid fuels									
Liquid fuels									
Gaseous fuels									
b Petroleum refining									
c Solid fuel transformation									
d Other									
Solid fuels									
Liquid fuels									
Gaseous fuels									
1A2 Industry									
a Combustion									
Solid fuels									
Liquid fuels									
Gaseous fuels									
c Actual from feedstocks									
Solid feedstocks									
Liquid feedstocks									
Gaseous feedstocks									
d Other									
e Off -road vehicles									
1A3 Transport									
a Road									
Catalyst controlled									
Liquid fuels									
Diesel									
Petrol									
Gaseous fuels/LPG									
Uncontrolled									
Liquid fuels									
Diesel									
Gasoline									
Gaseous fuels/ LPG									
b Rail									
Solid fuels									
Liquid fuels									
Gaseous fuels									
c Domestic civil aviation									
d Internal navigation									
e Other									
Solid fuels									
Liquid fuels									
Gaseous fuels									
4 Small combustion									
a Commercial/institutional									
Solid fuels									

            Liquid fuels
            Gaseous fuels
    b Residential
            Solid fuels
            Liquid fuels
            Gaseous fuels
    c Agriculture/Forestry
    d Other
5 Other

1B Fugitive emissions

- 1B1 Coal
  - a Underground mining
    - Hard coal
    - Brown coal
  - b Surface mining
    - Hard coal
    - Brown coal
  - c Post-mining activities
    - Hard coal
    - Brown coal
- 1B2 Oil and natural gas
  - a Oil
    - Production
    - Distribution
  - b Natural gas
    - Production
    - Transmission
    - Distribution

2 Industrial processes

- 2A Mineral products
  - 1 Cement production
  - 2 Lime production
  - 3 Limestone and dolomite use
  - 4 Soda ash production and use
  - 5 Asphalt roofing
  - 6 Road paving with asphalt
  - 7 Other (specify)
- 2B Chemical industry
  - 1 Ammonia production
  - 2 Nitric acid production
  - 3 Adipic acid production
  - 4 Carbide production
  - 5 Other (specify)
- 2C Metal production
  - 1 Iron and steel production
  - 2 Ferroalloys production
  - 3 Aluminium production
  - 4 Magnesium foundries
  - 5 Other (specify)
- 2D Other production
  - 1 Pulp and paper
  - 2 Food and drink
- 2E Halocarbons and sulfur hexafluoride
  - 1 Byproduct emission
  - 2 Fugitive emission
  - 3 Other (specify)
- 2F Consumption of halocarbons and sulfur hexafluoride
  - 1 Refrigeration and air conditioning equipment
    - Commercial
    - Residential
    - Mobile
  - 2 Foam blowing
    - Closed cell
    - Open cell

  3 Fire extinguishers
  4 Aerosols
  5 Solvents
  6 Other (specify)
2G Other (please specify)
3 Solvent and other product use
 3A Paint application
 3B Degreasing and dry cleaning
 3C Chemical products manufacture and processing
 3D Other (specify)
4 Agriculture
 4A Enteric fermentation
 4A1 Cattle
    a Beef
    b Dairy
    c Other
  2 Buffalo
  3 Sheep
  4 Goats
  5 Camels/Llamas
  6 Horses
  7 Mules and Asses
  8 Swine
  9 Poultry
  10 Other (specify)
 4B Manure management
 4B1 Cattle
   a Beef
     Anaerobic
     Liquid system
     Solid storage and dry lot
     Other (specify)
   b Dairy
     Anaerobic
     Liquid system
     Solid storage and dry lot
     Other (specify)
   c Other
     Anaerobic
     Liquid system
     Solid storage and dry lot
     Other (specify)
  2 Buffalo
  3 Sheep
  4 Goats
  5 Camels/Llamas
  6 Horses
  7 Mules and Asses
  8 Swine
     Anaerobic
     Liquid system
     Solid storage and dry lot
     Other (specify)
  9 Poultry
     Anaerobic
     Liquid system
     Solid storage and dry lot
     Other (specify)
 4C Rice
  1 Irrigated
  2 Rainfed
  3 Deep water
  4 Other (specify)
 4D Agricultural soils
  1 Peat soils

  2 Dry soils
  3 Other (please specify)
4E Prescribed burning of savannahs
4F Field burning of agricultural residue
  1 Cereals
  2 Pulse
  3 Tuber and root
  4 Sugar cane
  5 Other (please specify)
4G Other (please specify)
5 Landuse change and forestry
5A Changes in forest/woody biomass stocks
    1 Tropical forests
    2 Temperate forests
    3 Boreal forests
    4 Grasslands/ Tundra
    5 Other (please specify)
5B Forest and grassland conversion
    1 Tropical forests
    2 Temperate forests
    3 Boreal forests
    4 Grasslands/ Tundra
    5 Other (please specify)
5C Abandonment of managed lands
    1 Tropical forest
    2 Temperate forest
    3 Boreal forest
    4 Grasslands/ Tundra
    5 Other (please specify)
5D CO2 emissions/removals from soils
    1 Peat soils
    2 Other soils
5E Other (specify)
6 Waste
6A Solid waste disposal on land
    1 Managed waste disposal on land
    2 Unmanaged waste disposal on land
6B Waste water handling
  6B1 Industrial waste water
  6B2 Domestic and commercial waste water
  6B3 Other (specify)
6C Waste incineration
      1 Controlled for energy
      2 Uncontrolled not for energy
6D Other (specify)
7 Other (specify)
  7A Drinking water treatment
  7B Polluted surface waters
Memo items:
8 Memo items International Bunkers
    a Aviation liquid fuels
    b Marine liquid fuels
9 CO_2 emissions from biomass
10 Nature

5.5 Indicators

Greenhouse gas inventories give total emissions per sector per year. Indicators can be developed that give information on the trends over the years of greenhouse gas emissions per unit product or per capita. Examples that are already in use are the emission of carbon dioxide per capita in a country, the emission of methane per capita in a country, the emission of nitrous oxide per capita. Indicators can also be used to evaluate the development towards a sustainable society. However, in this case more detailed indicators are needed, e.g. the emission of different greenhouse gases per household for residential heating or electricity use. With detailed indicators good and bad performers on sustainability become immediately visible. To be able to develop good indicators, a common format is needed as well as an inventory of statistics for the construction of these indicators. A list of suggested indicators follows:

- Trend in CO_2 emissions per GDP in different industries per country;
- Trend in CO_2 emissions per GWh electricity per country;
- Trend in CO_2 emissions per ton of steel per country;
- Trend in CO_2 emissions per ton of aluminium per country;
- Trend in CO_2 emissions per unit of office space for heating;
- Trend in CO_2 emissions per unit of office space for electricity per country;
- Trend in CO_2 emissions per household for space heating;
- Trend in CO_2 emissions per household for electricity per country;
- Trend in CH_4 emissions per PJ of coal, oil and gas produced per country;
- Trend in CH_4emissions per PJ of coal, oil and gas used per country;
- Trend in CH_4emissions per ton of beef per country;
- Trend in CH_4emissions per ton of milk per country;
- Trend in N_2O emissions per ton of sugar, beef, milk etc. per country;
- Trend in N_2O emissions per ton of fertiliser produced per country;
- Trend in N_2O emissions per ton of manure produced per country.

This list is not meant to be complete, but is merely given to start the discussion. See also a report of OECD on indicators (Schipper, 1998), and two reports by Lehtilä et al. (1997a,b) from Finland. In order to build these indicators detailed information on the economy is needed. One effort to develop these kinds of indicators may be to finance pilot studies, foe example by the European Union and OECD.

5.6 Lessons for improving reporting of sectors

5.6.1 Carbon dioxide

To improve reporting and comparability across countries and with international datasets in carbon dioxide from energy, the standard statistical nomenclature should first be adopted by all countries. This standard already exists, but several difficult sectors are: combined heat and power (CHP) by producers within industry and fuel transformation. Some countries report CHP under the different industrial sectors, some countries choose to report part of CHP under energy and transformation, depending on the ownership of the plants. Second, a final decision has to be made on how to classify carbon dioxide emissions from fuel transformations. In iron and steel, the carbon dioxide emissions from coal used in the blast furnace to reduce the iron ore is sometimes classified as carbon dioxide from fuel and sometimes as carbon dioxide emissions from industrial processes. Finally, some countries report the process emissions from feedstock use under the different industrial sectors: the Netherlands reported this as actual emissions from feedstocks in one sector. This classification problem still has to be resolved.

5.6.2 Methane

Coal

The large differences that were encountered between national inventories and EDGAR were mainly the result of the use of different emission factors. A careful re-analysis of emission factors based on available inventories is recommended. A suggestion has been made to develop criteria for quality of measurement programmes, before emission factors are based on these. The two sets used by EDGAR and IPCC should be brought into line by the experts. Further, an evaluation of the possibility to incorporate a coal basin approach as used in EDGAR into the IPCC methodology is recommended, as well as to combine efforts for field experiments for methane from coal emission reductions. In different industrialised countries experiments have started in enhanced coal bed methane recovery (ECBMR). CO_2 is used to flood in situ coal strata. Carbon dioxide is adsorbed onto the coal matrix at the expense of methane. Methane is pumped up from wells drilled into the coal beds. Experiments have shown that practically no carbon dioxide is found in the recovered methane. This method can be profitable in areas where the coal is too deep for economic exploitation (Williams, 1998). Measurements could give more information on the methane content of coal strata, and the possibilities to capture and use it.

Oil and gas

The large differences between EDGAR and the national inventories for some countries were caused by the use of different emission factors. Some countries re-examined the use of their emission factors. It is recommended that the two sets of emission factors used by EDGAR and IPCC are brought into line by experts. More experimental research and measurements are needed in the regions with suspected high emissions. A methodology for up-scaling of measurement results to a national level must be developed before the start of a measurement programme, to be sure that the results can be used for developing updated emission factors. It is recommended to evaluate the recent history of emissions in Russia. The economic reform in Russia resulted in lower oil and gas production but has not yet been evaluated in terms of reduced emissions.

Combustion

The reporting on methane emissions from fossil fuel and traditional biofuel combustion is for many countries not complete. The differences are often caused by these gaps in reporting. It is recommended to improve on biofuel statistics within the countries. Seeing the large range in emission factors, the default IPCC emission factors need evaluation by experts. Some industrialised countries underestimate the existing use of traditional fuelwood in the energy mix. Statistics of fuel wood must therefore be improved in industrialised countries as well.

Enteric fermentation and manure

The differences between the national estimates and EDGAR are a consequence of the detail of reporting on each source, rather than a difference in methodology. The detailed reporting as used in country reports is recommended in this sector. If FAO statistics are available on this level of detail, these can be used for verification. Developing a global set of emission factors based on the Blaxter and Clapperton formula (1964) and using information on weight of cattle, and amount and quality of food intake in each country for representative cattle types are recommended. This calculation was already partly performed by Gibbs and Johnson (EPA, 1994) and Woodbury and Hashimoto (EPA, 1994). Evaluating the effect of changing diets on emissions is recommended. Most countries used one set of emission factors throughout 1990-1995. This means that no effects of measures or autonomous developments were taken into account. The trend over the years is merely a trend in cattle numbers. If the effects of changing diets are to be taken into account, the emission factors should be calculated using the IPCC Tier 2 equations each year. There is a strong need for measurement programmes in developing countries to evaluate the validity of the Blaxter and Clapperton method in those situations. It may be a good start to do measurements on methane release from tropical cattle types, including improved breeds.

Rice

The differences between the national estimates and EDGAR are a consequence of the rather weak international databases on planted rice area and the aggregated methane emission factors used in EDGAR. It is recommended to develop a database of rice planted area (e.g. on the basis of the IMAGE climate database) with information on growing period and soil moisture. Information on major soil types using remotely sensed information and soil maps can be used for further detail. Especially rice on peat soils will emit much methane. An example of rice expansion on peat is the transmigration project of Indonesia, where large numbers of people from Java were encouraged to migrate to newly developed agricultural areas in Irian Jaya, some on peat soils. A review of the methane emission factors used by countries for each soil type and rice variety is recommended and also a more detailed emissions factor database. Criteria for good practice should be developed for incorporation of emission factors from measurement programmes into this database. It is recommended to develop a database on fertiliser and manure application in the different rice planted areas. A new global estimate of methane emissions from wet rice fields was made by Sass and others, reported in the IGAC Newsletter (Sass et al., 1998). Sass used the revised IPCC methodology but, confronted with the lack of information on rice area differentiation and organic matter application, he made some extra assumptions. The total emission estimate is rather low compared to earlier IPCC estimates: 40 instead of 60 Tg methane per year.

