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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 1°x1° grid

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PREFACE

This report describes the results of a joint project of RIVM and TNO to establish a Emission Database for Global Atmospheric Research (EDGAR) comprising a number of consistent global inventories of direct and indirect greenhouse gas emissions, including halocarbons, both on a per country basis as well as on $1^o x 1^o$ grid. The database has been developed with financial support from the Dutch Ministry of the Environment and the Dutch National Research Programme on Global Air Pollution and Climate Change (NRP), in close cooperation with the Global Emissions Inventory Activity (GEIA), a component of the International Atmospheric Chemistry Programme (IGAC) of IGBP. This report is an extended version of the final report prepared for the NRP. Being part of both the NRP and the GEIA, the results of the project are available for use by policy makers and NRP and other research groups, which can have access to the results through FTP. This study is unique in that it combines data both at the country level and at grid-cell level, disaggregated at the sectoral level, thereby creating internally consistent and complete emissions inventories that can be used for policy support applications and for atmospheric modelling.

Version 2.0 of EDGAR has been limited validated (for global, and for some compounds regional, totals); a more thorough validation at the regional and sectoral level is anticipated in a follow-up project. It can be expected, that periodically new data and other improvements will be included in new versions of the database, of which the updated results will again be released.

The database could not have been developed without the help of many persons and organizations outside the EDGAR project team. Notwithstanding the help of persons not mentioned here, we would like to mention in particular the assistance and cooperation of the following persons and organizations, which is greatfully acknowledged: dr. Robert J. Andres and dr. Greg Marland of Oak Ridge National Laboratory, for providing information on CO_2 emission factors for fossil fuel combustion and flaring; dr. Carmen M. Benkovitz and Mr. M. Altaf Mubaraki at Brookhaven National Laboratory, for their help in evaluating emission factors for SO_2 from the production of non-ferro metals, for locating many coal mines in the USA, and for providing data on oil and gas production in the USA and on the NAPAP inventories; dr. Frank Carnovale of Coffey Partners Int. PTY Ltd, for providing Australian emission inventory data on NMVOC; the Conseil Europèen des Federations de l'Industrie Chimique (CEFIC) and the Japanese Association for the Hygiene of Chlorinated Solvents (JAHCS), for providing overviews of solvent use for important parts of the world; prof.dr. David O. Hall and dr. Frank Rosillo-Calle, of the Biomass User's Network's Information and Skills Centre at King's College (UK) for their cooperation, information and advice on biofuel consumption data; dr. Wei Min Hao at the Intermountain Fire Science Laboratory, for providing the biomass burning maps; the IEA for providing additional information on conversion factors for the energy statistics; members of IPCC Expert Groups, for their valuable information of several aspects; Mrs. Janice L.W. Jolly of the International Copper Study Group at Lisbon, for providing information on global copper production facilities; dr. Niels Kilde at RISØ, for providing information on international shipping; dr. G.J.M. Linssen and drs. Thea van Dijk of the Dutch Ministry of Economic Affairs, for providing information on global lead and zinc production facilities; dr. Jennifer A. Logan at Harvard University, for providing the $1^o x 1^o$ population distribution map, which has been a pivotal element in the construction of the grid-based emission inventories; dr. Archie McCulloch at ICI Chemicals

& Polymers Ltd, for his information and advice on N_2O from global adipic and nitric acid production and on the distribution of halocarbon consumption per country; dr. Elaine Matthews at NASA-GISS, for providing preliminary maps of global production of fossil fuels; dr. P.M. Midgley of M&D Consulting, for stimulating discussions and contributions on chlorinated solvent use data; Mr. Kari Nevalainen at the UN-ECE Statistical Division, for providing global data through the Information Environmental Data Service (IEDS); dr. Cindy Nevison for providing the map for N_2O from oceans; Mr. John Stork of Novem (NL), for providing documentation on the location of global coal mining activities; dr. Zissis Samaras at the Aristotle University, Thessaloniki (GRC), for providing his global inventory of emissions from road transport; and last but not least we wish to mention the cooperation with the various Working Groups of the Global Emissions Inventory Activity (GEIA), which is convened by dr. Thomas E. Graedel of AT&T. In particular we would like acknowledge NASA and dr. Alex Guenther of NCAR for providing, through the FTP site of the GEIA data distribution centre located at the National Center for Atmospheric Research (NCAR), Version 1 of the GEIA aircraft emissions and natural NMVOC emissions data sets, respectively.

In addition, for Version 1.0, an interim version especially developed for environmental assessment of aircraft emissions at 5^ox5^o, we particularly thank the following persons for their valuable contribution: dr. Charles T. Walker at AEA, Technology, Culham (UK) for the use of the WSL air traffic database; dr. Peter J. Newton of the British Department of Trade and Industry (DTI), for computer runs with the DTI air traffic model; dr. Roger M. Gardner of the British Department of Transport, for his advice on gridded aircraft emissions inventories; dr. Jean-Francois Müller of the Belgian Institute for Space Aeronomy (OMA) for providing the gridded inventory of surface source emissions; and drs. René Baart of PSB, who developed the EDGAR software to handle the emission inventories on 5^ox 5^o resolution.

To improve to readability of this report for readers of different backgrounds a list of abbreviations, chemical compounds, units and conversion factors has been added to the report.

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APPENDIXES:

TABLE CAPTIONS

FIGURE CAPTIONS

ABBREVIATIONS

AESA	Atmospheric Effects of Stratospheric Aircraft
AFEAS	Alternative Fluorocarbons Environmental Acceptibility Study
AP-42	Air Pollutant report of EPA; Fourth Edition
AL	Activity Level
ANCAT	Abatement of Nuisances Caused by Air Transport (environmental committee of ECAC)
AUS	Australia
BoM	Bureau of Mines
BUN	Biomass User's Network
CAN	Canada
CCEE	Collaborating Centre for Energy and Environment (UN)
CIS	Commonwealth of Independent States (i.e. former USSR)
DDR	Former German Democratic Republic
DEU	Germany
ECAC	European Civil Aviation Conference
ECE	Economic Commission for Europe (UN)
ECN	Netherlands Energy Research Foundation
EDGAR	Emission Database for Global Atmospheric Research
EF	Emission Factor
EMEP	European Programme for Monitoring and Evaluation of long-range transmission of air Pollutants
EU	European Union
FAO	Food and Agricultureal Organization (UN)
FCCC	Framework Concention on Climate Change (UN)
FTP	File Transfer Protocol
GEIA	Global Emissions Inventory Activitiy (IGAC)
GHG	Greenhouse gas
GIS	Geographical Information System
GISS	NASA Goddard Institute for Space Studies
HSRP	High-Speed Research Programme
IEA	International Energy Agency
IGAC	International Global Atmospheric Chemistry programme
IGBP	International Geosphere-Biosphere Programme
ILZSG	International Lead and Zinc Study Group
IMAGE	Integrated Model to Assess the Greenhouse Effect (of RIVM)
IMO	International Maritime Organisation
IPCC	Intergovernmental Panel on Climate Change
ISIC	International Standard Industrial Code
KNMI	Royal Netherlands Meteorological Institute
LAE	RIVM Laboratory of Waste Materials and Emissions
LDC	Less Developed Countries (IPCC/CPB region)
LHV	Lower Heating Value
LLO	RIVM Laboratory for Air Research
LOTOS	Long-Term Ozone Simulation
LPG	Liqified Petrol Gas
LULU	Luchtvaart en Luchtverontreiniging (Dutch acronym for 'Air traffic and air pollution')
LUW	Landbouw Universiteit Wageningen (Agricultural University Wageningen)
MEP	TNO Institute of Environmental Sciences, Energy Research and Process Innovation

MPA	Measuring Plan Aerosols (Dutch acronym)
NA	Not Available; Not Applicable; also: Nitric Acid
NAPAP	National Acid Precipitation Assessment Programme
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NLD	Netherlands
NLR	National Aerospace Laboratory
NRP	Dutch National research Programme on Global Air Pollution and Climate Change
OECD	Organisation for Economic Cooperation and Development
OGJ	Oil and Gas Journal
OLADE	Organizacion LatinoAmericana de Energia (Latin American Energy Organisation)
OTS	Other Transformation Sector (energy)
pop. dens.	population density
PHOXA	Photochemical Oxidant and Acid Deposition Model Application within the Framework of Control Strategy Development
RCO	Residentials, Commercials and Other stationary, non-industry sector
RIM+	Environmental Accounting Programme 'plus';
RIO	Road, Inland shipping and Other land transport
SEI	Stockholm Environment Institute
TPES	Total Primary Energy Supply (IEA definition)
TNO	Netherlands Organization for Applied Scientific Research
UBA	Umwelt Bundes Ambt (German EPA)
UN	United Nations
UNEP	United Nations Environment Programme
3D	Three-dimensional

CHEMICAL COMPOUNDS

AA	Adipic Acid
CFCs	Chlorofluorocarbons
CH_4	Methane
CO	Carbon monoxide
CO-C	Carbon monoxide, expressed as C (element)
CO_2	Carbon dioxide
CO_2-C	Carbon dioxide, expressed as C (element)
CTC	Carbon Tetra Chloride
HCs	Hydrocarbons
HNO_3	Nitric Acid
H_2SO_4	Sulphuric Acid
H_2O	Water (vapour)
MCF	Methyl Chloroform (1,1,1-Trichloroethane)
N	Nitrogen (element basis)
NA	Nitric Acid
NO_x	Nitrogen oxide (NO and NO_2), expressed as NO_2
NO_x-N	Nitrogen oxide (NO and NO_2), expressed as N (element)
N_2O	Nitrous oxide
N_2O-N	Nitrous oxide, expressed as N (element)
NMVOC	Non-Methane Volatile Organic Compounds
S	Sulphur (element basis)
SO_2	Sulphur dioxide
SO_2-S	Sulphur dioxide, expressed as S (element)
VOC	Volatile Organic Compounds (may include or exclude methane)

UNITS

MJ	Mega Joule (10^6 Joule)
GJ	Giga Joule (10^9 Joule)
TJ	Tera Joule (10^{12} Joule)
PJ	Peta Joule (10^{15} Joule)
EJ	Exa Joule (10^{18} Joule)
Mg	Mega gramme (10^6 gramme)
Gg	Giga gramme (10^9 gramme)
Tg	Tera gramme (10^{12} gramme)
Pg	Peta gramme (10^{15} gramme)
ton	metric tonne (= 1 000 kilogramme = 1Mg)
kton	kiloton (= 1 000 metric tonne = 1 Gg)
Mton	Megaton (= 1 000 000 metric tonne = 1 Tg)

CONVERSION FACTORS FOR EMISSION FACTORS

From element basis to full molecular mass:

$C \rightarrow CO_2$:	x 44/12 = 3.6666
$C \rightarrow CH_4$:	x 16/12 = 1.3333
$C \rightarrow CO$:	x 28/12 = 2.3333
$N \rightarrow N_2O$:	x 44/28 = 1.5714
$N \rightarrow NO$:	x 30/14 = 2.1428
$N \rightarrow NO_2$:	x 46/14 = 3.2857
$N \rightarrow NH_3$:	x 17/14 = 1.2143
$N \rightarrow HNO_3$:	x 63/14 = 4.5
$S \rightarrow SO_2$:	x 64/32 = 2

From full molecular mass to element basis:

CO_2	$\rightarrow C$:	x 12/44 = 0.2727
CH_4	$\rightarrow C$:	x 12/16 = 0.75
CO	$\rightarrow C$:	x 12/28 = 0.4286
N_2O	$\rightarrow N$:	x 28/44 = 0.6363
NO	$\rightarrow N$:	x 14/30 = 0.4667
NO_2	$\rightarrow N$:	x 14/46 = 0.3043
NH_3	$\rightarrow N$:	x 14/17 = 0.8235
HNO_3	$\rightarrow N$:	x 14/63 = 0.2222
SO_2	$\rightarrow S$:	x 32/64 = 0.5

ABSTRACT

A global emission source database called EDGAR has been developed jointly by TNO and RIVM to meet the urgent need of atmospheric chemistry and climate modellers and the need of policy-makers. The purpose of the EDGAR database was to estimate for 1990 the annual emissions per sector of direct and indirect greenhouse gases (CO_2, CH_4, N_2O, CO, NO_x, non-methane VOC) and SO_2, including ozone-depleting compounds (halocarbons), on a regional and grid basis. To meet the aim of establishing the global emissions from both anthropogenic and biogenic sources, a complete set of data would be required. This is to allow estimation of the total source strength of the various gases with a $1^o x 1^o$ resolution (altitude resolution of 1 km), as agreed upon in the Global Emissions Inventory Activity (GEIA) of the International Atmospheric Chemistry Programme (IGAC). As insights in this field are still changing, due attention was paid in the setup of the system to flexibility on the disaggregation of sources, spatial and temporal resolution, and species. This report presents a description of the construction and contents of the database, as well as the type and sources of data:

- the methodology used in establishing the set of inventories,
- the structure and main functions of the database system;
- the setup of the emission source categories;
- the description of sources and related data (activity levels, emission factors, maps used to allocate emissions on grid);
- resulting emission inventories (by region and on grid), including a first validation;
- uncertainties and limitations;
- policy applications, and
- conclusions summarizing the achievements of this project.

The global total source strength of anthropogenic emissions in 1990 is estimated to be 29.8 Pg CO_2 (including partial oxidation to compounds other than CO_2), 320 Tg CH_4, 3.2 Tg N_2O-N (excluding a background emission from arable lands of 1.4 Tg N_2O-N), 974 Tg CO, 102 Tg NO_2, 148 Tg SO_2 and 178 Tg NM-VOC emissions. In addition, natural emissions of N_2O and reactive NMVOC are included in the database, with global estimates of 6.6 and 3.6 Tg N_2O-N from natural soils and oceans, respectively, and 1182 Tg NMVOC (as CH_4) from vegetation and oceans. An indication of the uncertainty in the data has been provided separately. A partial validation, obtained by comparing our estimates per major source with other global total estimates generally showed a good agreement. This was also true for NO_2 and SO_2, when we compared our estimates with other regional inventories for Europe and Asia.

EXECUTIVE SUMMARY

This report describes the applied methods and the results of a project to establish a number of global inventories of direct and indirect greenhouse gas emissions, including halocarbons. Subsequently, the the following topics are discussed:
- the methodology used in establishing the set of inventories;
- the structure and main functions of the database system;
- the setup of the emission source categories;
- the description of sources and related data (activity levels, emission factors, maps used to allocate emissions on grid);
- resulting emissions inventories (by region and on grid);
- uncertainties and limitations;
- policy applications, and
- conclusions summarizing the achievements of this project.

The following compounds were considered: the direct greenhouse gases CO_2, CH_4 and N_2O; the indirect greenhouse gases NO_x (+), SO_2 (-) (also acidifying gases), CO and VOC (also gases contributing to the formation of photochemical smog); and the ozone-depleting compounds (halogenated hydrocarbons). We note that NO_x, CH_4 and CO are also precursors of tropospheric ozone, which enhances radiative forcing (greenhouse effect) and is also a toxic compound.

Objectives

The objectives of this study were to construct a global emission database to meet the needs of a variety of users: (1) atmospheric chemistry and climate modellers requiring gridded global emission data as input into their models; (2) RIVM's needs for global monitoring of climate affecting emissions, and for aggregated emission factors as input into RIVM's climate model 'IMAGE 2.0' (Integrated Model to Assess the Greenhouse Effect); (3) policy support applications for ministries, IPCC or FCCC, requiring country- and region-specific estimates of current greenhouse gas emissions and their trends.

To meet these needs, a global emission source database called Emission Database for Global Atmospheric Research (EDGAR) has been constructed, which is able to generate the annual global emissions of the greenhouse gases from both anthropogenic and biogenic sources for the base year 1990 on a regional/country and grid basis. The finest spatial resolution of the data is $1^{o}x1^{o}$ (with an altitude resolution of 1 km for aircraft emissions), as agreed upon in the Global Emissions Inventory Activity (GEIA) of the International Atmospheric Chemistry Programme (IGAC). However, information can also be extracted in the form of tables per region (or country). In this way EDGAR meets the present urgent requirements of modellers as well as the needs for policy applications. As insights in this field are still changing, due attention was paid in the setup of the system to flexibility on the disaggregation of sources, spatial and temporal resolution, and species.

Methodology

RIVM and TNO have constructed this global database on the basis of the conclusions of a feasibility study performed by TNO. The work consisted, for one part, of data selection, collection and processing, and for the other, of implementing the database system (information analysis, system design, software development).

In order to have a flexible system that facilitates easy updates of the contents and modification or expansion of emission sources, locations, compounds, reference years, maps etc., we designed the database system in a modular fashion, using the so-called *process approach.* In general, emissions are first calculated on a country basis by multiplying activity levels (also called process or base levels) with emission factors per compound. These define the source strength as emission per unit time and per unit activity of the process. With definitions of sources and regions as groupings of (sub)processes and countries, respectively, we are able to generate emission tables per region and source type.

In addition, we have defined a spatial allocation function for each process to convert country emissions to the $1^o x 1^o$ grid by relating a grid map to each process. In some cases of land use, where activities are not defined at the country level but directly as activities or emissions per grid cell, we have defined this map coupled to the process either as base level on grid, or as direct emissions on grid. Currently, only one map per process can be defined (i.e. not for multiple years so as to take into account changes of distributions in time). At present, groups of point sources can only be represented as gridded maps (for which a conversion routine is available).

Selection of main source categories and spatial resolution (countries and grid) was based on: a) available statistical data; b) quality and consistency of related data; c) relevance for individual compounds; d) relevance for models and policy-making (e.g. the IMAGE 2 model and the formats for national inventories prepared under the Framework Convention on Climate Change [FCCC]); and e) compliance (now or in the future) with other emission inventories (particularly with GEIA). Countries were chosen for the availability of statistical data, including historical time-series, while the grid definition complies with that agreed on within GEIA.

Data on activities were selected on the basis of internationally accepted statistical data, assembled by an international organization which has performed consistency checks of the data. This data is usually collected at the country level, ensuring that comparable data are used for each country and that future maintenance (updates) can be done in an efficient way. For biogenic land-related sources we used gridded data as the basic activity data.

So as not to duplicate activities worldwide, RIVM and TNO have, amongst others, been cooperating with activities in the framework of the Global Emissions Inventory Activity (GEIA), which is a component of the International Global Atmospheric Chemistry Programme (IGAC) Core Project of the International Geosphere-Biosphere Programme (IGBP). In this programme inventories are developed and exchanged between the participating international groups interested in this area. In the framework of GEIA, TNO and RIVM have committed themselves to coordinating a number of inventories (anthropogenic VOC, anthropogenic and natural N_2O emissions). Besides these inventories/contributions from EDGAR to GEIA, earlier inventories by GEIA and other institutes are included in EDGAR.

The database, located at RIVM, serves as an analysis tool, and an emission generator for other atmospheric modelling groups, both within RIVM and TNO, and externally. In addition, it functions as the database to provide the IMAGE model with the basic data to drive the model calculations on emissions.

Contents of the database

EDGAR Version 2.0 consists of: (a) fossil-fuel related sources and (b) biofuel combustion, both on a per country basis; (c) industrial production and consumption processes (including solvent use) also on a per country basis; (d) landuse-related sources, including waste treatment, partially on a grid basis and partially on a per country basis; and (e) natural sources on a grid basis.

Activity data were taken from international statistical data available, e.g. from IEA (energy data), UN (industrial production and consumption) and FAO (agricultural data). This data is usually collected at the country level, except for three biogenic sources, where we used gridded data as basic activity data (e.g. in soil types).

Emission factors are either defined uniformly for all countries, such as for CO_2, or evaluated for individual countries, or groups of countries (regions). In the latter case we often distinguished between OECD countries, Eastern Europe and the former USSR, and other non-OECD countries. In some cases, such as for road traffic, we used emission estimates for individual countries and independently defined activity levels to derive country-specific emission factors.

In Version 2.0 major point sources are included, when available, as distribution parameters by combining them per source category in so-called thematic maps. Thematic maps on a $1^o x 1^o$ grid were used as a spatial allocation function to convert - per source or per process - country emissions to gridded emissions. For fuel combustion in industry and electric power generation, we used point-source information and area-source data from the TNO-MEP database ('LOTOS') and from US-EPA to distribute country totals for Europe and the USA, respectively, combined with population density for other regions. The same approach was used for some industrial sources. A population density map was used a default when no source-specific map was available. Also, for sources where point-source data was available for only a limited number of countries, we used this map to distribute the emissions for other countries.

Results and limitations

An intermediate version of EDGAR V1.0 was constructed with functions to process and combine emissions of NO_x, CO and CH_4 on a $5^o x 5^o$ grid from existing inventories. The results of this version were used to generate aircraft and surface source emissions for studies on the environmental impact of aircraft emissions and the atmospheric effects of global methane emissions in support of policy development by the Dutch government.

Version 2.0 of EDGAR, which has been in operation since October 1995, includes data sets covering all major anthropogenic and most natural sources, both on a per region/country basis and per $1^o x 1^o$ grid. The major source categories used for generating the standard EDGAR output files are aggregates of more detailed processes. They are, in general, defined in compliance with those often used in other inventories (e.g. FCCC/IPCC, Corinair, NAPAP).

Global total and regional results of EDGAR Version 2.0 are presented by showing the results per main source and by comparing global totals of EDGAR with best 'middle' estimates and uncertainty ranges for global total emissions provided by the Intergovernmental Panel on Climate Change (IPCC). A summary table per compound has been included, with the calculated regional anthropogenic emissions for major sources and regions in 1990, including a brief discussion of the main features. The global total source strength of anthropogenic emissions in 1990 is estimated to be 29.8 Pg CO_2 (including partial oxidation to other compounds than CO_2), 320 Tg CH_4, 3.2 Tg N_2O-N (excluding a background emission from arable lands of 1.4 Tg N_2O-N), 974 Tg CO, 102 Tg NO_2, 148 Tg SO_2, and 178 Tg NM-VOC emissions. In addition, natural emissions of N_2O and reactive NMVOC were included in the database, with global estimates of 6.6 and 3.6 Tg N_2O-N from natural soils and oceans, respectively, and 1182 Tg NMVOC (as CH_4) from vegetation and oceans. An indication of the uncertainty in the data has been provided separately. A partial validation was carried out, by comparing our estimates per major source with other global total estimates, and for NO_2 and SO_2 by comparing with other regional inventories for Europe and Asia.