Agricultural waste burning

The reporting in this sector is irregular. Statistics on agricultural waste burning are weak. The emission factor used in the Tier 1 approach (1% of carbon combusted is emitted as methane) needs evaluation in the light of newly reported values.

Savanna burning

The reporting in this sector is not complete. Bush fires in Australia are reported here. The emission factors need re-evaluation in the light of new information that has become available through country studies.

Soils

It is very important that a clear definition is drawn up for anthropogenic methane emissions from soils. The largest source is managed wet peat soils. Originally these were natural emissions, however, if these peat soils are reclaimed and have become farmland, have these emissions become anthropogenic because these soils are managed. In some countries draining of peat soils has resulted in slightly lowered methane emissions. Can a reduction realised after 1990 be subtracted from total emissions?

Waste

Differences between national estimates and EDGAR estimates are a consequence of the weak methodology used in both country estimates and EDGAR estimates. It is recommended both to start an extensive programme for methane recovery from landfills at the same time measuring the potential and actual emissions and to make an effort to apply the time-dependent method (as used in the Netherlands and the UK) to countries with large landfills near the largest cities in the world. An international database on waste management, waste in place, organic carbon content, oxidation in topsoil, and potential methane emissions should be developed.

Landuse change

A comparison between country estimates and EDGAR was not possible because of the scattered reporting on carbon dioxide, methane and nitrous oxide emissions and/or sinks from landuse change and deforestation. Developing global databases on forests, carbon stocks per hectare and deforestation, reforestation and reafforestation from all information available is recommended. An IPCC special report on carbon dioxide from forestry and soils is in preparation. However, new methodology for national inventories will not be available by the end of 1999. An effort to revise and update the methodology is recommended.

5.6.3 Nitrous oxide

The analysis for N_2O emissions presented in Section 3.3 reveals that the publication of the revised 1996 Guidelines for National Greenhouse Gas Inventories will have implications for future National Communications. The methodology developed for agricultural N_2O emissions for the Revi*sed 1996 IPCC Guidelines* differs to a large extent from the methodology in the original *1995 IPCC Guidelines.* Most important, the new method aims at assessing the full nitrogen cycle and all impacts of agricultural activities on N_2O. The consequence of this new approach is that a number of sources are included in the IPCC Guidelines that in earlier versions were not mentioned. These ‘new’ sources may account for two-thirds of the total agricultural N_2O emissions. Since agriculture is by far the most important source of anthropogenic N_2O, this considerably affects national estimates of N_2O emissions. Several Annex I countries estimated their N_2O emissions including some, but not all, of these "new" sources in their second National Communications. It therefore seems important to encourage countries to actually quantify all sources of N_2O that are distinguished in the new Guidelines to make the N_2O inventories complete.

With respect to the IPCC Guidelines, we can conclude that there is no need to update the methodology for N_2O in the short term. The method includes all sources of N_2O and is mostly based on recent studies. Nevertheless, Mosier et al. (1998) acknowledge that the method is a rough and generalised approach which ignores climatic and other differences between countries. This results from the requirements that the IPCC Method needs to apply to any world country and uses readily available data as input. For specific countries where statistics are available, such as the Netherlands, a more reliable, country-specific estimate could be made. Mosier et al. (1998) identified the following research needs that could improve the method in the long run:

(i) defining different emission factors for temperate and tropical world regions,
(ii) utilising process-based models to estimate national emissions, and
(iii) integrating knowledge on the coupled C and N cycle in the IPCC Guidelines.

Mosier et al. (1998) furthermore suggest performing a quantitative uncertainty analysis on national greenhouse gas inventories in order to identify the most uncertain components of methodologies.

6. Discussion and conclusions

6.1 Conclusions for carbon dioxide

National inventories as reported to the Climate Convention Secretariat and compiled by the Secretariat in tables (UNFCCC/CP/1996/12/Add.2 and UNFCCC/CP/1998/11/Add.2) and country results (as cited in Braatz et al., 1996) are compared with EDGAR 2.0 (Olivier et al., 1996; 1999) emission estimates. Relatively large differences were analysed. Eventually, this kind of comparison of semi-independent databases may contribute to the validation and verification of both national inventories, and EDGAR, and contribute to improvement of IPCC methodologies for estimating emissions. It may also improve reporting to the Climate Convention.

Table 6.1 Global totals for carbon dioxide

Source	Number of countries	NC1 ($Pg\ CO_2$/year)	NC2 ($Pg\ CO_2$/year)	Global budget[a] ($Pg\ CO_2$/year)
Annex I countries[b]	NC1=34, NC2=35	13.7	14.3	-
Country studies[c]	31	5.1	5.1	-
Global database[d]	124	6.7	6.7	-
Total	190	25.4	26.1	26.0

[a] IPCC (1995) (7.1 Pg C x 44/12)
[b] UNFCCC (1997)
[c] Braatz et al. (1996)
[d] Olivier et al. (1996; 1999)

For CO_2, the difference between the estimated global budget of fossil fuels and the sum of the available inventories is small (<10%) (Table 6.1 and 6.2). However, the IPCC global budget (1996) was obtained from a similar global database of emission estimates. Thus, the expected global budget and the sum of inventory data are expected to be similar. This makes the comparison for CO_2 less meaningful.

Table 6.2 Global totals for carbon dioxide expressed in Pg carbon

Source	Number of countries	NC1 (Pg C/year)	NC2 (Pg C/year)	Global budget[a] (Pg C/year
Annex I countries[b]	NC1=34 NC2=35	3.6	3.9	-
Country studies[c]	31	1.4	1.4	-
Global database[d]	124	1.8	1.8	-
Total	190	6.8	7.1	7.1

[a] IPCC (1995)
[b] UNFCCC (1997)
[c] Braatz et al. (1996)
[d] Olivier et al. (1996; 1999)

Differences that were found between the estimates in the first and second National Communications are explained by the fact that countries have updated estimates using improved methodology. For some European countries differences between national reports and EDGAR estimates are also caused by the use of different base years. For EDGAR estimates of carbon dioxide emissions to become comparable – for instance within 5% - to country emissions, the IEA energy data for many countries (including conversion factors) as well as country-specific emission factors need a thorough evaluation. The activity data for industrial processes in EDGAR also need improvement for some countries. Clearer definitions are needed for the allocation of emissions from combined heat and power. Should Combined Heat and Power (CHP) be reported within industry or within power generation? The confusion about allocation to process emissions or combustion emissions of coking coal use in the iron and steel industry should be dealt with in order to make national inventories comparable at the sector level.

6.2 Conclusions for methane

For methane, the discrepancy between the global budget and the sum of national inventories is about 22% in the NC1 column, and 16% in the NC2 column with updated methane emissions for Annex I countries and the country study of India added (Table 6.3). The global budget was derived from atmospheric measurements and is therefore independent of the inventory data. The agreement between the two budgets is within the expected level of uncertainty, which is 30%, thus giving confidence in the Revised IPCC Guidelines.

Table 6.3 Global totals for methane

Source	Number of countries	NC1 (Tg CH_4/year)	NC2 (Tg CH_4/year)	Global budget[a] (Tg CH_4/year)
Annex I countries[b]	33	104	108	-
Country studies[c]	31	66	84	-
Global database[d]	125	121	121	-
Total	189	291	313	375 (300-450)

[a] IPCC (1995)
[b] UNFCCC (1997)
[c] Braatz et al. (1996) and Mitra and Battacharya (1998)
[d] Olivier et al. (1996; 1999

Four types of differences were found when emission estimates from national inventories and EDGAR 2.0 were compared:

A. Differences as a result of different emission factors
These differences can be relatively large, for instance, in the case of methane emissions from manure, rice and waste. Measurements may be needed to improve country-specific emission factors. This information may be needed for the development of new IPCC default emission factors.

B. Differences because of the use of different activity levels
These differences point to the fact that EDGAR uses internationally available activity data, which, in some cases, differ from national statistics. Also, in some cases EDGAR used available approximations instead of detailed country-specific statistics. For example, the methane emissions from rice are different because it is hard to find data on areas planted and flooded each year.

C. Differences due to gaps in national estimates or EDGAR
Various national communications and country study reports are not complete or not yet available (collection of reports in 1997, analysis took place in 1998). When compared with EDGAR these gaps are very distinct. Country studies were made for capacity building and to learn about IPCC methodology. We expect a complete reporting when more official national communications come due. EDGAR showed gaps, for example, in methane emissions from waste water treatment. EDGAR missed some of the new independent states in Eastern Europe. National reports showed gaps as well. No comparison of methane emission estimates was possible for the following agriculture and land use sectors: agricultural waste burning, savanna burning, deforestation and biomass burning, because the reporting in the national estimates for these sectors is very scattered.

D. Differences due to different definitions on the anthropogenic part of emissions
These differences occur in estimates of methane from soil, wetlands and land use change. IPCC Guidelines should make these definitions clearer.

Our analysis indicates that review and evaluation of emission inventories of greenhouse gases can be useful because:

a. the exchange, review and comparison of emission estimates promote dialogue, the sharing of information and consensus about the emission estimates among scientists and policy-makers.

b. The comparison of national inventories with EDGAR estimates has identified potential areas for future improvement in the IPCC methodology to estimate emissions and has indicated areas for improvement of good practice in inventory compilation.

c. The comparison of national methane emissions with (semi)-independent scientific database results can contribute to validation of the emission inventories and to the reduction of the uncertainty in the emission estimates. This is especially important with respect to the flexible mechanisms that have been introduced in the Kyoto Protocol.

The national communications as available for this study were not transparent. A third party could not recalculate the emissions. In the national communications only summaries of emissions are published. The transparency of the emissions inventory is reduced this way because not all data is available for a third party to review the inventory. Often a reference is made to a background report with the more complete emission inventory. These background documents are crucial in a review procedure but are not always readily available. Therefore it is important that emission inventories also be made readily available and become an official document in the Climate Convention. To make inventories more transparent, the UNFCCC is recommended to publish standard data tables in their Guidelines for reporting, and countries are advised to improve the detailed reporting on emission factors and activity data in the national inventory reports.

When comparing national inventories and EDGAR estimates for 1990, the net large differences for methane between national reports and EDGAR 2.0 are 30 Tg (Table 3.28). This may be an indication for the uncertainty of the methane emission inventories. The global total methane emissions estimated from national data, country studies and EDGAR data to fill in the missing countries, fall short of the middle estimate of the ranges in the IPCC budget as published in 1994. The aggregated world total anthropogenic methane emission of 320 Tg compares with the low end of the range of 300-450 Tg methane per year as published by IPCC (1994). This may indicate that IPCC default emission factors from the Guidelines and/ emission factors used in national communications are generally too low.

6.3 Conclusions for nitrous oxide

For nitrous oxide, the sum of inventories is close to the lower level of the range of the global budget (Table 6.4). The global budget was obtained from observed atmospheric increases and is independent of the inventory data. However, the estimate of total anthropogenic emissions (9 Tg) in Table 6.4 was based on previous IPCC estimates (IPCC, 1995). Using the Revised 1996 IPCC Guidelines (IPCC, 1997), the mid-point estimate for world-wide anthropogenic emissions is higher: 11-12 Tg N_2O/yr (Mosier et al., 1998; Kroeze et al., 1999), but still within the range deduced from trends in atmospheric N_2O. The Revised Guidelines methodology has been used to estimate historic emissions of N_2O, which in turn were used as input to a simple atmospheric box model for simulating trends in atmospheric N_2O in line with the observed trends (Kroeze et al., 1999). These results indicate that on a global scale, the Revised IPCC Guidelines are not inconsistent with trends in atmospheric concentrations.

Table 6.4 Global totals for nitrous oxide in Tg N_2O per year

Source	Number of countries	NC1	NC2	Global budget[a]
Annex I countries[b]	33	2.0	2.2	-
Country studies[c]	31	0.1	0.1	-
Global database[d]	125	2.8	2.8	-
Total	189	4.9	5.1	9 (5-13)

[a] IPCC (1995) (3-8 Tg N/year , midpoint 5.7, x 44/28)

[b] UNFCCC (1997)

[c] Braatz et al. (1996)

[d] Olivier et al. (1996; 1999)

National estimates of N_2O emission were analysed. We compared estimates as presented in the first (NC1) and second (NC2) National Communications with estimates from the Emission Database for Global Atmospheric Research (EDGAR). Clearly, agriculture is the most important anthropogenic source of N_2O on a global scale as well as in most country estimates. Fuel combustion, industry and biomass burning are less important sources of N_2O.

Of the 25 countries that were included in the analysis, four (Greece, Hungary, Japan and the UK) have reported NC1 emissions within 10% of the EDGAR estimate. For 13 countries, the EDGAR estimate is 30 - 75% lower than the NC1 reported emission, and for 8 countries the EDGAR estimate is 15 - 550% higher. A comparison of EDGAR estimates with the second national communications (NC2) reveals that for only nine countries is the difference between EDGAR and NC2 smaller than between EDGAR and NC1. While this implies that most countries revised their estimates for total N_2O, these revisions do not reduce the difference between EDGAR and the NC1 estimate.

For about two-thirds of the countries the EDGAR estimate for agricultural emissions of N_2O is lower than the estimate reported in the second national communications. In addition, it is clear that most NC2 estimates are higher than NC1 estimates. Both findings may be induced by the publication of the *Revised 1996 IPCC Guidelines*, which include more agricultural sources and revised (higher) emission factors than the *1995 Guidelines*. About one-third of all countries report agricultural emissions that do not exceed EDGAR, which could be an indication that these countries do not report all agricultural sources of N_2O. In-depth analysis of a number of countries shows that country estimates could increase considerably if emissions were estimated following the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories.*

For N_2O from fuel use the analysis indicates that the EDGAR estimates for fossil fuel combustion are relatively low, while the estimates for biofuel are relatively high when compared to the National Communications. In addition, the EDGAR estimate for N_2O from traffic is lower than in the National Communications in all countries studied. Furthermore, the comparison reveals that for all countries considered the EDGAR estimates are lower than the National Communication, indicating that the EDGAR estimates for industry may also be on the low side.

Table 6.5. Reasons for differences between national reports and EDGAR 2.0 estimates for CO_2

Sector IPCC	Activity Data	Emission Factor	Gaps	Allocation	Methods
1A Fuel combustion	X			X	X
1B Fugitive emissions	X	X	X		
2 Industrial processes	X		X		
3 Solvent use	NA	NA	NA	NA	
4A Enteric fermentation	NA	NA	NA	NA	
4B Manure management	NA	NA	NA	NA	
4C Rice cultivation	NA	NA	NA	NA	
4D Agricultural soils	X	X	X		
4E Prescribed burning of savannahs	X	X	X		
4F Field burning of agricultural residues	X	X	X		
4G Other					
5 Land use change and forestry	X	X	X	X	X
6A Solid waste disposal on land	NA	NA	NA	NA	
6B Wastewater handling	NA	NA	NA	NA	
6C Waste incineration	X		X		
6D Other					
7 Other					
Memo items					
International Bunkers Aviation	X		X	X	
International Bunkers Marine	X		X		
Emissions from biomass	X		X	X	X

NA = not applicable. X = reason for difference. Blank = not a reason for difference

6.4 Overview of reasons for differences between national inventories and EDGAR 2.0

6.4.1 Carbon dioxide

In Table 6.5 an overview is given of the assumed reasons for differences encountered in the comparison of national reports with EDGAR estimates. In Table 6.6 a prioritisation is made of possible improvements. Reasons for differences and the choices made are explained below.

Table 6.6. Priorities for further research aiming at reducing differences between national reports and EDGAR 2.0 estimates for CO_2

Sector	Act. data	Em. Factor	Gaps	Allocation	Methods
1A Fuel combustion	X			X	
1B Fugitive emissions	X		X		
2 Industrial processes			X		
3 Solvent use	NA	NA	NA	NA	NA
4A Enteric fermentation	NA	NA	NA	NA	NA
4B Manure management	NA	NA	NA	NA	NA
4C Rice cultivation	NA	NA	NA	NA	NA
4D Agricultural soils			X		
4E Prescribed burning of savannahs			X		
4F Field burning of agricultural residues			X		
4G Other					
5 Land use change and forestry	X		X		X
6A Solid waste disposal on land	NA	NA	NA	NA	NA
6B Wastewater handling	NA	NA	NA	NA	NA
6C Waste incineration	X				
6D Other					
7 Other					
Memo items					
International Bunkers Aviation	X				
International Bunkers Marine					
Emissions from biomass	X				

NA = not applicable. X = priority. Blank = no priority

In fuel combustion (sector 1A in Table 6.5 and 6.6) the differences are mainly caused by differences in activity data between national studies and the international database of IEA. This is related to differences in the total amount of energy used according to energy statistics and differences in the allocation within this sector. Another reason for differences between national and EDGAR estimates lies in the different methods used: the IPCC reference method or national, more detailed methodology. Improvements are needed in the allocation among sectors and in the comparability of national and international energy statistics. For some countries differences have been encountered in the estimate of the fraction of feedstock use emitted as carbon dioxide. Under fugitive emissions (sector 1B in the table) some countries report CO_2 emissions that are vented from CO_2-rich gas wells. Differences in activity data and emission factors between EDGAR and the national report and gaps in reporting pose problems, i.e. EDGAR estimates this for some countries but national reports do not. Improvements can be made in reporting this source. Comparison of emissions from industrial processes (sector 2 in the table) will be improved provided countries report all sub-sectors. The reporting of CO_2 emissions from agriculture (sector 4 in Table 6.5 and 6.6) is unclear in the definitions. Sometimes CO_2 is seen as an unimportant emission because of regrowth of vegetation the next year, hence, the gaps in reporting and the problems with activity data and emission factors. Improvements are needed in definitions of storage and release of carbon from soils and vegetation. Reporting on land use change and forestry (sector 5 in the tables) is very scattered. IPCC is developing new methodology for this sector. Even after the adoption of this methodology by IPCC and the conference of the parties to the Climate Convention, problems will still remain with the collection of good activity data. Reporting in sector 6, notably waste incineration, is showing gaps. The problem is to establish the amount of the waste and the related emissions from fossil origin. Reporting bunker emissions is not complete. Some countries have problems separating international from internal flights. Reporting emissions from biomass burning is not complete. For many countries it is unclear whether biomass burning is sustainable. Biomass burning seems to be under-reported in many industrialised countries.

6.4.2. Methane

In Table 6.7 an overview is given of the assumed reasons for differences encountered in the comparison of national reports with EDGAR estimates. A prioritisation is of possible improvements is given in Table 6.8. Reasons for differences and the choices made are explained below.

Table 6.7. Reasons for differences between national reports and EDGAR 2.0 estimates for CH_4

Sector	Act. data	Em. factor	Gaps	Allocation	Methods
1A Fuel combustion	X	X	X		
1B Fugitive emissions	X	X	X		
2 Industrial processes			X		
3 Solvent use	NA	NA	NA	NA	NA
4A Enteric fermentation	X	X			X
4B Manure management	X	X			X
4C Rice cultivation	X	X			
4D Agricultural soils			X		
4E Prescribed burning of savannahs	X	X	X		
4F Field burning of agricultural residues	X	X	X		
4G Other					
5 Land use change and forestry	NA	NA	NA	NA	NA
6A Solid waste disposal on land	X	X			X
6B Wastewater handling	X	X			
6C Waste incineration	X	X			
6D Other					
7 Other					
Memo items					
International Bunkers Aviation		X			
International Bunkers Marine		X			
Emissions from biomass	X	X			

NA = not applicable. X = reason for difference. Blank = no reason for difference

Table 6.8. Priorities for further research aiming at reducing differences between national reports and EDGAR 2.0 estimates for CH_4

Sector	Act. data	Em. Factor	Gaps	Allocation	Methods
1A Fuel combustion			X		
1B Fugitive emissions	X				
2 Industrial processes					
3 Solvent use	NA	NA	NA	NA	NA
4A Enteric fermentation	X	X			
4B Manure management	X				
4C Rice cultivation	X	X			
4D Agricultural soils	X		X		
4E Prescribed burning of savannahs	X				
4F Field burning of agricultural residues	X				
4G Other					
5 Land use change and forestry					X
6A Solid waste disposal on land	X				X
6B Wastewater handling	X				
6C Waste incineration					
6D Other					
7 Other					
Memo items					
International Bunkers Aviation					
International Bunkers Marine					
Emissions from biomass	X				

NA = not applicable. X = Priority. Blank = no priority.

Reporting methane emissions from fossil fuel combustion is not complete, and the activity data and emission factors are not clear. Improvements can be made by measuring country specific emission factors. Reporting fugitive emissions of methane is hampered by a lack of activity data and uncertainty in the emission factors. Some gaps were encountered. Improvements can be made by measuring for the development of country-specific emission factors. In agriculture, reporting methane emissions from enteric fermentation is hampered by the use of different methodologies. Statistics on livestock and emission factors are uncertain for different species. Improvements can be made by measuring emissions in different countries. The use of fixed emission factors per animal must be abandoned because changes in what the cows eat (called rations, specifically referring to the amount of protein-rich feeds compared to the amount of fodder) have effects on emissions. Methane emissions form 4-7 % of gross energy intake. Cows with a high proportion of fodder in the ration excrete relatively more methane; cows in industrialised countries with high protein feeds excrete relatively less methane. Reporting of methane emissions from manure is not complete. Activity data on manure management systems are lacking for most countries. Emission factors are uncertain. Methodologies among countries differ. Improvements are needed in all respects but especially in activity data. Comparison between methane emission estimates for rice cultivation from EDGAR and some Asian countries demonstrated a difference in the emission factors and activity data used. Measuring country-specific emission factors locally can make improvements. Methane emissions from agricultural soils showed gaps in reporting. The difficulty is the definition of the anthropogenic part of the emission. Methane emissions from savanna burning showed gaps in reporting. If reported by countries, the differences with EDGAR were large because of differences in activity data and emission factors. Using satellite images for the estimate of areas burned each year can make a difference. The same applies to field burning of agricultural residues. No methane was reported from land use change but draining of peat areas or wetland conservation can in principle have effects on emissions. More research is needed in this area. Methane emissions from solid waste disposal on land are highly uncertain. Yet the highest reductions can be realised here. A serious lack of activity data even in industrialised countries is evident. Large differences are also caused by the use of different methods to estimate methane emissions. The Tier 1 IPCC method that was used in EDGAR delivers an estimate that is roughly 40% lower than the country estimates based on Tier 2 methodology. It is suggested here to abandon the Tier 1 methodology, as the Tier 2 methodology needs roughly the same input data. Larger differences are caused by uncertainty in activity data. The reporting of methane from wastewater handling and waste incineration is scattered. Methane emissions from bunker fuels are not reported at all but should be. Many countries do not report methane emissions from biomass burning. Improvement is hampered by the lack of information on amounts of biomass burned.

6.4.3 Nitrous oxide

In Table 6.9 an overview is given of the assumed reasons for differences in N_2O encountered in the comparison of national reports with EDGAR estimates.

Transport is the main source of nitrous oxide emissions within the fuel combustion sector. The main source is cars that are equipped with 3-way catalysts to avoid NO_x emissions. EDGAR reported consistently 40-100% lower emissions than the countries did. The activity data and emission factors can clearly be improved. The main industrial sources of nitrous oxide are the production of nitric and adipic acid. EDGAR reported consistently lower emissions than the countries did. Yet there are some industrial sources identified by Oonk and Kroeze (1998) that were not reported in either country or EDGAR estimates. Gaps should be covered in new IPCC methodology being developed. Solvent and other uses were not reported, but nitrous oxide from anaesthesia could be reported here. Nitrous oxide emissions from agriculture were difficult to compare with EDGAR emissions because EDGAR estimates contained a different set of sub-sectors than the national reports. EDGAR used different activity data and emission factors as well. Nitrous oxide from manure management systems and sewage treatment, and the emission from indirect agricultural sources like leaching and runoff to surface waters, were reported in second national reports. EDGAR estimates were lower for most countries because EDGAR 2.0 does not consider all agricultural sources identified in the Revised IPCC

Guidelines. Improvements are expected in EDGAR 3.0. EDGAR estimated nitrous oxide from biomass burning. For some countries with large forestry industries, these estimates were much larger than the country estimates. Improvements can be made in the emission factors and activity data. The reporting on rice cultivation, burning of savannahs and agricultural residues was scattered, just as in the land use change and forestry sectors. Developing good activity data can lead to improvements. Reporting was not complete in bunker emissions, but emission factors could be evaluated here. The priorities for improvement are given in Table 6.10.

Table 6.9. Reasons for differences between national reports and EDGAR 2.0 estimates for N_2O

Sector	Act. data	Em. Factor	Gaps	Allocation	Methods	Remarks
1A Fuel combustion	X	X				EDGAR low
1B Fugitive emissions	NA	NA	NA	NA	NA	NA
2 Industrial processes	X	X	X			EDGAR low
3 Solvent use			X			
4A Enteric fermentation	NA	NA	NA	NA	NA	NA
4B Manure management	X	X	X		X	
4C Rice cultivation	X	X	X			
4D Agricultural soils	X	X	X		X	
4E Prescribed burning of savannahs	X	X	X			
4F Field burning of agricultural residues	X	X	X			
4G Other						
5 Land use change and forestry	X	X	X			
6A Solid waste disposal on land						
6B Wastewater handling	X	X				
6C Waste incineration						
6D Other						
7 Other						
Memo items						
International Bunkers Aviation	X	X				
International Bunkers Marine	X	X				
Emissions from biomass	X	X				

NA = not applicable. X = reason for difference. Blank = no reason for difference.