Our estimates in Version 2.0 are generally in line with 'best estimates' of IPCC, which we consider to be the aggregates of various scientific emission estimates, and certainly within the uncertainty ranges. Further validation of EDGAR results, either by comparison with other inventories or in more regional detail, has not been been carried out. An extensive validation of the database, e.g. with GEIA and FCCC inventories, is anticipated in a follow-up project. It is very difficult to assess the accuracy of the estimates. However, an indication of the overall uncertainty per compound and per major source has been provided giving the order of magnitude of the uncertainties at the regional level. In this version emissions are given as annual totals. Time profiles to distribute emissions over seasons or calender months are not provided. The functionality in modelling and calculating past and future emissions is limited. However, for grid-based scenario calculations a linkage of the IMAGE model with gridded 1990 emissions inventories from EDGAR is currently under construction through the User Support System of IMAGE.

External users can use either the gridded emission data or the summary tables per region. Through FTP (File Transfer Protocol) access to publicly available data at RIVM's anonymous FTP site is possible. These files are provided together with a documentation file, describing the source categories and summarizing the data sources used to construct the inventories. For internal users at RIVM and TNO-MEP all detailed data, contained in the database, and software functions for inspection and reporting, are available for various applications.

Now, sectoral gridded emission inventories and regional emissions data are available for atmospheric modellers and for policy support studies. However, during the project also several contributions were made at the scientific level and for policy applications:

- to the Dutch government: provision of regional and gridded data to evaluate the environmental impacts of global aircraft emissions (referred to as EDGAR Version 1.0 with data on a $5^o x 5^o$ grid);
- to GEIA: participation in and/or coordination of GEIA working groups on N_2O, NMVOC and data management, and compilation of GEIA inventories of N_2O and NMVOC;
- to the FCCC: through participation and/or leading of IPCC expert groups on national emission methodologies, and by providing policy relevant information and texts for the Draft IPCC Guidelines for National Greenhouse Gas Inventories;
- to IMAGE 2: provision of aggregate emission factors for base years;
- to the UN-ECE/EMEP handbook: provision of process descriptions for a number of chemical production processes;
- to other GEIA/IGAC research: compilation of maps for a number of sources.

Policy implications

Using the possibilities of EDGAR to make different cross-sections, per source and per compound, key areas (sectors/regions) can be identified where emission reductions could be achieved. Our first conclusions concern the identification and location of large contributors of greenhouse-gas emissions and of the rapidly growing sources. In addition, by comparing activity intensities and emission factors, regionally or in time, we can infer which emission sources can be controlled most efficiently and what the technical feasibility of emission reductions is. Other policy applications such the development of default methodology and emission factors for preparing national inventories under the FCCC have been mentioned above.

Although it was not planned within the project to include specific country inventories, national greenhouse gas inventories, such as submitted to the Conference of Parties within the Framework Convention on Climate Change (FCCC), can also be included in the database, using options to import alternative data sets (e.g. national sets) for emission calculations. One likely future policy application of the database is comparison of global EDGAR and national FCCC inventory data as a means of validating both global and national estimates. This will be done by evaluating recommended default emission factors and providing new estimates for global total emissions, taking into account the submitted FCCC data.

Conclusions

The main goal of this project was to create a database with the information necessary to calculate globally gridded emissions in the base year 1990, and also historical emissions where both activity levels and emission factors were readily available. This has been accomplished, firstly, through the construction of a preliminary and intermediate Version 1.0 of EDGAR, with functions to process and combine emissions of NO_x, CO and CH_4 on a $5^o x 5^o$ grid from existing inventories. These inventories were used to generate aircraft and surface source emissions for a study of the environmental impact of aircraft emissions and of the atmospheric effects of global methane emissions. Version 2.0 of EDGAR, which has been in operation since October 1995, includes data sets covering all major anthropogenic and most natural sources of greenhouse gases for 1990, regionally as well as on a $1^o x 1^o$ grid. For number of sources, e.g. CO_2, historical emissions can also be calculated. This version has been validated by comparison of global results for main sources with other global estimates. It has a limited function in calculating past and future emissions, and does not include uncertainty estimates per country or per grid cell, but regional overall uncertainty by source and compound.

In this report we give a scientific description of the contents of Version 2.0 and present some of the tabular and gridded results extracted from the database, including a first comparison with IPCC estimates. Also uncertainties connected to the data and to the resulting emission tables and gridded maps are discussed. We show the potential for policy applications by making different cross-sections per source, region and year, from which we can infer the locations and types of the largest contributors of greenhouse-gas emissions, and identify the fastest growing sources. By comparing activity intensities and emission factors regionally or in time, it is possible to draw conclusions regarding which emission sources can be controlled most efficiently and to point out key sectors and regions where substantial emissions may be achieved.

Our main objective in creating an emission database serving both policy-making and atmospheric modelling has been accomplished. In conjunction with the uncertainty table and comparisons provided in this report, we have created a comprehensive database with consistent underlying activity, emission-factor and grid-allocation data per source sector.

SAMENVATTING

Dit rapport beschrijft de gebruikte methodiek, opzet en resultaten van een project om een aantal mondiale inventarisaties te maken van de emissie van directe en indirecte broeikasgassen, inclusief CFK's en andere ozonafbrekende stoffen. Achtereenvolgens worden de volgende onderwerpen besproken:

- de gebruikte methoden bij de opzet van de inventarisaties,
- de structuur en belangrijkste functies van het database-systeem,
- de opzet van broncategorieën, beschrijving van bronnen en hun data (activiteitenniveaus, emissiefactoren, kaarten om de emissies over een grid te verdelen),
- resulterende emissie-inventarisaties (per regio en op grid),
- onzekerheden en beperkingen in de datasets,
- beleidstoepassingen, en
- conclusies waarin de in het project bereikte resultaten worden samengevat.

Daarbij zijn de volgende stoffen in kaart gebracht: de directe broeikasgassen CO_2, CH_4 en N_2O; de indirecte broeikasgassen NO_x (+), SO_2 (-) (die ook verzurende stoffen zijn), CO en VOS (die ook bijdragen aan de vorming van fotochemische smog); en de ozonlaagafbrekende stoffen (gehalogeneerde koolwaterstoffen). Opgemerkt wordt dat NO_x, CH_4 en CO ook bijdragen aan de vorming van troposferisch ozon, die bijdraagt aan de versterkte stralingsforcering (broeikaseffect) en zelf eveneens een toxische stof is.

Doelstelling

Het doel van het project was het construeren van een mondiale emissie-database die voldoet aan de vereisten van een gedifferentieerde gebruikersgroep: (1) atmosferisch-chemici en klimaat-modelleurs, die mondiale emissiedata op grid nodig hebben als invoer van hun modellen; (2) RIVM, vanwege de behoefte aan het monitoren van mondiale broeikasgas-emissies en geaggregeerde emissiefactoren voor het klimaatmodel IMAGE 2.0 (Integrated Model to Assess the Greenhouse Effect); (3) beleidsondersteunende toepassingen voor bijv. ministeries, IPCC of FCCC, waarvoor schattingen nodig zijn van de huidige broeikasgas-emissies per land of per regio en van de trends ervan.

Om aan deze wensen tegemoet te komen is de mondiale emissiedatabase EDGAR (Emission Database for Global Atmospheric Research) opgezet, die in staat is voor het basisjaar 1990 per regio/land en op grid een schatting te geven van de jaarlijkse mondiale emissies van broeikasgassen van zowel menselijke als biogene bronnen. De hoogste ruimtelijke resolutie van de data is $1^o x 1^o$ (met een hoogte-resolutie van 1 km voor vliegtuigemissies), zoals overeengekomen binnen de *Global Emissions Inventory Activity* (GEIA) van het *International Atmospheric Chemistry Programme* (IGAC). Informatie kan echter ook in de vorm van tabellen per regio (land) worden verkregen. Op deze wijze is EDGAR in staat zowel aan de huidige urgente wensen van modelleurs als aan de informatie-behoefte voor beleidstoepassingen te voldoen. Omdat de inzichten op dit terrein nogal snel kunnen veranderen, is hier bij de opzet van het systeem rekening mee gehouden door de keuze van onderverdeling van bronnen, de ruimtelijke en temporele resolutie en de stoffen flexibel te houden.

Gebruikte methoden

RIVM en TNO hebben de opzet van de database gebaseerd op de conclusies van een voorstudie, die door TNO uitgevoerd is. De werkzaamheden bestonden voor een deel uit het selecteren, verzamelen en verwerken van data (bestanden en rapporten), en voor een deel uit het ontwikkelen van het databasesysteem (informatie-analyse, systeemopzet, software-ontwikkeling). Teneinde een flexibel systeem te maken, waarin het gemakkelijk is om data te vervangen en bronnen, locaties, basisjaren, kaarten etc. te wijzigen of uit te breiden, is het databasesysteem modulair opgezet waarbij gebruik is gemaakt van de zgn. *procesbenadering*. In het algemeen worden emissies eerst berekend per land door vermenigvuldiging van basisomvangen (ook wel activiteitenniveaus of procesniveaus genoemd) met emissiefactoren per stof, die de bronsterkte per tijdseenheid en per eenheid van activiteit van het proces aangeven. Tezamen met definities van bronnen en regio's als resp. procesgroepen en locatiegroepen (landengroepen) kunnen we emissietabellen per regio en per broncategorie genereren.

Daarnaast werd voor ieder proces een ruimtelijke verdelingsfunctie gedefinieerd om de per land berekende emissies te kunnen verdelen op het $1^{o}x1^{o}$ grid door aan elk proces een grid-kaart te koppelen. In bepaalde gevallen van landgebruik, waarbij de activiteiten niet per land maar direct als activiteiten of emissies per gridcel gedefinieerd zijn, werd deze aan het proces gekoppelde kaart gedefinieerd als een activiteit op grid of direct als emissies op grid. Thans is het slechts mogelijk om één kaart per proces te definiëren (dus niet voor meerdere jaren om verschuivingen van de ruimtelijke verdeling in te tijd te kunnen meenemen). Puntbronnen kunnen op dit moment alleen als groep op een grid-kaart gerepresenteerd worden; om deze kaart aan te maken is een conversie-functie beschikbaar).

De selectie van de belangrijkste broncategorieën en ruimtelijke resolutie (zowel landen als grid) was gebaseerd op: a) de beschikbare statistische informatie; b) kwaliteit en consistentie van gerelateerde data; c) relevantie voor individuele stoffen; d) relevantie voor modelleurs en beleidstoepassingen (bijv. t.b.v. het IMAGE 2 model en het formaat waarin nationale inventarisaties in het kader van het Klimaatverdrag opgesteld worden); e) aansluiting (nu of in de toekomst) bij andere emissie-inventarisaties (met name die van GEIA). De definitie van landen was zoveel mogelijk gekozen in relatie met de beschikbare statistische informatie, inclusief historische tijdreeksen, terwijl de grid-definitie overeen komt met die van GEIA.

De dataselectie van activiteiten was gebaseerd op internationaal geaccepteerd statistisch materiaal, dat verzameld is door een internationale organisatie die ook de consistentie ervan bewaakt. Deze informatie is meestal verzameld per land, hetgeen een redelijke zekerheid geeft dat per land vergelijkbare data gebruikt worden en dat toekomstig onderhoud (updates) efficiënt kan geschieden. Voor biogene land-gerelateerde bronnen gebruikten we data op grid als basis-activiteiten.