Table 6.10. Priorities for further research aiming at reducing differences between national reports and EDGAR 2.0 estimates for N_2O

Sector	Act. data	Em. Factor	Gaps	Methods
1A Fuel combustion	X	X		
1B Fugitive emissions	NA	NA	NA	NA
2 Industrial processes			X	
3 Solvent use			X	
4A Enteric fermentation	NA	NA	NA	NA
4B Manure management	X			
4C Rice cultivation				X
4D Agricultural soils				X
4E Prescribed burning of savannahs	X			
4F Field burning of agricultural residues	X			
4G Other				
5 Land use change and forestry				X
6A Solid waste disposal on land				
6B Wastewater handling				
6C Waste incineration				
6D Other				
7 Other				
Memo items				
International Bunkers Aviation				
International Bunkers Marine				
Emissions from biomass	X	X		

NA = not applicable. X = Priority. Blank = no priority.

6.5 Summary conclusions

The comparison of national inventories with the EDGAR database estimates lead to the following conclusions:

1. In some sectors large gaps were found in reporting both in EDGAR 2.0 as in national reports. For carbon dioxide these were land use change and forestry, agriculture, and waste and bunker emissions. For methane, gaps were found in reporting for biomass burning, savannah burning, agricultural waste burning and bunker emissions. For nitrous oxide, gaps were found in reporting emissions from biomass burning, agriculture, land use change and bunkers. The IPCC is assisting countries in this process of closing gaps by improving the methodology for land use change and forestry. Improvements in the methodology for reporting may also be needed in biomass burning, agriculture and bunker emissions.

2. Some sectors showed a bias. The EDGAR estimates for Annex I countries for fugitive methane emissions were generally higher; for non-Annex I countries EDGAR estimates were generally lower. The reason was the use of different emission factors. The EDGAR estimates for methane from waste were generally lower. The reason was the use of simple tier 1 IPCC methodology in EDGAR, while Annex I countries used Tier 2 IPCC methods. The EDGAR estimates for nitrous oxide were lower for most countries, with an exception for EDGAR estimates for nitrous oxide from biomass burning for Annex-I countries. This was generally much higher. The reason was the use of different emission factors in most sectors. The high estimates for nitrous oxide emissions from biomass burning in EDGAR were due to EDGAR using higher activity assumptions.

3. Differences found in carbon dioxide emissions from fossil fuel use point to differences in the underlying energy data. Country data and the International Energy Agency (IEA) data used in EDGAR should be the same because countries' statistical bureaux report to the IEA. The fact that differences have been encountered means that energy data may not be so robust as previously thought. Differences found are higher than 5-10% in many Annex-I countries. These differences can also be caused by independent top-down calculations from fuel supply data at the IEA.

4. The detailed analysis as reported here should be done on a regular basis and using annual inventory reports by countries under the Kyoto Protocol. Only with such an analysis reductions of emissions by policy measures can be separated from other reasons for change in emissions. Such a detailed analysis can be carried out using EDGAR as a reference database.

5. Transparency in reporting can be improved by the mandatory use of standard data tables for reporting emissions, activity data and aggregated emission factors for all sectors. A suggestion for the level of detail of such tables is given in this report.

6. Our analysis showed that national inventories from industrialised countries (Annex I countries) as reported in National Communications are not transparent. Compliance of the Kyoto Protocol can not be reviewed based on this information alone. Annual national inventory reports are needed for review, and a more detailed standard reporting format is recommended for national inventories. A review for the Kyoto Protocol can thus be made on the basis of equal information from all industrialised countries.

7. Precise and complete information on emissions from non-Annex I countries is still missing. A lack of statistics on long term trends and a lack of country-specific emission factors make national inventories from these countries incomplete and inaccurate, especially for agriculture, forestry and land use change. Energy statistics could also be much improved.

8. This report based its analysis mainly on information from the Climate Secretariat, EDGAR and non-Annex I countries. A more thorough analysis for developing countries is possible after the quality of national reports is improved and more country-specific emission factors have been developed.

9. At this moment only a limited part of the global budget is addressed by the submitted National Communications of Annex I countries (see box below). It is important to make a complete inventory of Annex I countries and to establish the contribution on Non-Annex I countries, when, in the course of time, they are going to participate in the protocol.

Source	Gg CO_2/year	Tg CH_4/year	Tg N_2O/year
NC2	14	108	2.2
Global budget	26	375	8
% addressed by NC's	≈ 50%	≈ 30%	≈ 25%

Thus, it can be concluded that the participation of countries should increase and the evaluation of the reported emissions should be more accurate.

10. At this moment based on the available information on national emissions and atmospheric data it is difficult to make definite conclusions on possibilities of verification of national inventories through use of measuring data and atmospheric models.

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References

Ahmed, A.U., M. Reazuddin and K. Islam, 1996: Bangladesh emissions of greenhouse gases, preliminary findings. In Braatz et al. (1996).

Alcamo, J. and J. Bartnicki. 1990. Uncertainty analysis of a long range transport model. IIASA Laxenburg, Austria.

Alcamo, J. (ed.), 1994: IMAGE 2.0. Integrated Modeling of Global Climate Change. Book and Special Issue of Water, Air and Soil Pollution, 76. Kluwer Acad. Publishers.

Alcamo, J., G.J.J. Kreileman, M. Krol and G. Zuidema, 1994: Modelling the Global Society-Biosphere-Climate System. Part 1: Model description and testing. Water, Air and Soil Pollution 76, 1-35. Kluwer.

Alcamo, J. and E. Kreileman, 1996: Emission scenarios and global climate protection. Global Environmental Change, 6, 4.

Andreae, M.O., 1991: Biomass burning: its history, use and distribution and its impact on environmental quality and global climate. In: Levine, J.S. (ed), Global Biomass Burning. MIT Press, Cambridge MA, pp 3-28.

Andres, R.J., G. Marland, I. Fung and E. Matthews, 1996: A 1 x 1 degree distribution of carbon dioxide emissions from fossil fuel consumption and cement manufacture, 1950 - 1990. Global Biogeochemical Cycles 10, 419-429.

Anonymous, 1999: Debate over Terrestrial Carbon Sink Continuous. Global Environmental Change Report Vol XI, No 6, 26 March 1999.

Baas J., 1991: Literature search on nitrous oxide emissions from road trafic (in Dutch). TNO Rapport R 91/322. TNO-IMW, Delft, The Netherlands.

Baas, J., 1994: Nitrous oxide emissions from road transport in the Netherlands. TNO Report R 94/208. TNO Institute of Environmental Sciences. Delft, The Netherlands.

Beck, L. 1998: EPA's Data Attribute Rating System. Discussion paper submitted for an IPCC Expert Meeting on Managing Uncertainty in National Greenhouse Gas Inventories. October 1998, Paris.

Berdowski, J.J.M., G.P.J. Draaijers, L.H.J.M. Janssen, M. van Loon, M.G.M. Roemer, J.A. van Aardenne, A.T. Vermeulen, M. Vosbeek and H. Visser, 1998: Independent checks for validation of emission estimates: the METDAT example. Paper presented at a meeting of the IPCC/OECD/IEA Programme for National Greenhouse Gas Inventories on " Managing Uncertainty in National Greenhouse Gas Inventories", Paris 13-14 October 1998.

Berdowski, J., J.G.J. Olivier and C. Veldt, 1993: Methane from fuel combustion and industrial processes. In: Van Amstel, A.R. (ed.): Proceedings International IPCC Workshop "Methane and Nitrous Oxide, methods in national emission inventories and options for control". RIVM report 481507-003, Bilthoven, the Netherlands.

Bodhaine, B.A. and R.M. Rosson (eds.), 1988: Geophysical monitoring for climate change No. 16. Summary report 1987. Air Resources Laboratory, GMCC, Boulder, Colorado, USA, pp. 1-110.

Bouwman, A.F., I. Fung, E. Matthews, and J. John, 1993: Global analysis of the potential for N_2O production in natural soils. Global Biogeochem. Cycles 7, 557-597.

Bouwman, A.F., Van Der Hoek K.W., and Olivier J.G.J., 1995: Uncertainties in the global source distribution of nitrous oxide. J. Geophys. Res. 100, 2785-2800.

Bouwman, A.F. and J. Taylor, 1996: Testing high-resolution nitrous oxide emission estimates against observations using an atmospheric transport model. Global Biogeochemical Cycles 10: 307-318.

Bouwman, A.F., C. Kroeze and J. Taylor, 1996: On sources and atmospheric concentrations of nitrous oxide. IGAC Newsletter 6: 10-12.

Braatz, B.V., B.P. Jallow, S. Molnar, D. Murdiyarso, M. Perdomo and J. Fitzgerald, (eds.) 1996: Greenhouse Gas Emission Inventories. Interim Results from the US Country Studies Program. Kluwer Academic Publishers. Dordrecht, Boston, London.

Bouttier, F., 1994: A dynamical estimation of forecast error covariances in assimilation systems. Weather Rev. 122.

Brown, M.K.M., 1993: Deduction of emissions of source gases using an objective inversion algorithm and a chemical transport model. J. Geophys. Res. 98, D, 12639-12660.

Brown, M.K.M., 1995: The singular value decomposition method applied to the deduction of the emissions and the isotopic composition of atmospheric methane. J. Geophys. Res. 100 D, 11425-11446.

Builtjes, P., 1992: LOTOS database. LOTOS default emission factors for CO, CH_4, NMVOC, NO_x, N_2O and

NH_3. Delft, the Netherlands.

Buret, J., A. Agoumi and F.A. Senhaji, 1994: National Report of Morocco: Climate and Africa Project. SEI Stockholm 41.

CEEST (Centre for Energy, Environment, Science and Technology), 1994: Sources and Sinks for Greenhouse Gases in Tanzania. Final report prepared for UNEP/GEF. CEEST report 121.

CDIAC (Carbon Dioxide Information and Analysis Center), 1993: Trends 1993.

Ciais, P., P.P. Tans, J.W.C. White, M. Trolier, R.J. Francey, J.A. Berry, D.R. Randall, P.J. Sellers, G.J. Collatz and D.S. Schimel, 1995: Partitioning of ocean and land uptake of CO2 as inferred by δ^{13} C measurements from the NOAA/CMDL Climate Monitoring and Diagnostics Laboratory global air sampling network. J. Geophys. Res. 100, D3, 5051-5070

Ciais, P., A.S. Denning, P.P. Tans, J.A. Berry, D.R. Randall, G.J. Collatz, P.J. Sellers, J.W.C. White, M. Trolier, H.A.J. Meijer, R.J. Francey, D. Monfray and M. Heimann, 1997: A three dimensional synthesis study of $\delta^{18}O$ in atmospheric CO_2. 1. Surface fluxes. J. of Geophys. Res. 102, D5: 5857-5872.

Ciais, P., P.P. Tans, A.S. Denning, R.J. Francey, M. Trolier, H.A.J. Meijer, J.W.C. White, J.A. Berry, D.R. Randall, G.J. Collatz, P.J. Sellers, D. Monfray and M. Heimann, 1997: A three dimensional synthesis study of $\delta^{18}O$ in atmospheric CO_2. 2. Simulations with the TM2 transport model. J. Geophys. Res. 102, D5: 5873-5883.

Conway, T. J. , P.P. Tans, L.S. Waterman, D.R. Kitzis, K.A. Masarie, M. Stavish and N. Zhang, 1994: Evidence for interannual variability of the carbon cycle from the NOAA/CMDL global air sampling network, J. Geophys. Res., 99, 22831-22855.

Crutzen, P.J. and Andreae, M.O., 1990: Biomass burning in the Tropics: impact on atmospheric chemistry and biogeochemical cyles. Science 250, 1669-1678.

Dlugokencky, E.J., L.P. Steele, P.M. Lang and K.A. Masarie, 1994: The growth rate and distribution of atmospheric methane. In J. Geophys. Res. 99: 17021-17043.

Dlugokencky, E.J., J.M. Harris, Y.S. Chung, P.P. Tans and I. Fung, 1994: The relationship between the methane seasonal cycle and regional sources and sinks at Tae-ahn Peninsula, Korea. Atmospheric Environment, 27A: 2115-2120.

Dlugokencky, E.J., K.A. Masarie, P.M. Lang and P.P. Tans, 1998: Continuing decline in the growth rate of the atmospheric methane burden. Nature, 393: 447-450.

Drummond, J.R., 1992: Measurements of pollution in the troposphere (MOPITT). In: Gille, J. and G. Visconti, (eds.) The use of EOS for Studies of Atmospheric Physics. North-Holland, Netherlands. pp. 77-101.

Enting, I.G., C.M. Trudinger, R.J. Francey and H. Granek, 1993: Synthesis Inversion of Atmospheric CO_2 using the GISS Tracer Transport Model. CSIRO Technical paper No 29

Enting, I.G., C.M. Trudinger and R.J. Francey, 1995: A synthesis inversion of the concentration of $\delta^{13}C$ of atmospheric CO_2. Tellus B 47: 35-52.

EPA, 1994: International Anthropogenic Methane Emissions: Estimates for 1990. Environmental Protection Agency, USA, Office of Policy Planning and Evaluation, 2122. Report EPA 230-R93-010. Washington DC.

Ethiopian Energy Authority, 1994: National Greenhouse Gas Emissions 1987-1993. Ethiopian Climate Change Study Project 235.

European Environment Agency, 1997: Summary of European Union emissions of 1994 and 1995.

Fan, S., M. Gloor, J. Malman, S. Pacala, J. Sarmiento, T. Takahashi and P. Tans, 1998: A large terrestrial carbon sink in North America implied by Atmospheric and Ocean carbon dioxide data and models. Science 282, 442-446.

FAO, 1960-1999: Agrostat. Database. Rome.

Filar, J.A. and R. Zapert, 1993: Uncertainty analysis of a greenhouse effect model. Report 93/3. School of Mathematics. University of South Australia.

Fowler, D., 1999: Experimental designs appropriate for flux determination in terrestrial and aquatic systems at the 10 m^2 to 10.000 m^2 scale, and at the level of environmental province or landscape as a function of environmental characteristics. (In press).

Fowler, D., K.J. Hargreaves, T.W. Choularton, M.W. Gallagher, T. Simpson and A. Kaye, 1996: Measurements of regional CH_4 emissions in the UK using boundary layer budget methods. Energy Convers. Mgmt. 37, 769-775.

Fung, I., J. Jones, J. Lerner, E. Matthews, M. Prather, L.P. Steele and P.J. Fraser, 1991: Three-dimensional Model synthesis of the Global methane cycle. J. Geophys. Res. 96: 13011-13065.

Geller, L.S., J.W. Elkins, J.M. Lobert, A.D. Clarke, D.F. Hurst, J.H. Butler and R.C. Myers, 1997: Tropospheric SF6: Observed latitudinal distribution and trends, derived emissions and inter hemispheric exchange time. Geophys. Res. Lett. 24, 675-678.

Gibbs, M.J. and R.A. Leng, 1993: Methane emissions from livestock. In Van Amstel, A.R. (ed.), Proceedings of the International IPCC Workshop on Methane and Nitrous Oxide: Methods in national emission inventories and options for control. RIVM report 481507-003. Bilthoven, the Netherlands.

Gibbs, M. and D. Johnson, 1994: Methane emissions from digestive processes of livestock. In Adler, M.J. 1994: International anthropogenic methane emissions: Estimates for 1990. USEPA.

GoS, Governent of Senegal, 1994: National Greenhouse Gases Inventory. Final report prepared for UNEP/GEF. Ministry of Environment and Nature Protection, Republic of Senegal. 138.

Graedel, T.E., T.S. Bates, A.F. Bouwman, D. Cunnold, J. Dignon, I. Fung, D.J. Jacob, B.K. Lamb, J.A. Logan, G. Marland, P. Middleton, J.M. Pacyna, M. Placet and C. Veldt, 1993: A compilation of inventories of emissions to the atmosphere. Global Biogeochemical Cycles, 7, 1: 1-26.

Hall., D.O. 1991: Biomass energy. Energy Policy 19, 8: 711-737.

Hall, D.O., F. Rosillo-Calle and J. Woods, 1994: Biomass utilization in households and industry: Energy use and development. Chemosphere 29, 5: 1099-1119.

Hao, W.M., M.H. Liu and P.J. Crutzen, 1990: Estimates of annual and regional releases of CO_2 and other trace gases to the atmosphere from fires in the tropics, based on the FAO statistics for the period 1975-1980. In: Goldhammer, J.G. ed. Fire in the Tropical Biota. Springer Verlag, Berlin, pp. 440-462.

Harnisch, J., R. Borchers, P. Fabian and M. Maiss, 1996: Tropospheric trends for CF_4 and C_2F_6 since 1982 derived from SF_6 dated stratospheric air. Geophys. Res. Lett. 23, 1099-1102.

Hartley, D. and R. Prinn, 1993: Feasibility of determining surface emissions of trace gases using an inverse method in a three-dimensional chemical transport model. J. of Geophys. Res., 98, D3, 5183-5197.

Heimann, M., 1996: Closing the atmospheric CO_2 budget: inferences from new measurements of $^{13}C/^{12}C$ and O_2/N_2 ratios. IGBP Newsletter, 28: 9-11.

Hein, R., P.J. Crutzen and M. Heimann, 1997: An inverse modeling approach to investigate the global atmospheric methane cycle. Global Biogeochemical Cycles 11, 1: 43-76.

Hollander, J.C.Th. and M.E.J.P. Vosbeek, 1996: Evaluation and validation of methane emissions in the Netherlands and the contribution from various sources. TNO-MEP report R 96/188. Delft.

Houghton, J.T., G.J. Jenkins, and J.J. Ephraums (eds.), 1990: Climate change. The IPCC scientific assessment. Published for the Intergovernmental Panel on Climate Change, Cambridge University Press.

Houghton, J.T., B.A. Callander, and S.K. Varney (eds.), 1992: Climate change 1992. The supplementary report to the IPCC scientific assessment. Published for the Intergovernmental Panel on Climate Change, Cambridge University Press.

Houghton, J.T., Meira Filho L.G., Bruce J., Hoesung Lee, Callander B.A., Haites E., Harris N. and Maskell K. (eds.) 1995: Climate change 1994. Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Emission Scenarios. Published for the Intergovernmental Panel on Climate Change, Cambridge University Press.

Houweling, S., 1998: Personal Communication.

Hutjes, R., P. Kabat, P. Jarvis, R. Valentini and H. Dolman, 1998: Fluxnet helps to reduce uncertainties in "Post-Kyoto" carbon debate. BAHC News 6, 10-13.

IISII, 1994: Steel Statistical Yearbook 1993. International Iron and Steel Industry Institute, Brussels.

IPCC, 1990: Climate Change. The IPCC scientific Assessment. Cambridge University Press.

IPCC, 1992: Climate Change. The supplementary report to the IPCC Scientific assessment. Cambridge University Press.

IPCC, 1994: Climate Change 1994. Radiative forcing of Climate Change. Cambridge University Press.

IPCC, 1996: Climate Change 1995. Part 1. The Science of Climate Change. Cambridge University Press.

IPCC/OECD/IEA, 1995: IPCC Guidelines for national inventories of sources and sinks of greenhouse gases. (Three volumes: Workbook, Reporting Instructions, Reference Manual). Paris.

IPCC/OECD/IEA, 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. OECD, Paris.

Janssen, L.H.J.M., J.T van der Wal, J.C. Th. Hollander, A. Vermeulen, M.E.J.P. Vosbeek, 1997: A database of methane concentrations as measured in the Netherlands and Europe. RIVM report 722501-003. Bilthoven.

Janssen, L.H.J.M., 1997: Estimating emissions of CO_2, CH_4 and N_2O using atmospheric data and models. A top-down analysis. In: Proceedings of the CKO/CCB Workshop on Bottom-up and Top-down Estimates of Greenhouse Gases, Bilthoven 27-6-1997. RIVM report 728001 006.

Janssen, L.J.H.M., P. van Velthoven, F. Dentener and A.R. van Amstel (eds.), 1997: Proceedings of the CKO/CCB Workshop on Bottom-up and Top-down Emission Estimates of Greenhouse Gases in Bilthoven on 27-6-1997. RIVM report 728001-006. Bilthoven, the Netherlands.

Janssen, L.H.J.M., J.G.J. Olivier and A.R. van Amstel, 1999: Comparison of CH_4 Emission Inventory Data and Emission Estimates from Atmospheric Transport Models and Concentration Measurements. Environmental Science and Policy 2, 295-314.

Janssen, L.H.J.M., J.G.J. Olivier and A.R. van Amstel, 1997: A comparison of bottom-up and top-down methane emission inventories. Discussion paper for the IPCC expert meeting on Methods for Assessment of Inventory Data Quality, November 5-7 1997 Bilthoven, The Netherlands.

Jol, A., 1996: Monitoring mechanism of European Community Greenhouse Gas Emissions. Report to the European Environment Agency from the European Topic Centre on Air Emissions.

Jol, A., 1996: Comparison of CORINAIR94 with IPCC inventories. European Environment Agency, Denmark.

Jol, A., 1997: CORINAIR 1994 Summary Report. Report to the European Environment Agency from the European Topic Centre on Air Emissions.

Kaiser, J. and K. Schmidt, 1998: Coming to grip with the World's Greenhouse Gases. Science 281: 504-506.

Kaminski, T., R. Giering and M. Heimann, 1997. Sensitivity of the seasonal cycle of CO_2 at remote monitoring stations with respect to seasonal surface exchange fluxes determined with the adjoint of an atmospheric transport model. Submitted to Physics and Chemistry of the Earth/

Keeling, C.D., R.B. Bacastow, A.F. Carter, S.C. Piper, T.P. Whorf, M. Heimann, W.G. Mook and H. Roeloffzen, 1989: A three-dimensional model of CO_2 transport based on observed winds: 1. Analysis and observational data. In: Aspects of Climate Variability in the Pacific and Western Americas, Geophysical Monograph 55, D.H. Peterson (ed.), American Geophysical Union, Washington DC, pp. 165-236.

Keeling, C.D., S.C. Piper and M. Heimann, 1989: A three-dimensional model of atmospheric CO_2 transport based on observed winds: 4. Mean annual gradients and interannual variations. In: Aspects of Climate Variability in the Pacific and Western Americas, Geophysical Monograph 55, D.H. Peterson (ed.), American Geophysical Union, Washington DC, pp. 305-363..

Keeling, C.D., T.P. Whorf, M. Wahlen and J. van der Plicht, 1995: Interannual extremes in the rate of rise of atmospheric carbon dioxide since 1980, Nature, 375: 666-670.

Keeling, R.F., S.C. Piper and M. Heimann, 1996: Global and hemispheric CO_2 sinks deduced from changes in atmospheric O_2 concentration. Nature 381: 218-221.

Keeling, C.D. and T.P. Whorf, 1998: Results of the SIO network. http://cdiac.esd.ornl.gov/trends/ (August 1998)

Keeling, C.D. J.F.S. Chin and T.P. Whorf, 1999: Increased activity of northern vegetation inferred from atmospheric CO_2 measurements. Nature 382, 88.

KEMA Nederland B.V., 1994-1999: Measurements Kollummerwaard.

Khalil, M.A.K. and R.A. Rasmussen, 1983: Increase and seasonal cycles of nitrous oxide in the earth's atmosphere. Tellus 35B, 161-169.

Khalil, M.A.K. 1992: A statistical method for estimating uncertainties in the total global budgets of atmospheric trace gases. J. Environ. Sci. Health, A27, 3: 755-770.

Khalil, M.A.K. and R.A. Rasmussen, 1992. The global sources of nitrous oxide. J. Geophys. Res. 97, 14651-14660.

Khalil, M.A.K. and R.A. Rasmussen, 1993: Decreasing trend of methane: unpredictability of future concentrations. Chemosphere 26, 803-818.

Khennas, S. and A. Gaid, 1994: Country Report Algeria. Climate and Africa Project. SEI, Stockholm. 52.

Ko, M.K.W. and N.D. Sze, 1982: A 2-D model calculation of atmospheric lifetimes for N_2O, CFC11 and CFC12. Nature 297, 317-319.

Ko, M.K.W., N.D. Sze and D.K. Weisenstein, 1991: Use of satellite data to constrain the model calculated atmospheric lifetime for N_2O: Implications for other gases. J. Geophys. Res. 96, 7547-7552.

Ko, M.K.W., N.D. Sze, W-C. Wang, G. Shia, A. Goldman, F. Murcray and C. Rinsland, 1993: Atmospheric sulfur hexafluoride: sources, sinks and greenhouse warming. J. Geophys. Res. 98, 10499-10507.

Komhyr, W.D., R.H. Gammon, T.B. Harris, L.S. Waterman, T.J. Conway, W.R. Taylor and K.W. Thoning, 1985: Global atmospheric CO_2 distribution and variations from 1968-1982. NOAA/GMCC CO_2 flask sample data. J. Geophys. Res. 90, 5567-5596.

Kreileman, E. and A.F. Bouwman, 1994: Computing land use emissions of greenhouse gases. Water, Air and Soil Pollution 76, 231-258.