Om geen inspanningen elders te dupliceren werken RIVM en TNO samen met de activiteiten in het kader van de *Global Emissions Inventory Activity* (GEIA), dat een onderdeel is van het *International Global Atmospheric Chemistry Programme (IGAC) Core Project* van het *International Geosphere-Biosphere Programme* (IGBP), waarin inventarisaties worden ontwikkeld en uitgewisseld door de deelnemende internationale onderzoeksgroepen. Binnen GEIA hebben TNO en RIVM zich gecommitteerd om een aantal inventarisaties te coördineren (anthropogene NMVOC, anthropogene en biogene N_2O emissies). Naast deze inventarisaties en bijdragen van EDGAR aan GEIA worden beschikbare inventarisaties van GEIA en andere organisaties in EDGAR opgenomen.

De database is op het RIVM geplaatst en dient als een instrument voor analyses; als emissiegenerator voor andere modelleringsgroepen, zowel binnen RIVM en TNO als daarbuiten; en voorziet het IMAGE-model van basisgegevens om de emissieberekeningen te kunnen uitvoeren.

Inhoud van de database

EDGAR Versie 2.0 bestaat uit: (a) fossiele energie-gerelateerde bronnen en (b) verbranding van biobrandstoffen, beide per land gedefinieerd, (c) industriële produktie- en consumptieprocessen (inclusief het gebruik van oplosmiddelen) ook per land, (d) landgebruik gerelateerde bronnen, inclusief afvalbehandeling, deels op grid en deels per land gedefinieerd, en (e) natuurlijke bronnen, op grid gedefinieerd. Belangrijke puntbronnen zijn in versie 2.0 opgenomen door ze per broncategorie te combineren tot een zgn. thematische kaart, die gebruikt wordt als ruimtelijke verdelingsfunctie om per bron of proces de per land berekende emissies om te zetten in emissies op grid.

Informatie over activiteitenniveaus is betrokken van beschikbare internationale statistieken zoals van de IEA (energie), UN (industriële produktie en consumptie), FAO (landbouw en veeteelt). Deze informatie wordt meestal verzameld per land, met uitzondering van drie biogene bronnen waarvoor data op grid gebruikt zijn als basisomvangen, bijv. van grondsoorten.

Emissiefactoren zijn ofwel uniform gedefinieerd voor alle landen gelijk, zoals bij CO_2, of geschat per land of per groep van landen (regio's). In het laatste geval wordt vaak onderscheid gemaakt tussen OESO-landen, Oost-Europa en de voormalige USSR, en ander niet-OESO-landen. In een aantal gevallen, zoals bij wegtransport, is uitgegaan van emissieschattingen per land en onafhankelijk daarvan vastgestelde activiteitenniveaus om daaruit landenspecifieke emissiefactoren af te leiden.

Belangrijke puntbronnen zijn als verdeelparameters gebruikt indien hierover data beschikbaar waren; thematische kaarten op $1^o x 1^o$ zijn gebruikt als verdeelfunctie om per land berekende emissies te converteren naar emissies op grid. Voor verdeling van emissies op grid van emissies van landelijk brandstofgebruik in de industrie en voor elektriciteitsopwekking is gebruik gemaakt van informatie over punt- en oppervlaktebronnen in Europa en de USA afkomstig van resp. de TNO-MW database 'LOTOS' en de EPA gecombineerd met bevolkingsdichtheid voor andere regio's. Bevolkingsdichtheid is default als verdeelkaart gebruikt wanneer geen bronspecifieke kaart beschikbaar was; zoals hiervoor geschetst, is indien puntbroninformatie voor slechts een beperkt aantal landen voor handen was, deze kaart ook gebruikt voor de overige landen.

Resultaten en beperkingen

Een voorlopige versie van EDGAR is gebruikt als interim-versie 1.0, met functies om emissies van bestaande inventarisaties op $5^o x 5^o$ van NO_x, CO en CH_4 te kunnen verwerken. De resultaten van deze versie zijn gebruikt om emissies voor luchtvaart en grondbronnen te genereren ten behoeve van een studie van de milieu-aspecten van luchtvaartemissies en een studie van de atmosferische effecten van mondiale methaanemissies, beide als ondersteuning van beleidsontwikkeling door de Nederlandse overheid.

Versie 2.0 van EDGAR, die operationeel is sedert oktober 1995, bevat datasets voor alle belangrijke anthropogene bronnen en voor de meeste natuurlijke bronnen, zowel op landen/regio-basis als op het $1^o x 1^o$ grid. De hoofd-broncategorieën, die gebruikt worden om de standaard uitvoerbestanden van EDGAR te genereren, zijn aggregaties van meer gedetailleerde processen en zijn in het algemeen in overeenstemming met die welke vaak in andere inventarisaties gebruikt worden (bijv. FCCC/IPCC, Corinair, NAPAP).

Mondiale totalen en regionale resultaten van Versie 2.0 van EDGAR worden gepresenteerd per hoofd-broncategorie; daarnaast worden mondiale totalen van EDGAR vergeleken met de beste 'middenschattingen' van het *Intergovernmental Panel on Climate Change* (IPCC) en met onzekerheidsschattingen van het IPCC. Per stof is een samenvattende tabel opgenomen met de berekende anthropogene emissies voor 1990 per brongroep en per regio, met een korte bespreking van de belangrijkste kenmerken. De totale bronsterkte van anthropogene emissies in 1990 wordt geschat op 29,8 Pg CO_2 (inclusief gedeeltelijke oxidatie tot andere stoffen dan CO_2), 320 Tg CH_4, 3,2 Tg N_2O-N (exclusief een achtergrondemissie van landbouwgronden van 1,4 Tg N_2O-N), 974 Tg CO, 102 Tg NO_2, 148 Tg SO_2, en 178 Tg NMVOS emissies. Daarnaast zijn natuurlijke emissies van N_2O and reactieve NMVOS in de database opgenomen, met een mondiaal totaal van 6,6 en 3,6 Tg N_2O-N voor resp. natuurlijke bodems en oceanen en 1182 Tg NMVOS (als CH_4) voor vegetatie en oceanen tezamen. Ook wordt een indicatie van de onzekerheid in de data gegeven. Een gedeeltelijke validatie is uitgevoerd door vergelijking per broncategorie van onze emissieschatting met andere schattingen van mondiale emissies, en voor NO_2 en SO_2 ook door vergelijking met andere regionale inventarisaties voor Europa en Azië.

De schattingen in Versie 2.0 komen in het algemeen redelijk overeen met de 'beste' schatting van de IPCC, die we beschouwen als het 'gewogen' gemiddelde van verschillende wetenschappelijke schattingen, en vallen zeker binnen de genoemde onzekerheidsbanden. Verdergaande validatie van de database, bijvoorbeeld met GEIA en FCCC inventarisaties, wordt voorzien in een vervolg-project.

Het is erg moeilijk om de nauwkeurigheid van de emissieschattingen af te leiden uit onzekerheden in de onderliggende data omdat die laatste vaak niet goed te schatten zijn. Om die reden zijn in de database geen uitvoerig geëvalueerde onzekerheidsschattingen opgenomen, maar wordt per stof en per broncategorie een indicatie van de totale onzekerheid gegeven die de mate van onzekerheid voor regionale emissies aangeeft. Ook tijdprofielen om jaaremissies over seizoenen of maanden te verdelen zijn in deze versie niet opgenomen. Versie 2.0 heeft een beperkte functionaliteit om historische en toekomstige emissies te berekenen. Er wordt echter gewerkt aan scenarioberekeningen op grid door het *User Support*

System van het IMAGE 2-model te koppelen aan gridkaarten met emissies per broncategorie voor 1990 afkomstig uit EDGAR.

Externe gebruikers kunnen gebruik maken van de emissies op grid of van de overzichtstabellen met verdelingen over regio's. Toegang tot de vrij beschikbare bestanden kan men krijgen via FTP (*File Transfer Protocol*) van de anonieme *FTP site* van het RIVM. Deze bestanden worden beschikbaar gesteld samen met een documentatiebestand, waarin de broncategorieën en databronnen kort beschreven worden. Voor interne gebruikers bij RIVM en TNO zijn voor verschillende toepassingen ook ander meer gedetailleerde data in de database beschikbaar, evenals de functies voor opvragen en rapportage.

Thans zijn sectorale emissieinventarisaties op grid en per regio beschikbaar voor modelleurs en voor beleidstoepassingen. Daarnaast zijn gedurende het project ook reeds verschillende bijdragen geleverd op wetenschappelijk gebied alsmede voor beleidsmatige toepassingen:

- aan de Nederlandse regering door het voorzien in regionale en gegridde emissiebestanden om de milieu-aspecten van de mondiale emissies van vliegverkeer te evalueren (ook wel EDGAR Versie 1.0 genoemd, met data op 5^ox5^o);
- aan GEIA-activiteiten door deelname aan en/of coördinatie van werkgroepen voor N_2O, NMVOS en data management, en door compilatie van GEIA-inventarisaties voor N_2O en NMVOS;
- aan het Klimaatverdrag (FCCC) door deelname aan of leiden van expertgroepen van de IPCC op het terrein van nationale emissiemethodologie-ontwikkeling, en door het voorzien in beleidsrelevante informatie en teksten ten behoeve van de *Draft IPCC Guidelines for National Greenhouse Gas Inventories*;
- aan het IMAGE 2-model door het leveren van geaggregeerde emissiefactoren voor basisjaren;
- aan het UN-ECE/EMEP-handboek door het leveren van procesbeschrijvingen voor een aantal chemische produktieprocessen;
- aan ander GEIA/IGAC-onderzoek door compilatie van kaarten voor een aantal bronnen.

Beleidstoepassingen

Met de mogelijkheden die EDGAR biedt om verschillende doorsneden te maken per bron en per stof kunnen de belangrijkste bronnen (sectoren/regio's) worden vastgesteld, waarvan de emissies gereduceerd kunnen worden - soms zelfs aanzienlijk. In het rapport worden de eerste conclusies gepresenteerd die getrokken kunnen worden over welke de belangrijkste bronnen zijn en waar die zich bevinden en over welke bron de sterkste toename vertoont. Daarnaast kunnen door vergelijking - bijv. tussen regio's of in de tijd - van intensiteiten van activiteiten en van emissiefactoren conclusies getrokken worden over welke bronnen het meest effectief gereduceerd kunnen worden en in welke mate dat technisch mogelijk is. Andere beleidsmatige toepassingen, zoals het leveren van *default* berekeningsmethodieken en emissiefactoren voor het maken van nationale inventarisaties in het kader van het Klimaatverdrag, zijn hierboven reeds genoemd.

Hoewel het binnen het project niet gepland was om specifieke landeninventarisaties op te nemen, kunnen nationale inventarisaties zoals die bijv. opgesteld worden in het kader van het

Klimaatverdrag ook in de database worden opgenomen. Dit is mogelijk omdat EDGAR een optie heeft om alternatieve datasets (bijv. nationale sets) op te nemen en te selecteren voor emissieberekeningen, al dan niet in combinatie met een andere dataset. Een waarschijnlijke beleidstoepassing van de database is vergelijking tussen en combinatie van EDGAR-data en nationale data opgesteld volgens FCCC-richtlijnen, om op deze wijze nationale rapportages te valideren, aanbevolen *default* emissiefactoren te evalueren, en nieuwe schattingen te geven van mondiale totale emissies op basis van ondermeer de ten behoeve van de FCCC gerapporteerde emissies.