Kreileman, E. and R. Leemans, 1997: Paper for Dutch workshop on top-down analysis. In Janssen, L.H.J.M. et. al. (eds.), 1997: Proceedings of the CKO/CCB Workshop on Bottom-up and Top-down Estimates of Greenhouse Gases, Bilthoven 27-6-1997. RIVM report 728001 006.

Kroeze, C., 1994: Nitrous oxide. Emissions inventory and options for control in the Netherlands. RIVM report 773001-004, Bilthoven, the Netherlands.

Kroeze, C., 1994: Nitrous oxide and global warming. Sci. Total Environ. 143, 193-209.

Kroeze, C., 1995: Comparison of inventory method for estimating national emissions of nitrous oxide (N_2O). Idojaras. Quart. J. Hung. Meteorol. Service 99, 209-225.

Kroeze, C., 1997: Nitrous oxide emissions: the new IPCC Guidelines for National Greenhouse Gas Inventories and the global N_2O budget Proceedings of the CKO/CCB Workshop on Bottom-up and Top-down Estimates of Greenhouse Gases; Bilthoven 27-6-1997. RIVM report 728001 006.

Kroeze, C., A. Mosier and L. Bouwman, 1999: Closing the global N_2O budget: A retrospective analysis 1500 - 1994. Global Biogeochemical Cycles, 13, 1-8.

Laan van der, H., N. de Kort, H. Gerritsen. L. Janssen, A. Kattenberg, R. Leemans, G. Nieuwenhuis, H. van pagee and J. Snel, 1998: Monitoring System Earth. Report by the Task Team Monitoring Systems. Dutch Ministry of Education,Culture and Science. The Hague.

Law, R. and I. Simmonds, 1996: The sensitivity of deduced CO_2 sources and sinks to variations in transport and imposed surface concentrations. Tellus 48B, 613-625.

Leach, G.A., 1988: Residential energy in the third world. Ann. Rev. Energy, 13, 47-65.

Leemans, R., A.R. van Amstel, C. Battjes, E. Kreileman and S. Toet, 1996: The land cover and carbon cycle consequences of large scale utilization of biomass as an energy source. Global Environmental Change 6, 335-357.

Lehtilä, A., I. Savolainen, S. Tuhkanen, 1997: Indicators of CO_2 emissions and energy efficiency. Comparison of Finland with other countries. Technical Research Centre of Finland VTT Publ. 328. Espoo.

Lehtilä, A., I. Savolainen and J. Sinisalo, 1997: Indicators describing the development of national greenhouse gas emissions. Comparison with other countries. Technical report, VTT Energy, P.O. Box 1606, 02044 VTT, Finland.

Lelieveld, J. and P.J. Crutzen, 1993: Methane emissions into the atmosphere, an overview. <CHECK> In: Janssen, L.H.J.M. et. al. (eds.), 1997: Proceedings of the International IPCC workshop on methane and nitrous oxide. National emission inventories and options for control. RIVM report 481507-003. Bilthoven, the Netherlands.

Lerner, J., E. Matthews and I. Fung, 1988: Methane emissions from animals: a global high resolution database. Global Biogeochemical Cycles, 2: 139-156.

Leuenberger, M. and U. Siegenthaler, 1992: Ice-age atmospheric concentration of nitrous oxide from an Antarctic ice core. Nature 360, 449-451.

Levin, I. and V. Hesshaimer, 1996: Refining of atmospheric transport model entries by the globally observed passive tracer distributions of ^{85}krypton and sulfur hexafluoride SF_6. J. Geophys. Res. 101, D11, 16745-16755.

Levin, I., H. Glatzel-Mattheier, T. Marik, M. Cuntz, M. Schmidt and D. Worthy, 1999: Verification of German methane emission inventories and their recent changes based on atmospheric observations. J. Geophys. Res. (in press).

Lim, B. and P. Boileau, 1999: Methods for assessment of inventory data quality: issues for an IPCC expert meeting. Environmental Science and Policy 2, 221-227.

Lim, B., P. Boileau, Y. Bonduki, A.R. van Amstel, L.H.J.M. Janssen, J.G.J. Olivier and C. Kroeze, 1999: Improving the quality of national greenhouse gas inventories. Environmental Science and Policy 2, 335-346.

Little, A.D., 1989: Methane emissions from the oil and gas production industries. Final report to Ruhrgas AG.

Maiss, M., and C.A.M. Brenninkmeijer, 1998: Atmospheric SF_6 trends, sources and prospects. Env. Science Techn. <ADD>

Marland, G. and R.M. Rotty, 1984: Carbon dioxide emissions from fossil fuels: a procedure for estimation and results for 1950-1982. Tellus 36B, 232-261.

Marland, G., R.M. Rotty and N.L. Treat, 1985: CO_2 from fossil fuel burning: Global distribution of emissions, Tellus 37, 243-258.

Marland, G. and T. Boden, 1991: CO_2 emissions modern record. In Trends '91: A compendium of data on Global change ed. by T. Boden et al. Carbon Dioxide Information Analysis Center, CDIAC, Oak Ridge National Laboratory, Oak Ridge TN, USA.

Marland, G., R.J. Andres and T.A. Boden, 1994: Global, regional and national CO_2 emissions. In Trends '93: A compendium of data on Global Change. ORNL/CDIAC USA.

Marland, G., T.A. Boden, A. Brenkert, R.J. Andres and J.G.J Olivier, 1997: CO_2 from fossil fuel burning: Updates on the magnitude, distribution, and uncertainty of emission estimates. Paper presented at the 5th International Carbon Dioxide Conference, Cairns, Australia, 8-12 September 1997.

Marland, G., A. Brenkert and J. Olivier, 1999: CO_2 from fossil fuel burning: a comparison of ORNL and EDGAR estimates of national emissions. Environmental Science and Policy 2, 265-273.

Martin, P., 1998: Estimating the CO_2 uptake in Europe. Science, 281, 1806.

Matthijssen, A.J.C.M. and C. Kroeze, 1996: Emissions of HFCs, PFCs, FICs and SF_6 in the Netherlands in 1990, 1994, 2000, 2005, 2010 and 2020. RIVM report 773001-008. Bilthoven, the Netherlands.

McInnes, G., 1995: CORINAIR 1990 summary tables. European Environment Agency, Copenhagen, Denmark.

McInnes, G., 1999: Overview of National Programmes to Reduce Greenhouse Gas Emissions. Prepared by the European Environment Agency and its Topic Centre on Air Emissions. Final Draft. Copenhagen, Denmark.

Minschwaner K., R.J. Salawitch, and M.B. McElroy, 1993: Absorption of solar radiation by O_2. Implications for O_3 and lifetimes of N_2O, $CFCl_3$, and CF_2Cl_3. J. Geophys. Res 98, 10543-10561.

Mitra, A.P., and S. Bhattacharya, 1998: Greenhouse Gas Emissions in India for the base year 1990 using IPCC standard methodology. Scientific Report 11, Centre on Global Change, National Physical Laboratory, New Delhi.

MNR (Ministry of Natural Resources), 1994: Sources and Sinks for Greenhouse Gases in Uganda. Final report prepared for UNEP/GEF 143. Kampala.

Montzka, S.A., R.C. Myers, J.H. Butler, J.W. Elkins, L.T. Lock, A.D. Clarke and A.H. Goldstein, 1996: Observations of HFC-134a in the remote troposphere. Geophys. Res. Lett. 23, 169-172.

Mook, W., 1996: Lecture on isotope measurements at Dutch Royal Academy of Science, KNAW, 27 January 1996, the Netherlands.

Mosier, A., C. Kroeze, C. Nevison, O. Oenema, S. Seitzinger and O. van Cleemput, 1998: Closing the global atmospheric N_2O budget: nitrous oxide emissions through the agricultural nitrogen cycle. (OECD/IPCC/IEA Phase II Development of IPCC Guidelines for National Greenhouse Gas Inventories). Nutrient Cycling in Agroecosystems 52, 225-248.

Mosier, A., C. Kroeze, C. Nevison, O. Oenema, S. Seitzinger and O. van Cleemput, 1999: An overview of the revised 1996 IPCC guidelines for national greenhouse gas inventory methodology for nitrous oxide from agriculture. Environmental Science and Policy, 2, 325-333.

Nevison C., 1994: A model analysis of the spatial distribution and temporal trends of nitrous oxide sources and sinks. Stanford University and NCAR Cooperative Thesis No. 147. National Center for Atmospheric Research, Boulder, Colorado, USA, 225 pp.

Nevison C., R.F. Weiss, and D.J. Erickson III, 1995: Global oceanic nitrous oxide emissions. J. Geophys. Res. 95, D11, 18369-18385.

Neue, H.-U. and R. Sass, 1998: The budget of methane from rice fields. In: IGACtivities Newsletter 12, March 1998, 3-11.

Ngobese, P., B. Scholes and M. van der Merwe, 1994: National report South Africa. Climate and Africa Project. SEI Stockholm 50.

Nisbet, E.G., I. Levin, G.P. Wyers, A.F. Roddy, 1997: Quantification of the west European methane emissions budget by atmospheric measurementsOffice for Official publications of the European Communities, Report EUR 17511 EN.

Obioh, I.B., S.A. Momodu, W.O. Siyanbola, F.O. Oketola, F.I. Ibitoye, J.F.K. Akinbami and A.O. Adegbulugbe, 1996: Nigeria's greenhouse gas inventory 1990. In Braatz et al. (1996).

Olivier, J.G.J., 1995: Scenarios for global emissions from air traffic. The development of regional and gridded emission scenarios for aircraft and surface sources, based on CPB scenarios and existing emission inventories for aircraft and surface sources. RIVM report 773002-3, Bilthoven, the Netherlands.

Olivier, J.G.J., A.F. Bouwman, C.W.M. van der Maas, J.J.M. Berdowski, C. Veldt, J.P.J. Bloos, A.J.H. Visschedijk, P.Y.J. Zandveld and J.L. Haverlag, 1996: Description of EDGAR Version 2.0: A set of Global emission inventories of greenhouse gases and ozone-depleting substances for all anthropogenic and most natural sources on a per country basis and on a $1^{o}x1^{o}$ grid. RIVM/TNO report 771060-002. Bilthoven, the Netherlands. TNO-MEP report no R96/119.

Olivier, J.G.J. and A. F. Bouwman, 1997: A global sectoral emission inventory of N_2O and comparison with atmospheric observations. In: Proceedings of the CKO/CCB Workshop on Bottom-up and Top-down Estimates of Greenhouse Gases, Bilthoven 27-6-1997. RIVM report 728001 006.

Olivier, J.G.J., A.F. Bouwman, J.J.M. Berdowski, C. Veldt, J.P.J. Bloos, A.J.H. Visschedijk, C.W.M. van der Maas and P.Y.J. Zandveld, 1999: Sectoral emission inventories of greenhouse gases for 1990 on a per country basis as well as on $1^{o}x1^{o}$. Environmental Science and Policy 2, 241-263.

OLF (Norwegian Oil Industry Association), 1993: Environmental Programme Phase II Summary Report. Stavanger. Norway.

Olson, J.S., J.A. Watts and L.J. Allison, 1983: Carbon in live vegetation of major world ecosystems. ORNL 5862. Oak Ridge National Laboratory, Tennessee, Environmental Sciences Division Publication 1997. US Department of Commerce.

Oonk, H. and C. Kroeze, 1998: Nitrous oxide (N_2O): Emissions and options for control. In: Meyers R.A. (Ed.) Encyclopedia of Environmental Analysis and Remediation. John Wiley and Sons, NY. 3035-3053.

Oram, D.E., C.E. Reeves, W.T. Sturges, S.A. Penkett, P.J. Fraser and R.L. Langenfelds, 1996: Recent tropospheric growth rate and distribution of HFC-134a (CF_3CH_2F). Geophys. Res. Lett. 23, 1949-1952.

Oram, D.E., W.T. Sturges, S.A. Penkett, A. McCulloch and P.J. Fraser, 1998: Growth of fluoroform (CHF3, HFC-23) in the background atmosphere. Geophys. Res. Lett. 25, 35-38.

Pearman, G.I., D. Etheridge, F. De Silva, and P.J. Fraser, 1986: Evidence of changing concentrations of atmospheric CO_2, N_2O and CH_4 from air bubbles in Antarctic ice. Nature 320, 248-250.

Phillips, O.L., Y. Mahli, N. Higuchi, W. Laurance, P.V. Nuenez, R.M. Vasquez, S.G. Laurance, L. V. Ferreira, M. Stern, S. Brown and J. Grace, 1998: Changes in the carbon balance of tropical forests: Evidence from long term plots. Science, 282.

Post, W.M., A.W. King and S.D. Wullschleger, 1997: Historical variations in terrestrial biospheric carbon storage. Global Biogeochemical Cycles 11, 99-109.