Conclusies

Het belangrijkste doel van het project was de samenstelling van een database met de informatie die nodig is om mondiale emissies op grid te berekenen voor het basisjaar 1990, en ook voor historische jaren indien zowel activiteitendata en emissiefactoren eenvoudig beschikbaar zijn. Dit is gerealiseerd door eerst als voorlopige database een interim-versie 1.0 van EDGAR samen te stellen, met functies om emissies van bestaande inventarisaties op 5^ox5^o van NO_x, CO en CH_4 te kunnen verwerken. De resultaten van deze versie zijn gebruikt om emissies voor luchtvaart en grondbronnen te genereren ten behoeve van een studie van de milieu-aspecten van luchtvaartemissies en een studie van de atmosferische effecten van mondiale methaanemissies. Versie 2.0 van EDGAR, die operationeel is sedert oktober 1995, bevat datasets voor alle belangrijke anthropogene bronnen en voor de meeste natuurlijke bronnen, zowel op landen/regio-basis als op het 1^ox1^o grid. Voor een aantal bronnen van broeikasgassen kunnen ook historische emissies, bijv. van CO_2, worden berekend. Deze versie is gevalideerd door vergelijking van mondiale resultaten per hoofdbroncategorie met andere schattingen. Versie 2.0 heeft een beperkte functionaliteit om historische en toekomstige emissies te berekenen en bevat geen interne onzekerheidsaanduidingen.
In dit rapport wordt een wetenschappelijke beschrijving gegeven van de inhoud van Versie 2.0 en worden een aantal resultaten uit de database gepresenteerd in tabel- en kaartvorm, inclusief een eerste validatie door vergelijking met IPCC-schattingen. Ook worden de onzekerheden in de onderliggende data en de resulterende emissietabellen en emissiekaarten op grid besproken. De mogelijkheden van EDGAR voor beleidstoepassingen worden geïllustreerd door het maken van verschillende doorsneden per bron, regio en jaar, waaruit de locatie en het type van de grootste emissiebronnen kunnen worden afgeleid en waaruit de snelst groeiende bronnen kunnen worden afgeleid. Door vergelijking van intensiteiten van activiteiten en emissiefactoren tussen regio's of in de tijd is het mogelijk om conclusies te trekken over welke bronnen het meest effectief gereduceerd kunnen worden en in welke mate dat technisch mogelijk is.

De hoofddoelstelling van het samenstellen van een emissiedatabase, die zowel beleidsmakers als atmosfeermodelleurs ondersteuning biedt, is bereikt. In samenhang met de onzekerheidstabel en de vergelijkingen die in dit rapport gemaakt zijn, is een complete database gecreëerd met consistente onderliggende data per broncategorie voor activiteiten, emissiefactoren en grid-kaarten.

1. INTRODUCTION

Studies of atmospheric chemistry and climate require gridded global emission data as input into the models. Within RIVM there is a need to monitor global emissions of greenhouse gases and other chemically reactive gases, to collect the underlying data as input to the emission calculations of RIVM's climate model IMAGE 2.0 (Integrated Model to Assess the Greenhouse Effect), and to support the validation of this model (Alcamo *et al.*, 1994). Emission data are required on a regional scale for tropospheric ozone modelling, e.g. as performed with the LOTOS (Builtjes, 1992) and the MOGUNTIA models (Lelieveld, 1990; Dentener, 1993; The and Beck, 1995). For policy applications, there is a need for country- and region-specific estimates of current greenhouse gas emissions and their trends.

Based on the conclusions of a feasibility study performed by TNO (Baars *et al.*, 1991) and to meet these needs, RIVM and TNO have carried out a project to develop the Emission Database for Global Atmospheric Research (EDGAR). This database has been developed to generate, on a regional and grid basis, the annual global emissions of greenhouse gases (including CO_2, CH_4, N_2O, CO, NO_x (NO and NO_2), non-methane VOC and SO_2) and ozone-depleting compounds (halocarbons) from both anthropogenic and biogenic sources. The base year for calculations in Versions 1 and 2 is 1990. The spatial resolution of the data is 1^ox1^o, with an altitude resolution of 1 km for aircraft emissions, as agreed upon in the Global Emissions Inventory Activity (GEIA) of the International Atmospheric Chemistry Programme (IGAC). However, information can also be extracted in tabular form for regions or countries. For most natural sources the temporal resolution is monthly, supplemented with information on the temporal variation of the other sources. In this way EDGAR meets the urgent requirements of modellers and is able to adapt to new developments in this field. The data comprise demographics, social and economic factors, landuse distributions and emission factors. As insights in this field are still changing, due attention has been paid to flexibility on the disaggregation of sources, spatial and temporal resolution, and species.

The database development consisted of implementing the database system (information analysis, system design, software development) and of data selection, collection and processing. Version 2.0 of the database system was completed in October 1995. The database, located at RIVM, serves as an analysis tool, as an emissions generator for other atmosphere modelling groups (both within RIVM and TNO and externally) and acts to provide the IMAGE model with the basic data to drive the emission calculations. External users have access to publicly available data files from RIVM's anonymous FTP site through FTP. A linkage to the IMAGE model for scenario calculations on grid is currently under development.

In order not to duplicate activities worldwide, RIVM and TNO have, amongst others, been cooperating on activities in the framework of the Global Emissions Inventory Activity (GEIA), which falls under the International Global Atmospheric Chemistry Programme (IGAC) Core Project of the International Geosphere-Biosphere Programme (IGBP). In this programme inventories are developed and exchanged between the participating international groups active in this area (Figure 1.1). In the framework of GEIA, TNO and RIVM have committed themselves to coordinating a number of inventories (anthropogenic VOC, anthropogenic and natural N_2O emissions). Besides these inventories/contributions from EDGAR to GEIA, earlier inventories by GEIA and other institutes are included in EDGAR. Inventories of NO_x from soils, and of NH_3, are also compiled within the GEIA framework. Since their completion will take longer than the time frame of the current EDGAR project, they are not discussed here. However, if needed, preliminary inventories can be provided to atmospheric modellers for testing purposes. Possible cooperation with the Stockholm Environment Institute (SEI) and the Collaborating Centre for Energy and Environment (CCEE) of UNEP has not been elaborated extensively, as these institutes do not maintain emission databases relevant for our task.

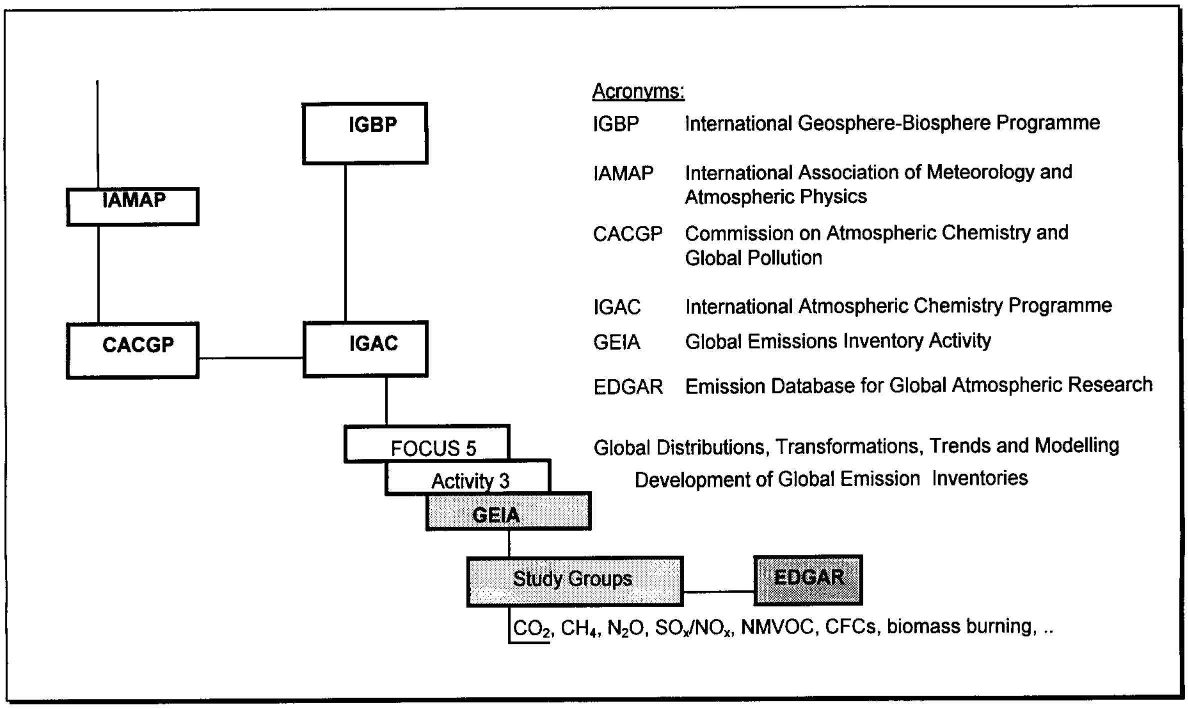


Fig. 1.1: International activities on global emission inventories.

In addition to the available gridded and regional inventories, the team members have contributed during the project:

- to GEIA actions, through participation and/or coordination of working groups on N_2O, NMVOC and data management, and by compiling GEIA inventories of N_2O and NMVOC;
- to the FCCC, through participation in and/or leading of IPCC expert groups on national emission methodologies, and by providing policy-relevant information and texts for the Draft IPCC Guidelines for National Greenhouse Gas Inventories;
- to the UNECE/EMEP handbook, by providing process descriptions for a number of chemical production processes;
- to evaluating the environmental impacts of global aircraft emissions by assessing the current and future global emissions from air traffic and surface sources; this was done in support of the Memorandum on Air Traffic and Air Pollution (LULU), which discusses policy actions of the Dutch government on this topic;
- to IMAGE 2, by providing aggregate emission factors for base years;
- to other GEIA/IGAC research, by compiling maps for a number of sources.

In this report we will discuss in the following order: the methodology used in establishing the set of inventories, structure and main functions of the database system, setup of the emission source categories, description of sources and related data (activity levels, emission factors, maps used to allocate emissions on grid), resulting emission inventories (by region and on grid), uncertainties and limitations, policy applications and conclusions summarizing the achievements in this project.

2. METHODOLOGY

2.1 User requirements

EDGAR is designed to be used by modelling groups on atmospheric chemistry and for scenario studies and policy assessments. The needs of Dutch modelling groups within the Dutch National Research Programme on Global Air Pollution and Climate Change (NRP) were identified in an feasibility study by TNO (Baars *et al.*, 1991) (Table 2.1.1).

Table 2.1.1: User requirements for Dutch atmospheric models

Type of model	Resolution	
	Spatial	Temporal
Ozone modelling	1°x1°	year, season
2-D models (MOGUNTIA)	5°x5°	month
GLOMAC	1°x1°	representative day/night
IMAGE	country	year
MPA smog episode model	5x5 km	1-6 h
Acidification models	5-15 km (0.5°x1°)	season

Source: Baars *et al.*, 1991.

To identify the minimum functionality for fulfilling the most urgent needs of these potential users, user requirements were discussed at a workshop held in 1992, in which participants from different atmospheric modelling groups were present. The conclusion was that providing annual global emissions for direct and indirect greenhouse gases at 1°x1° for the reference year 1990 was most urgently needed to improve the model analyses. Scientific users of the inventories are institutes and universities in the Netherlands such as RIVM, TNO, the Royal Netherlands Meteorological Institute (KNMI), the Netherlands Energy Research Foundation (ECN), the Agricultural University, Wageningen (LUW) and others, in particular those co-operating within the NRP, as well as international research groups. In addition, for policy-oriented applications options to extract cross-sections per region or country of emissions and aggregated emission factors are desirable, e.g. as input for the IMAGE 2 model and for validation studies of national inventories submitted under the FCCC. Our proposal at the workshop of providing access to publicly available data by FTP (File Transfer Protocol) from an anonymous FTP site was well received by the atmospheric modelling groups.

2.2 Analytic approach

We have chosen to construct the inventory database based on a number of elements which can be maintained independently. Thus, we were able to meet the various user requirements, such as gridded and regional emissions, aggregate emission factors on different scales and resolutions, and for different years. An additional advantage is that the system is flexible enough to handle future modifications, such as the possibility of annual monitoring of emissions (e.g. updates or replacement of distributions, activity data, emission factors, compounds).

In general we distinguish each source category into activity levels (production/consumption level per year) and emission factors per compound (source strength per unit of activity), both generally defined at the country level for one or more years, and thematic maps (e.g. population density) to distribute national emissions on a grid within a country using a one-to-one relationship for connecting a grid cell to a specific country. Activity levels and emission factors are defined for calendar years, at minimum for 1990; maps for allocating country emissions, preferably for 1990. Other temporal resolutions (e.g. division of annual emissions over 12 months or over four seasons) may be generated by establishing time profiles on grid per main source category, which multiplied by the gridded annual emission file will provide the gridded emissions for other time periods.

For some sources this analytical approach did not appear to be appropriate since the landuse sources of biomass burning (deforestation and savannah burning) and agricultural waste burning the activity levels were directly defined per grid cell (thus avoiding the distribution of primary data of national totals). Of course the different levels used for the primary emission estimates (country or grid cell) and conversions between levels introduce specific uncertainties in both spatial distribution and regional aggregation results. In the discussion of the inventory results, we will discuss briefly the key elements of the (inherent) uncertainties as we identified them.

Selection of main source categories and spatial resolution (countries and grid) was based on: a) available statistical data; b) quality and consistency of related data; c) relevance for individual compounds; d) relevance for models and policy making (e.g. the IMAGE 2 model and the formats for national inventories under the FCCC); and e) possible compliance (now or in the future) with other emission inventories (notably with GEIA). Countries were chosen for the availibility of statistical data, including historical time series, while the grid definition complies with the one agreed upon within GEIA. As will be explained below, most activity data were based on international statistics, defining the detailed source categories at which level output of EDGAR may by possible and desired by either policy makers (e.g. within FCCC/IPCC) or the modelling community (atmospheric modellers and the IMAGE 2 model). The major source categories used to generate the standard EDGAR output files, are aggregations of (more detailed) processes, generally defined in compliance with those often used in other inventories (e.g. FCCC/IPCC, Corinair, NAPAP).

2.3 Data selection and quality assurance

Data selection on activities was done on the basis of internationally accepted statistical data, assembled by an international organization which has performed consistency checks of the data, e.g. from IEA (energy data), UN (industrial production and consumption) or FAO (agricultural data). These data are collected at the country level, which - hopefully - ensures that for each country comparable data are used and that future maintenance (updates) can be done efficiently. For biogenic land-related sources we use gridded data, e.g. of soil types, as the basic activity data. This also defines the basic source categories used in EDGAR (Table 4.1.1).

These global statistics facilitate data processing, since all country data are essentially in the same format and already screened by the collecting organizations, thereby allowing flexible aggregation into world regions according to the user's needs. Because IEA is using ISIC categories to define economic sectors, the industrial subsectors distinguished are also proper categories for the combination with statistical data of the UN on physical and economic activity levels. However, international statistics do not always correspond well with data published by national authorities (Schipper *et al.*, 1992). On the other hand a limited number of countries cover a major part of the global total, e.g. energy use (see Schipper *et al.*, 1992). Hence, a consistency check on a large part of the data can be made relatively easily if it is considered necessary. Using these global statistical data also facilitates data processing, since all country data are essentially in the same format and already screened by the organizations collecting data.

Emission factors were evaluated separately. Representativity and availability of data as well as compliance with GEIA, OECD and European emission database systems were important aspects to consider. Existing inventories, notably of LOTOS, Corinair and NAPAP, were used to derive or 'simulate' national or regional emission factors. Emission factors for biogenic sources are often a function of the local climatic conditions, such as temperature, so here a more advanced approach was required. In the latter case the effective emission factors, e.g. per grid cell, have been calculated by the emissions module of IMAGE and the results have been imported in the EDGAR database. Thus, generally four approaches have been used in defining the emission factors: (1) globally uniform factors, in cases where no representative country specific factors could used; (2) specific factors for a number of individual countries or groups of countries, supplemented by a globally uniform factor for countries with no specific factor; (3) all country-specific emission factors, derived from a complete list of country specific emission estimates and the independently established activity level per country; (4) a hybrid method using grid-cell dependent factors, calculating emissions per grid cell off-line and including the resulting map with emissions on grid, instead of the factors in EDGAR.

An example of the first method are the emission factors for CO_2 from fossil-fuel combustion, which are strongly dependent on the energy content of the fuels. The second method was applied, for example, for CO and NO_x emissions from fuel combustion. An example of the third approach are most emission factors for road transport, derived from country specific estimates by Samaras (1993) and the energy data from IEA for gasoline, diesel and LPG consumption. The hybrid approach was used for N_2O from natural soils and for NO_x, CO and NMVOC emissions from air traffic.

The allocation of emissions on a grid has been dealt with in three ways. We tried to get recent point source data or maps of major point sources on file by category, such as power plants and large industries producing basic materials. The point source data were used to allocate all or part of national activities. If these were not available, a population density map was used to allocate national emissions to the grid cells. For three biogenic sources the activity level data were defined per grid cell.

Although only emissions estimates for main source categories are made available to external users, which is sufficient to meet the user requirements as expressed at the functionality workshop, a full data source description of the underlying data is available for all data included in EDGAR.

Quality checks have been made on the result of the final data processing (e.g. on consistency, anomalies, completeness etc.) to guarantee the numerical quality of the data, besides a full reference to and a careful selection of the data source. Quality assurance is implemented following documented procedures on data processing (e.g. by logging all quality checks). Although all sources are included, the research focused on the major source categories shown in Table 2.3.1. This means, for instance, that when spatial activity level data or regional emission factors are lacking or incomplete, no additional effort was made to enhance the quality of the spatial emissions data. In those cases, aggregate country data are spatially distributed using a simple surrogate allocation function such as population density and using default or regionally calibrated emission factors. However, for some sources such as oceans, volcanoes or lightning no emissions will be generated for all or some compounds by lack of reliable data, even of a limited quality. These sources will be dealt with when more knowledge becomes available. Whenever possible, compliance with developed GEIA inventories was pursued. However, within the time-frame of the construction of EDGAR this was only feasible for a few inventories such as emission factors for CO_2, aircraft emissions data and natural NMVOC emissions. Others were either not (yet) available or did not provide structured information required for EDGAR.

Table 2.3.1: Major source categories used in EDGAR and dominant sources of trace gases

Source category	CO_2	CH_4	N_2O	CO	NO_x	NMVOC	SO_x	hal.HCs
Fossil fuel use								
Fossil fuel production		x				x		
Gas distribution		x						
Power generation	x		x		x		x	
Other stationary combustion (industry, residentials)	x		x	x	x		x	
Transportation	x		x	x	x	x	x	
Biofuel combustion								
Residentials	x	x	x	x	x	x		
Industry	x							
Industrial processes/solvent use								
Solvent use						x		x
Halocarbon use								x
Other industrial processes	x		x	x	x	x	x	
Landuse and waste handling								
Agriculture		x	x					
Animals (ruminants/excreta)		x	x					
Biomass burning	x	x	x	x	x	x	x	
Waste combustion/landfills		x		x	x	x		
Natural sources								
Natural soils			x		o	x	o	
Natural vegetation						x		
Oceans	o		x					
Lightning					o			
Other natural sources		x					o	

Note: x = source corresponds to a sizeable fraction of global total emissions;
o = source corresponds to a sizeable fraction of global total emissions, but not included in Version 2.0.

2.4 Description of database structure, selected data and resulting inventories

The design and implementation of Version 2.0 in terms of the database structure and the software for data processing, inspection, calculations on grid and per region, and extractions of results on file, as maps and in tabular form, are summarized briefly in the next chapter. This report focuses on the contents on the database. In subsequent chapters we discuss first the definition of sources, locations and compounds, next to the data on activities, factors and maps were selected to estimate the emissions on grid and finally the resulting compilation of gridded inventories by compound and by source. The latter includes a brief comparison with other inventories. In the last chapters we will present our conclusions with respect to usability and limitations for modellers and policy applications of Version 2.0.

2.5 Availability of results

For internal users, i.e. at RIVM and TNO-MEP, all detailed data contained in the database and software functions for inspection and reporting are available for various applications. External users can use either the gridded emissions data or the regional summary tables. Access of publicly available data is possible by FTP (File Transfer Protocol) from RIVM's anonymous FTP site [node name: info.rivm.nl (131.224.1.22)]. These files are provided together with a documentation file, describing the source categories and summarizing the data sources used to construct the inventories. In addition, a limited number of ad hoc requests for data may be transmitted through by e-mail, in particular if on request of the Dutch Ministry of the Environment. Data transfer in other formats is possible within separate projects, in which TNO or RIVM cooperate with external parties.

3. STRUCTURE OF THE DATABASE

In order to have a flexible system that facilitates easy updates of the contents and modification or expansion of emission sources, locations, compounds, reference years, maps etc. we designed the database system in a modular fashion, using the so-called *process approach*. In general, emissions are first calculated on a country basis by multiplying activity levels (also called process levels or base levels) with emission factors per compound, which define the source strength as emission per unit of time and per unit of activity of the process. With definitions of sources and regions as groupings of (sub)processes and countries, respectively, we are able to generate emission tables per region and source type.

In addition, we defined a spatial allocation function for each process to convert country emissions to the 1°x1° grid by relating a grid map to each process. In some cases of land-use, where activities are not defined at the country level but directly as activities or emissions per grid cell, we have defined this map coupled to the process either as base level on grid or as direct emissions on grid. Currently, only one map per process can be defined (i.e. not for multiple years to take into account changes of distribution in time). At present, groups of point sources can only be represented as gridded maps (for which a conversion routine is available).

3.1 Structural design of the database system

The central concept of the database system is the process approach. In principle, no emissions data are stored in the database, but the underlying processes that cause the emissions: activity levels, environmental factors and locations (Van der Maas *et al*, 1995).