Prinn, R., D. Cunnold, R. Rasmussen, P. Simmonds, F. Aleya, A. Crawford, P. Fraser, and R. Rosen, 1990. Atmospheric emissions and trends of nitrous oxide deduced from 10 years of ALE-GAGE data. J.Geophys.Res. 95, D11, 18369-18385.

Prinn, R., et al., 1998: Results of the ALE/GAGE network; http://cdiac.esd.ornl.gov/trends/ (June 1998)

Pulles, T., K. Mareckova, L. Kozakovic, P. Esser, J. Berdowski, 1996: Verification of CORINAIR 90 emission inventory by comparison with ambient air measurements. TNO-MEP report R 96/001.

Quay, P. D., S. L. King, J. Stusman, D.O. Wilbur, L. P. Steele, I. Fung, R.H. Gammon, T. A. Brown, G.W. Farwell, P. M. Grootes and F. H. Smidt, 1991: Carbon isotopic composition of atmospheric methane: Fossil and biomass burning source strengths. Global Biogeochemical Cycles 5: 25-47.

Rayner, P.J., I.G. Enting and C.M. Trudinger, 1996: Optimizing the CO_2 observing network for constraining sources and sinks. Tellus 48B, 433-444.

Reimer, R.A., R.A. Parrett and C.S. Slaten, 1992: Abatement of N_2O emissions produced in adipic acid. Proceedings of 5th International Workshop on Nitrous oxide Emissions. Tsukuba, Japan.

Ritter, M., 1997: CORINAIR 94 Summary Report. European Emission Inventory for Air Pollutants. Report to the European Environment Agency from the European Topic Centre on Air Emissions. Copenhagen, Denmark.

Ritter, M., 1997: Monitoring mechanism of Community CO_2 and other Greenhouse Gas Emissions. National Emission Inventories 1994/95. A report to the European Environment Agency from the European Topic Centre on Air Emissions. Copenhagen, Denmark.

Roy, C.R., 1979: Atmospheric nitrous oxide in the mid-latitudes of the Southern Hemisphere. J. Geophys. Res. 84, C7, 3711-3718.

Samaras, Z. and C. Veldt, 1993: Global emissions from road transport. Paper and data diskettes submitted to the 3rd GEIA workshop, Amersfoort, the Netherlands.

Salt, J. and A. Moran, 1997: International greenhouse gas inventory systems: A comparison between CORINAIR90 and IPCC methodologies in the European Union. Global Environmental Change, 7, 317-336.

Schipper, L. 1998: The IEA indicators effort: Extension to carbon emissions as a measure of sustainability. Discussion paper for an Expert group meeting on managing uncertainty in national greenhouse gas inventories. Paris, October 13-15, 1998.

Slanina, J., P. Warneck, N.M. Bazhin, H. Akimoto and W.M. Kieskamp, 1993: Assessment of uncertainties in the projected concentrations of methane in the atmosphere. Report based on Proceedings of the International Workshop held in Moscow, Russia, July 20-21, 1992. International Union of Pure and Applied Chemistry.

Smith, I.M. and L.L. Sloss, 1992: Methane emissions from coal. IEA Coal Research. London.

Smith, I.M., 1997: Methane emissions from coal. IEA Coal Research. London.

Smith, K.R., M.A.K. Khalil, R.A. Rasmussen, S.A. Thorneloe, F. Manegdeg and M. Apte, 1993: Greenhouse gas emissions from biomass and fossil fuel stoves in developing countries: a Manila pilot study. Chemosphere 26, 479-505.

Stijnen, J., A.W. Heemink, L.H.J.M. Janssen and J.T. van der Wal, 1997: Estimation of methane emissions in Europe using Kalman smoothing. Proceedings of Air Pollution 97. Bologna, 16-18 September 1997.

Stijnen, J.W., A.W. Heemink, X.F. Zhang, L.H.J.M. Janssen and B. Farnham, 1998: Data assimilation in air pollution models. Computational Mechanics Publications, Southampton, UK.

Steele, L.P., P.J. Fraser, R.A. Rasmussen, M.A.K. Khalil, T.J. Conway, A.J. Crawford, R.H. Gammon, K.A. Masarie and K.W. Thoning, 1987: The global distribution of methane in the troposphere. J. Atm. Chem. 5, 125-171.

Steele, L.P., E.J. Dlugokencky, P.M. Lang, P.P. Tans, R.C. Martin and K.A. Masarie, 1992: Slowing down of the global accumulation of atmospheric methane during the 1980s. Nature 358, 313-316.

Subak, S., P. Raskin and D. Von Hippel, 1992: National greenhouse gas accounts: current anthropogenic sources and sinks. SEI Boston MA, USA.

Subak, S., 1999: On evaluating accuracy of national methane inventories. Environmental Science and Policy 2, 229-240.

Tans, P.P., T. Conway and T. Nakazawa, 1989: Latitudinal distribution of the sources and sinks of atmospheric carbon dioxide derived from surface observations and an atmospheric transport model. J. Geophys. Res. 94, D4, 5151-5172.

Tans, P.P., I.Y. Fung and T. Takahashi, 1990: Observational constraints on the global atmospheric CO_2 budget. Science, 247: 1431-1436.

Tans, P.P. 1997: A note on isotopic ratios and the global atmospheric methane budget. Global Biogeochemical Cycles 11, 1:77-81.

Taylor, J.A., G. Brasseur, P. Zimmerman and R. Cicerone, 1991: A study of the sources and sinks of methane and methyl chloroform using a global three-dimensional Lagrangian tropospheric tracer transport model. J. Geophys. Res. 96, 3013-3044.

The, T.H.P. and J.P. Beck, 1995: Scenario studies on effects of methane emissions using a 3-D tropospheric model. RIVM report 722501-003. Bilthoven, the Netherlands.

Tian H., J.M. Melillo, D.W. Kicklighter, A.D. McGuire, J.V.K. Helfrich, B. Moore III and C.J. Vorosmarty, 1998: Effect of interannual climate variability on carbon storage in Amazonian ecosystems. Nature 396, 664-667.

Toure, S., A. Gougou, B. Diane, A. Kouame, 1996: Preliminary Greenhouse Gas Inventory, Cote d'Ivoire. In Braatz et al. (1996).

Tyler, S.C., 1986: Stable carbon isotope ratios in atmospheric methane and some of its sources. J. Geophys. Res. 91, 13233-13238.

Tyler, S.C., P. Zimmermann, C. Cumberbatchm, J.P. Greenberg, C. Westberg and J.P.E.C. Darlington, 1988: Measurements and interpretation of $\delta^{13}C$ of methane from termites, rice paddies and wetlands in Kenya. Global Biogeochemical Cycles 2, 341-355.

UN, 1993: Industrial Commodity Production Statistics. UN-ECE Statistical Division through International Environmental Data Service (IEDS). Geneva, Switzerland. Data on diskette.

UN, 1995: Industrial Commodity Production Statistics Database 1970-1992. UN, New York. Data on diskettes.

UNFCCC, 1996: Second review and synthesis of first national communications. Addendum 2: Tables. Geneva.

UNFCCC/CP/1997/L.7/Add.1: Kyoto Protocol to the United Nations Framework Convention on Climate Change. COP3, Kyoto, Japan.

UNFCCC/CP/1998/11/Add.1: Second Compilation and Synthesis of Second National Communications. COP4, Buenos Aires, Argentina.

UNFCCC/CP/1998/11/Add.2: Tables of inventories of anthropogenic emissions and removals of greenhouse gases for 1990-1995 and projections up to 2020. COP4, Buenos Aires, Argentina.

USEPA, 1994: International Anthropogenic Methane Emissions: Estimates for 1990. Office of Policy Planning and Evaluation. EPA 230-R-93-010.

Van Aardenne, J.A., G.R. Carmichael, H. Levy II, D. Streets and L. Hordijk, 1999: Anthropogenic NO_x emissions in Asia in the period 1990-2020. Atm. Env. 33, 633-646.

Van Aardenne, J.A., J.G.J. Olivier, F.J. Dentener, C.G.M. Klein Goldewijk and J. Lelieveld, 1999: A high resolution dataset of historical anthropogenic trace gas emissions for the period 1890-1990. Submitted to Global Biogeochemical Cycles.

Van Amstel, A.R. (ed.), 1993: Proceedings of an International IPCC workshop on Methane and Nitrous Oxide: Methods in national emission inventories and options for control. RIVM 481507-003. Bilthoven, the Netherlands.

Van Amstel, A.R., 1993: Transparency of National Emission Inventories. In: Proceedings of an International IPCC workshop on Methane and Nitrous Oxide: Methods in national emission inventories and options for control. RIVM 481507-003. Bilthoven, the Netherlands. pp 27-35.

Van Amstel, A.R., R.J. Swart, M.S. Krol, J.P. Beck, A.F. Bouwman and K.W. van der Hoek, 1993: Methane, the other greenhouse gas. Research and Policy in the Netherlands. RIVM 481507-001, Bilthoven, the Netherlands.

Van Amstel, A.R., R.A.W. Albers, C. Kroeze, A.J.C.M. Matthijsen, J.G.J. Olivier and J. Spakman, 1994: Greenhouse gas emissions in the Netherlands 1990, 1991, 1992 and projections for 1990-2010. (A background report for the first National Communication of the Netherlands for the Climate Convention). RIVM report 773001-3. Bilthoven, the Netherlands.

Van Amstel, A.R., 1995: Greenhouse gas emissions in the Netherlands. Methodology and data for 1993 and provisional for 1994. RIVM report 773001-010, Bilthoven, the Netherlands.

Van Amstel, A.R., C. Kroeze, L.H.J.M. Janssen, J.G.J. Olivier and J.T. Van der Wal., 1997: Greenhouse Gas Emission Accounting. Preliminary study as input to a joint International IPCC Expert Meeting/CKO-CCB Workshop on Comparison of Top-down versus Bottom-up Emission Estimates. WIMEK/RIVM report 728001 002. Bilthoven, the Netherlands.

Van Amstel, A.R., J.G.J. Olivier, L.H.J.M. Janssen and J. Berdowski, 1997: Comparison of bottom-up inventories, methane as an example. Discussion paper for the IPCC expert meeting on Methods for Assessment of Inventory Data Quality, November 5-7 1997 Bilthoven, the Netherlands.

Van Amstel, A.R., L. Janssen and B. Lim (eds.) 1999: Greenhouse Gas Inventory Quality. Special Issue of Environmental Science and Policy 2, 217-361.

Van Amstel, A.R., J.G.J. Olivier and L.H.J.M. Janssen, 1999: Analysis of differences between national inventories and an Emissions Database for Global Atmospheric Research (EDGAR). Environmental Science and Policy 2, 275-293.

Van Amstel, J.G.J. Olivier and P.G. Ruyssenaars, 1999: Monitoring of Greenhouse Gas Emissions in the Netherlands: uncertainty and priorities for improvement. Proceedings of a national workshop, Bilthoven, 1 September 1999. WIMEK/RIVM report 773201 002. Bilthoven, the Netherlands.

Van der Wal, J.T., J. Stijnen and L.H.J.M. Janssen, 1997: Using observed methane concentrations in assessing regional emissions in Europe. Submitted for Proceedings of Air Pollution 97, Bologna, 16-18 September 1997.

Veldt, C. 1994: NMVOC emission factors and profiles for petroleum refineries. TNO-MW, Delft, the Netherlands.

Veldt, C. and J.J.M. Berdowski, 1995: Note on the combustion of biomass fuels. Emission factors for CO, CH_4 and NMVOC. TNO report 94/218. Delft.

Veltkamp, A.C., R. Eisma, A.T. Vermeulen, W.M. Kieskamp, W.C.M. van den Bulk, B. Beemsterboer, O. Zwaagstra, J.J. Mols, A. Hensen and G.P. Wyers, 1995: Validation of methane source strengths. Netherlands Energy Research Foundation, Report ECN-C-95-034. Petten.

Vermeulen, A.T., B. Beemsterboer, W.C.M. van den Bulk, R. Eisma, A. Hensen, W.M. Kieskamp, J.J. Mols, J. Slanina, A.C. Veltkamp and G.P. Wyers, 1996: Validation of methane emission inventories for NW-Europe. Netherlands Energy Research Foundation. Report ECN-C-96-088. Petten, the Netherlands.

Vermeulen, A. T., R. Eisma, A.Hensen and J. Slanina, 1999: Transport model calculations of NW-Europe methane emissions. Environmental Science and Policy 2, 315-324.

Wahlen, M., N. Tanaka, R. Henry, B. Deck, J. Zeglen, J.S. Vogel, J. Southon, A. Shemish, R. Fairbanks and W. Broecker, 1989: Carbon-14 in methane sources and in atmospheric methane: The contribution from fossil carbon. Science 245, 286-290.

Weiss R.F., 1981a: Determination of carbon dioxide and methane by dual catalyst flame ionization chromatography and nitrous oxide by electron capture chromatograhy. J. Chrom. Sci. 19, 611-616.

Weiss R.F., 1981b: The temporal and spatial distribution of tropospheric nitrous oxide. J. Geophys. Res. 86, C8, 7185-7195.

Williams, R.H. 1998: Hydrogen production from coal and coal bed methane, using byproduct CO_2 for enhanced methane recovery and sequestering the CO_2 in the coal bed. In Proceedings of the Fourth International Conference on greenhouse gas control technologies, Interlaken, Switzerland, 30 Aug. – 2 Sept. 1998.

WMO-GAW, 1996: Trace gas atmospheric concentrations. Measurement database. Japan.

Woodbury, J. and A. Hashimoto, 1994: Methane emissions from livestock manure. In Adler, M.J. 1994: International anthropogenic methane emissions: Estimates for 1990. USEPA.

Zhang, X-F., 1996: Data assimilation in air pollution monitoring. Thesis. Delft University, the Netherlands.

Zhang, X-F., A.W. Heemink, L.H.J.M. Janssen, P.H.M. Janssen and F.J. Sauter, 1999: New computationally efficient Kalman filter for the evaluation of the CH_4 budget in Europe. Applied Mathematical Modelling 23, 109-129.

Appendix A: Glossary

This Glossary contains terms identified at the IPCC Expert Group Meeting on 'Managing Uncertainty in National Greenhouse Gas Inventories' held in Paris, 13-15 October 1999 (IPCC, 1999), except form terms indicated with an asterix (*), which are described by the authors of this report.

Accuracy [2]

The tendency of values of an *estimator* to come close to the quantity they are intended to estimate. See also *Precision*. So far as inventories are concerned accuracy means that estimates are neither over estimates nor underestimates of true avulse, so far as can be judged, and that the uncertainties are reduced so far as practicable

Bias [2]

(1) In problems of estimation, an estimator is said to be *biased* if its expected value does *not* equal the parameter it is intended to estimate.
(2) In sampling, a *bias* is a systematic error introduced by selecting items from a wrong population, favouring some of the elements of a population, or poorly phrasing questions.

Comparability

In the IPCC inventory context inventories are said to be *comparable* with the Guidelines if they are produced using the Guidelines, or by using methods that are mathematically equivalent to those in the Guidelines, or which can be shown to give more accurate estimates than the methods in the Guidelines for source categories contained in the Guidelines.

Compliance [1]

Compliance is the act of conforming or yielding to a specified norm or protocol. In the inventory development process, compliance indicates conformity to development protocols or international agreements. In this sense the compliance issue can be thought of as verification of adherence to these established and agreed norms.

Confidence [1]

The term confidence is used to represent trust in a measurement or estimate. Having confidence in inventory estimates does not make those estimates accurate or precise, but will help to develop a consensus that the data can be applied to problem solving.

Consistency [2]

(1) An *estimator* (depending on the sample size of n) is said to be *consistent* if the probability that it will assume a value arbitrarily close to the parameter it is intended to estimate *approaches one* when n becomes infinite.
(2) In the IPCC inventory context, consistency can mean that the methods used are the same throughout the time series being reported.

Estimate [2]

A number or an interval, based on sample data produced by an estimator; also the result of a model calculation or other estimation procedure.

National Communication *

National report on national circumstances, national emissions and sinks, climate policies and measures, emission projections, expected impacts and adaptation measures, activities implemented jointly, financial assistance, technology transfer, science programmes and awareness building on climate change. An official report submitted by each Party to the Conference of Parties to the UN Framework Convention on Climate Change (UNFCCC).

National Inventory *

National annual report on greenhouse gas emissions and sinks. Usually this report is more detailed than the chapter on emission inventories in the National Communication. Annually, Annex I Parties send their national inventory to the Climate Convention Secretariat as official submission. Many Parties consider it as an official annex to their National Communication.

National Report *

In this context this refers to national inventories that have not been submitted to the Climate Convention Secretariat of the Conference of Parties to the UNFCCC. Mostly compiled for less developed countries that have no official obligation yet to report their national greenhouse gas emissions. This may refer e.g. to inventories compiled as part of the US Country Study Programme (CSP) of the UNEP programme on compilation of national inventories.

Precision [2]

The precision of an *estimator* is its tendency to have its values cluster closely about the expected value of its sampling distribution; thus, it is related inversely to the *variance* of this sampling distribution - the smaller the variance, the greater the precision.

Transparency [2]

(1) Transparency is used to represent the condition of being clear and free from pretence.
(2) In the context of compiling emission inventories under the UNFCCC this means:
  a) the construction of the emission estimates is clearly explained;
  b) the documentation of the inventory is sufficient for another party to reconstruct it;
  c) the documentation sufficiently clarifies the major causes of emission trends in the inventory.
  Transparency will be greatly increased if the data collected and reported by different agencies will be similar and, therefore, easily understood by other parties and comparable to the data presented by the other parties.

Uncertainty [1]

Uncertainty is a statistical term that is used to represent the degree of accuracy and precision of data. It often expresses the range of possible values of a parameter or a measurement around a mean or preferred value.

Validation [1]

(1) Validation is the establishment of sound approach and foundation. The legal use of validation is to give an official confirmation or approval of an act or product.
(2) In the context of emission inventories validation involves checking to ensure that the inventory has been compiled correctly in line with reporting instructions and guidelines. It checks the internal consistency of the inventory.

Verification [1]

Verification refers to the collection of activities and procedures that can be followed during the planning and development, or after completion of an inventory that can help to establish its reliability for the intended applications of that inventory. Typically, methods external to the inventory are used to check the truth of the inventory, including comparisons with estimates made by other bodies or with emission and uptake measurements determined from atmospheric concentrations and/or concentration gradients of these gases.

Definitions are extracted from:

[1] The European Environment Agency, *Atmospheric Emission Inventory Guidebook (CD-ROM)*, section on Procedures for Verification of Emission Inventories; Copenhagen, 1997.

[2] Freund, J.E., and F.J. Williams, *Dictionary/Outline of Basic Statistics*, 195 pp., Dover Publications, Inc., New York, NY, 1966.

Appendix B: Country inventory comparisons, for top-down comparisons grouped into semi-hemispheric regions

Hemisphere	Country	EDGAR Gg CO_2	NC1 Gg CO_2	NC2 Gg CO_2	EDGAR Gg CH_4	NC1 Gg CH_4	NC2 Gg CH_4	EDGAR Gg N_2O	NC1 Gg N_2O	NC2 Gg N_2O
SH	Australia	259807	288965	273123	4476	6243	5140	69	60.1	79
NH-H	Austria	57382	59200	61880	452	603	587	7	4.1	11.6
NH-H	Belgium	108248	114410	116090	599		634	15		30.8
NH-H	Bulgaria	71579	82990	96878	515	1370	1413	16	22.5	30.8
NH-H	Canada	431022	462643	464000	3851	3088	3200	368	95.5	86
NH-H	Czech Rep.		165792	165490		942	888		24	25.8
NH-H	Denmark	51513	52025	52277	407	407	421	13	10.3	34
NH-H	Estonia		37797	37797		323	105		2.4	2.3
NH-H	Finland	50541	53900	53800	264	252	246	143	22	18
NH-H	France	352105	366536	378379	3757	2896	3017	126	176.7	181.7
NH-H	Germany	992478	1014155	1014155	6136	5682	5682	126	211	226
NH-M	Greece	73754	82100	84575	426	343	443	13	13.7	17.3
NH-H	Hungary	65771	71673	83676	708	545	664	11	11.4	12.9
NH-H	Iceland	1905	2172	2147	19	23	14	0.2	0.6	0.4
NH-H	Ireland	30242	30719	30719	657	796	811	14	42.3	29.4
NH-M	Italy	404151	428941	432150	2388	3901	2329	44	120.3	164.5
NH-M	Japan	1071427	1155000	1124532	3336	1382	1575	52	55.2	105.3
NH-H	Latvia		22976	24771		159	186		2.4	22.5
NH-H	Lithuania			39535			378			13.2
NH-H	Luxembourg	10085	11343	12750		24	24	0.1	0.6	0.6
NH-H	Monaco		71	71						
NH-H	Netherlands	147138	167600	167550	1002	1060	1104	19	51.5	51.2
SH	New Zealand	25347	25476	25476	1032	1986	1706	40	17.1	47.5
NH-H	Norway	44764	35514	35544	265	290	432	21	15	15
NH-H	Poland	362718	414930	476625	4619	6100	3141	82	156	70
NH-H	Portugal	41810	42148	47123	421	226	809	8	10.5	14

Hemisphere	Country	EDGAR Gg CO_2	NC1 Gg CO_2	NC2 Gg CO_2	EDGAR Gg CH_4	NC1 Gg CH_4	NC2 Gg CH_4	EDGAR Gg N_2O	NC1 Gg N_2O	NC2 Gg N_2O
NH-H	Romania	46234	42148		2202	1954		30	106.8	
NH-H	Slovakia		58278	60032		347	409		16	12.5
NH-H	Slovenia			13935			176			5.1
NH-M	Spain	217746	227322	226423	2027	2151	2181	39	93.9	94.2
NH-H	Sweden	55576	61256	55445	364	329	324	8	15.2	9.2
NH-H	Switzerland	42602	45070	45070	313	332	244	4	15.6	11.5
NH-H	Ukraine			700107			9453			23.4
NH-H	UK	575640	577012	583747	3868	4531	4464	111	108.3	120
NH-M	USA	4804805	4957022	4960432	41512	27000	29578	531	411.4	425
NH-H	Russian Fed.		2388720	2372300	47000	27000	26500		89.6	225.7
T	Bolivia				757	600	600			
T	Costa Rica				168	164	164			
T	Mexico				4192	3894	3894			
T	Peru				835	1374	1374			
SH	Venezuela				1818	3178	3178			
T	Algeria				757	1370	1370			
T	Botswana				366	537	537			
T	Cameroon				514	461	461			
T	C d' Ivoire				586	717	717			
T	Ethiopia				2003	1491	1491			
T	Gambia				26	32	32			
T	Ghana				347	1078	1078			
T	Morocco				378	443	443			
T	Nigeria				3264	2692	2692			
T	Senegal				258	306	306			
SH	South Africa				2334	2837	2837			
T	Tanzania				1349	1303	1303			
T	Uganda				484	1277	1277			
T	Zimbabwe				501	381	381			

Hemisphere	Country	EDGAR Gg CO_2	NC1 Gg CO_2	NC2 Gg CO_2	EDGAR Gg CH_4	NC1 Gg CH_4	NC2 Gg CH_4	EDGAR Gg N_2O	NC1 Gg N_2O	NC2 Gg N_2O
T	Bangladesh				5696	974	974			
NH-M	China				40472	34287	34287			
T	India				35969		18672			
T	Mongolia				352	330	330			
T	Philippines				2241	1027	1027			
T	Thailand				5065	7002	7002			
	Total	10396390	13545904	14318604	243.348	170.040	194705	1910.3	1982	2216.4
	RoW1 tot = CS	6115295	6115295	6115295	110.732	67755	86427			
	RoW2 = EDGAR	6665550	6665550	6665550						
	World total	**23177235**	**26326749**	**27099449**						
	Gt C	6.3	7.1	7.3						

	CO_2-EDGAR [1,2,3)]	CO_2-NC-1	CO_2-NC2	CH_4-EDGAR	CH_4-NC-1	CH_4-NC-2	N_2O-EDGAR	N_2O-NC-1	N_2O-NC-2
NH-H	0.9565819	1.7246157	1.9437549	77.419	59.279	65.326	1.1223	1.2103	1.2836
NH-M	3.5033258	3.5785966	3.5725769	90.161	69.064	70.393	0.679	0.6945	0.3568
T	1.7271412	1.7271412	1.7271412	66.108	27.453	46.125	0	0	0
SH	0.0770686	0.0849841	0.0807024	9.66	14.244	12.861	0.109	0.0772	0.1265
Tot	6.2641176	7.1153376	7.3241754	243.348	170.040	194.705	1.9103	1.982	1.7669

1) Russia not included and RoW1 and RoW2 equally divided between NH-M and T/

2) EDGAR +CS + ROW2 = 6.3 Gt C
EDGAR total = 6.8 Gt C; difference is due to differences in CO_2 emission is CS en EDGAR for those countries.

3) In EDGAR is deforestation for OECD and EIT countries not recorded, but for LDC it is.
For biofuel an additional 10% CO_2 emission is calculated because of assumed " non-sustainable use" .

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