A process is defined as an activity in which a product or waste material is transformed into another product or waste material, where energy is used and emissions are produced. This definition is quite general and can be used in many ways. A process can be the production of steel, the manufacturing industry in general, the production of maize, public transportation, painting of boats, the production of electricity etc. A process always has a number of properties:

* A process has only one 'explanatory variable' for the volume of an environmental factor (emission, energy or waste material). Examples of explanatory variables are: crude steel produced in the steel industry and passenger kilometres for the process of public transportation. If there is a need for more than one explanatory variable more processes will be identified.
* This explanatory variable has a specific activity level for each historical year: the process level (e.g. the production of steel in the Netherlands in 1990).
* The process has one environmental load factor (emission factor, energy factor and/or waste factor) for each pollutant or energy carrier, e.g. g SO_2 per kg steel produced in the Netherlands, MJ coal consumed per kg steel.
* A process has a location: an area (country or region), line, point or grid cell. Different regional scales can be used. The same process on different locations can have different load factors. When no load factor is given the factors of the parent process are used. This hierarchy is also taken into account with the process levels: to get the process level of a region the process levels of its sub-regions are added. Alternatively, emissions from area sources can be distributed over grid cells by relating a selected thematic map (such as population density) to such a process.
* A process can contain two or more subprocesses. A subprocess itself can be split in sub-subprocesses etc. To split a process in subprocesses a number of conditions have to be met to maintain consistency.

Emissions, energy use and waste stream are calculated by multiplying the *process levels* per location with the *load factors*. Thus, the emissions of compound *x* for a list of processes are calculated as:

$$\text{Emission}_x = \sum_{i=1}^{P} AL_i * EF_{ix}$$

where:

P = the total number of processes

AL_i = process level (base level) of process *i* in a historical year at a specific location

EF_{ix} = is the environmental load factor (here emission factor) of compound *x* for process *i* in a historical year at a specific location

Processes can contain subprocesses, in which emission factors are inherited from the mother process, if no factor is specified explicitly. Likewise, these properties can be defined at different locations (often countries), which are also hierarchically related: the world total has continents as sublocations; continents have countries (or an ocean) as sublocation. And within countries states or provinces may be defined.

In the process approach *inheritance* of emission factors and related maps is incorporated. Inheritance of emission factors, either through the process tree or via location tree, or from a previous year, *respectively*, and of related maps (via the process tree) is a very powerful tool to define emission factors and spatial allocation functions which are common to many subprocesses and sublocations in a very efficient and transparant way in a database that contains thousands of subprocesses, over hunderd countries, and activity data for more than ten years.

Figure 3.1.1 shows the data model of processes in EDGAR. In principle, no emissions data are stored in the database, but the underlying processes that cause the emissions: activity levels, environmental factors and locations.

The principle of processes in a process tree and the limitations in the relation between a process and its subprocesses leave some problems to be overcome, such as the emissions which are partly caused by the combustion of energy and partly caused by processes (e.g. leakage, production losses etc.). It must be possible to separate these two emissions (also called combustion emissions and process emissions, respectively). To solve some of these problems the concept of energy process is introduced. An energy process is a special type of process with a specific energy carrier as input and an energy carrier as output. It is linked to other processes by the energy factor for energy carrier of these other processes. The special feature of an energy process is its indirect process level: the process levels of the linked processes and their energy factors determine the process level that is used for the calculation of the emissions.

3.2 Software implementation

EDGAR has been built with a relational database system (Ingres), advanced 4GL graphical development tools (Windows 4GL) and a Geographical Information System (GIS) (ARC/Info). The application has a client server architecture with a GIS server (UNIX) and an Ingres server (UNIX or OS/2). The front end of EDGAR is available on X terminals (Motif), MS-Windows PCs and OS/2 PCs. The database contains more than 100 tables, most of which were defined identical for all environmental

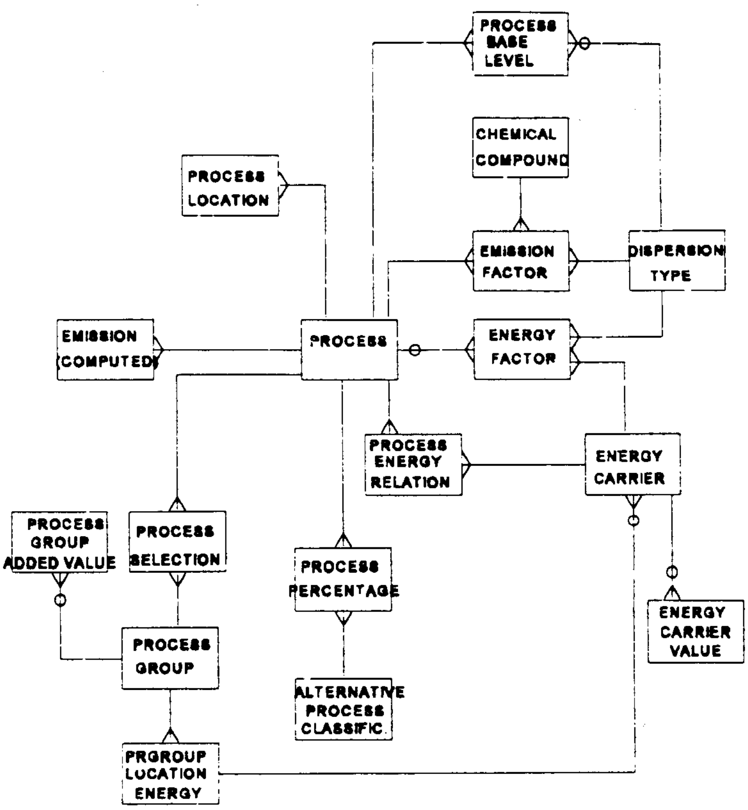


Fig. 3.1.1. Detailed data model of processes. Each box represents one database table; relationships between records in tables are either one-to-one (line) or one-to-more (fork); relationships are not always obligatory (circle in line).

databases within the RIM$^+$ framework (national, European and global).

Basic functionalities of the software are: system set-up (emission source categories, correspondence tables, definition of activity levels, emission compounds etc.), data import (conversion, checking, analysis, and processing), emissions calculations, inspections and exporting of results (maps, tables, aggregated input data).

The development of this global database framework was part of the development of a comprehensive system of environmental databases at RIVM/LAE called RIM$^+$, which have a national, European and global scope (Van der Laan and Bruinsma, 1993). Although each of the three subsystems share the same basic functionalities, the actual implementation of each is somewhat different due to different user requirements. EDGAR differs mainly from the other databases by the quantity of data to be processed, the emphasis on the location of activities (countries, regions, points or grid cells), and by its specific import/export and data analysis facilities. For a more detailed description of the database design and implementation we refer to a separate report by Van der Maas *et al.* (1995), which also acts as technical background document of the software system.

3.3 Results: functions of the EDGAR programme

Version 2.0 of the EDGAR software includes the following basic functions:

a. System set-up: definition, name and structure of detailed emission sources (processes), correspondence tables, definition of activity levels, emission compounds etc.;

b. Definition and name of major source categories, world regions, data sets for variables connected to each category, including spatial allocation functions for putting total country emissions on the 1°x1° grid, and references for all data included in the database
c. Data conversion and processing of files with specific formats: conversion, import and inspection by value and using maps of (1) activity levels, either by country or on grid; (2) emission factors, whether national, regional or global; (3) allocation functions (gridded maps) to allocate national emissions to a grid. Data conversion includes converting 5°x5° grid files (Müller format) to regular EDGAR 5°x5° format (compatable with the MOGUNTIA model of LLO), and summation of point source data to a 1°x1° grid file, while checking the country labels of the cells;
d. Emission calculations on grid and by region of selected source categories (or all sources) and inspection of results using maps (on grid and by country) and tables (by process, region, and country);
e. Emission calculations for historical and future years can also be performed, provided that data on activity levels and emission factors are processed into the database. However, calculation of policy alternatives, defined as sets of policy measures, on top of a reference scenario, is not possible in this version. For scenario calculations, also on grid, the IMAGE model is the best tool for consistently combining actions of all source categories. A linkage of the proper emissions files from EDGAR with the IMAGE model is under construction.
f. Generation of color maps and black/white/grey tinted maps of existing grid maps, activity data per country and of emission results;
g. Export of emission results in a specific format (maps, tables, aggregated input data) on paper and on file.
h. Export of activity data and emission factors for selected locations, sources, data sets.
i. On-line help option provided with most screens;
j. Mail-to-developers option for reporting comments on the usability of EDGAR to the database administrator.
k. Options for batch calculations (e.g. overnight) in case of very large calculations, which need maximum internal memory and calculating capacity of the system and would otherwise obstruct the simultaneous use of the EDGAR and other modules of RIM+ by other users.

Several windows and functions were developed as part of the joint development of the environmental database systems framework within RIM+ (national, European and global).

4. SETUP OF THE EMISSION SOURCE CATEGORIES

4.1 Structure of sources and locations

EDGAR consists of: (a) fossil-fuel related sources and (b) biofuel combustion, both on a per country basis, (c) industrial production and consumption processes (including solvent use) also on a per country basis, (d) landuse-related sources, including waste handling, partially on a grid basis and partially on a per country basis, and (e) natural sources, on a grid basis. In Version 2.0, major point sources are included by combining them by source category on so-called thematic maps, used as spatial allocation function to convert per source or process country emissions to gridded emissions. In Chapter 5 we will describe the selected activity data, emission factors and maps used for calculating emissions on a 1x1 degree grid for each source category.

The five major source categrories mentioned above are also used for reporting purposes. Table 4.1.1 lists the standard source sectors used to calculate and report regional and gridded emissions. In Appendices S.1 to S.3 lists and definitions are presented of more detailed source sectors, which were predefined and can be used to analyse data in EDGAR. The definition of the 15 major world regions is given in Table 4.1.2, including four major countries and the oceans used for tabular reporting of regional distributions. In Appendix R.1 a full list of countries for each region is given, thereby also defining the countries or territorial entities used in Version 2.0. This definition complies with the regions distinguished in RIVM's global change model IMAGE 2, which is based on a maximum homogenity of economic and climatological characteristics and spatial proximity of the countries within a region (Alcamo *et al.*, 1994). Based in these criteria USA, Canada, the former USSR and Japan are considered as separate regions.

The finest spatial resolution of the data is 1°x1°, with grid cells with borders defined on whole coordinates, e.g. one cell has South-West corner coordinates (-180,90), as agreed upon in the Global Emissions Inventory Activity (GEIA), a component of the International Atmospheric Chemistry Programme (IGAC) Core Project of the International Geosphere-Biosphere Programme (IGBP). For aircraft emissions an altitude resolution of 1 km is used. For converting per country emission to the 1°x1° grid we use a one grid cell to one country relationship, as defined for 186 countries by NASA-GISS, extended with 21 minor entities for which in some cases separate statistical data on activities were found. In Appendix R.2 more details on this topic are given.

Table 4.1.1: Standard source categories used for reporting regional and gridded emissions

Main source	Code	Standard reporting source category
Fossil fuel use		
- Industry (& energy transf.):	F10	Industry (excluding energy industries such as refineries)
	F20	Power generation (including public cogeneration)
	F30	Other transformation sector (refineries, coke ovens, gas works, etc.)
- Non-industry:	F40	RCO (Residential, Commercial, Other)
- Transport:	F51	Transport: road
	F54	Transport: rail, inland shipping, other/non-specified (RIO) (land non-road)
	F57	Transport: air
	F58	Transport: international shipping (bunkers)
	F60	Non-energy use and chemical feedstocks (for CO2 only)
- Fuel production/transmission:	F70	Coal production
	F80	Oil production, transmission and handling
	F90	Gas production and transmission
Biofuel combustion		
	F10	Industry (including other transformation sector)
	F40	RCO (notably Residentials)
Industrial processes/solvent use		
	I10	Iron and steel (excluding coke ovens and blast furnaces)
	I20	Non-ferro (copper, lead, zinc, aluminium)
	I30	Chemicals (various)
	I40	Building materials (cement)
	I50	Pulp and paper (not included in V2.0)
	I60	Food (not included in V2.0)
	I70	Solvent use
	I80	Evaporation road transport (included in V2.0 under fuel combustion)
	I90	Miscellaneous industry (including halocarbon use)
Landuse and waste treatment		
	L10	Agriculture (rice cultivation, fertilizer use)
	L20	Animals (ruminants/excreta)
	L30	Biomass burning (large scale, non-energy)
	L40	Waste treatment (combustion/landfills, non-energy)
Natural sources		
	N10	Natural soils (including grasslands)
	N20	Natural vegetation
	N30	Wetlands
	N40	Oceans
	N50	Lightning (not included in V2.0)
	N60	Volcanoes (not included in V2.0)

Table 4.1.2: Definition of EDGAR world regions

Region	Countries in region
A: CANADA	Canada
B: USA	USA
C: LATIN AMERICA	Central and South America
D: AFRICA	Africa
E: OECD EUROPE	European Union (15), Iceland, Norway, Switzerland, excluding Turkey (which was allocated in 'Middle East')
F: EASTERN EUROPE	Former Centrally Planned Europe: Albania, Bulgaria, former Czechoslovakia, Hungary, Poland, Romania, former Yugoslavia
G: CIS (FORMER USSR)	Former USSR (including Estonia, Latvia and Lithuania)
H: MIDDLE EAST	Afghanistan, Bahrain, Cyprus, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, Turkey, United Arab Emirates, Yemen (united)
I: INDIA REGION	Bangladesh, Bhutan, India, Maldives, Myanmar (former Burma), Nepal, Pakistan, Sri Lanka
J: CHINA REGION	China, Hong Kong, Kampuchea (former Cambodia), North Korea (Dem. People's Rep.), Laos, Macau, Mongolia, Vietnam
K: EAST ASIA	Brunei, Indonesia, South Korea (Rep. of), Malaysia, Papua New Guinea, Philippines, Thailand, East Timor
L: OCEANIA	Australia, New Zealand, minor Pacific islands
M: JAPAN	Japan
X: OCEANS	Oceans/sea (including large waters such as Mediterranean Sea, Caspian Sea)
Y: ANTARCTICA	Antarctica (land area below 60° south latitude)

Note: The regional subdivision A to M matches with the continental regions used in the IMAGE 2 model (Alcamo *et al.*, 1994), thereby facilitating exchange of emission factors and emissions maps for gridded scenario calcultations.

4.2 Compounds, NMVOC compound groups and reference years

Table 4.2.1 lists the compounds for which global gridded inventories are provided in Version 2.0. These are direct and indirect greenhouse gases as currently reported in the UN Framework Convention on Climate Change (FCCC) or in other conventions such as the Convention on Lange Range Transboundary Transport. In addition the datebase contains information on the use and emission of ozone-depleting substances as reported according to the Montreal Protocol and its later modifications in London and Kopenhagen, including some related compounds for which data are available. To fulfill the needs of atmospheric modellers, total NMVOC emissions have been split in 25 compound groups as shown in Table 4.2.2.

Table 4.2.1: Compounds in Version 2.0

Direct GHGs	Indirect GHGs	CFCs and related substances
CO_2	CO	CFC-11
CH_4	NO_x	CFC-12
N_2O	NMVOC [1)]	CFC-113
CFCs (see list)	SO_2	CFC-114
		CFC-115
		Halon-1211
		Halon-1301
		HC-10 (CCl4) (CTC)
		HC-140a (MCF)
		CH4Br
		HCFC-22
		HCFC-142b

[1)] See Table 4.2.2 for NMVOC compound groups used in Version 2.0.

Table 4.2.2: Standard NMVOC compound groups in Version 2.0

Main group	Code	Standard compound group
Alkanols (alcohols)	v01	Alkanols (alcohols)
Alkanes	v02	Ethane
	v03	Propane
	v04	Butanes
	v05	Pentanes
	v06	Hexanes and higher
Alkenes/alkynes (olefines)	v07	Ethene (ethylene)
	v08	Propene
	v09	Ethyne (acetylene)
	v10	Isoprenes [1)]
	v11	Monoterpenes [1)]
	v12	Other alk(adi)enes/alkynes (olefines)
Aromatics	v13	Benzene (benzol)
	v14	Methylbenzene (toluene)
	v15	Dimethylbenzenes (xylenes)
	v16	Trimethylbenzenes
	v17	Other aromatics
Esters	v18	Esters
Ethers	v19	Ethers
Chlorinated hydrocarbons	v20	Chlorinated hydrocarbons
Alkanals (aldehydes)	v21	Methanal (formaldehyde)
	v22	Other alkanals (aldehydes)
Alkanones (ketones)	v23	Alkanones (ketones)
Carboxylic acids	v24	Acids
Other NMVOC	v25	Other NMVOC

[1)] Used for biogenic sources only.

5. SOURCE CATEGORIES AND RELATED DATA

This chapter describes how the emission estimates in EDGAR were derived in terms of underlying data. Firstly, the general approach to the gridded emission estimates from EDGAR is discussed. Next, the use of the LOTOS and the US-EPA database within EDGAR is outlined. Finally, each emission source category in the EDGAR database will be discussed in more detail.

General approach to emission estimates

The activity data in EDGAR are from international statistics, e.g. IEA (energy data), UN (industrial production and consumption), and FAO (agricultural data). This data is mostly collected at the country level, except for three biogenic sources where we used gridded data as basic activity data, e.g. of soil types. Using these global statistical data appeared most efficient for data processing, since all country data are essentially in the same format. However, country codes often change in time and differ between organizations and some modifications of original codes was often necessary. Also, since IEA uses the so-called ISIC classification the distinguished industrial sub-sectors are also proper categories for combination with statistical data of the UN on physical and economical activity levels.

Emission factors are either defined uniformly for all countries, such as for CO_2, or evaluated for individual countries or for groups of countries (regions). In the latter case we often distinguished between OECD countries, Eastern Europe and former USSR, and other non-OECD countries. In some cases, such as for road traffic, we used emission estimates for individual countries and independently defined activity levels to derive country specific emission factors.

When available, major point sources are included as distribution parameters; thematic maps on $1^{o}x1^{o}$ grid were used as allocation functions to convert country emissions to gridded emissions. For fuel combustion in industry and electric power generation, we used point source information and area source data from the TNO-MW database 'LOTOS' and from US-EPA to distribute country totals for Europe and the USA, respectively. Fot the other regions population density was used as a correlate. The same approach was used for some industrial sources.

A population density map was used a default when no source-specific map was available, or when point source data were available for few countries only. The population map used is the Harvard map of Logan (personal comm., 1993), which was constructed with a higher city resolution (over 25 000) and for a more recent year (1987) than the map of NASA-GISS, which refers to 1985 and used data for cities with over 50 000 inhabitants. Both maps are based on the same country-to-grid cell conversion convention defined for 186 countries by NASA-GISS based on work by Lerner *et al.* (1988). For historical reasons, both maps are currently used in different GEIA inventories. Based on international statistics EDGAR is able to provide emission estimates for a number of small territorial entities (mostly islands), which were not present on the Harvard map. To include these emissions in the grid calculation, 21 entities were added to the original map. For more details on the Harvard population map and the additions/modifications of the population map and the country-to-grid conversion table we refer to Appendix M.1.

Implementation of LOTOS and US-EPA inventories in EDGAR

The LOTOS database was developed primarily for tropospheric ozone modelling, and includes emission estimates of SO_2, NO_x, CO, CH_4, NMVOC, N_2O and NH_3. The national emission totals by source category have been calculated from statistical data from several literature sources and from emission factors developed for the LOTOS database. The regionalization of the emissions has been done mainly on the basis of point source data. Whenever point source data were not available, population density was used to calculate the emissions per grid cell. In addition to the statistical information, additional data from many other sources has been used enhance the quality of the database. The area covered by the LOTOS database extents from 10° W to 60° E and 35° N to 70° N.

The US-EPA database is an extrapolation of the 1985 NAPAP inventory (EPA, 1993). It contains area sources for counties and a large number of point sources. The area sources have been converted to the 1°x1° grid for EDGAR according to population density. The database contains emissions of SO_2, NO_x, CO and NMVOC. Because the level of detail in the source categories of EPA is higher than in the EDGAR database, the EPA source categories were aggregated into the EDGAR processes.

In order to maintain the high spatial resolution of the LOTOS and US-EPA data on the one hand, and the connection with statistical information in the EDGAR model on the other hand, for the production and fuel consumption figures for the effective emission factors for each combination of sector and fuel were calculated per country and these were imported into the database. The maps of the corresponding emissions were imported into the database as thematic maps, i.e. maps used for allocating the emissions.

5.1 Fossil fuel use

Fossil fuel use comprises production, transformation (i.e. production of secondary fuels such as coke and oil products) and combustion of fossil fuels (Table 5.1.1). Process (i.e. non-combustion) emissions from coke ovens and refineries are also included here.

Table 5.1.1: Sectors used as fuel combustion source categories

EDGAR sector	IEA sector	Remark
F10. Industry	Industry	Excluding the energy sector (e.g. power generation, refineries)
F20. Power plants	Electricity generation	Public electricity, autoproducers of electricity, CHP plants
F30. Other transformation	Other fuel transformation	Refineries [1], coke ovens [1], blast furnaces, gas works, district heating, etc.
F40. RCO:	Other sector:	Sum of stationary non-industry sources (e.g. dwellings)
F41. - Commercial	- Commercial	= Commercial and public services
F42. - Residential	- Residential	= Household dwellings
F43. - Other	- Other end-use sectors	= IEA subsectors 'Agriculture' and 'Other/Non-Specified'
F50. Transport:	Transport:	Road, rail, air, and water transport, excluding marine bunkers
F51. - Road transport	- Road	Excluding off-road vehicles
F54. - RIO transport	- Rail,inland waterways,other	=Rail, inland shipping & other/non-specified transport [2]
F57. - Air transport	- Air transport	= Domestic & international air transport
F58. International shipping	Marine bunkers	International shipping as defined by bunker fuel consumption

[1] Emissions from refineries were calculated using emission factors based on refinery inputs (including combustion emissions from refineries), and for coke ovens using factors based on coke production (including combustion emissions), except for CO_2 and N_2O.

[2] Including pipeline transport.

Activity data

The energy production and consumption data set have been constructed with some minor additions/modifications to have a better spatial distribution and a more complete estimate for major source categories. Basically, we used the IEA energy statistics 1971-1992 for 112 IEA countries, extended with 71 countries using IEA totals and country splits according to UN data (IEA/OECD, 1994; UN, 1993). For another six countries estimates by Samaras for road transport have been added, whereas for 37 IEA/UN countries specific estimates for road transport have been added to existing country data sets, which did not specify fuel consumption at the level of road transport (Samaras, 1993). For coal production we have split the 1990 data in underground and surface mining, using separate country specific assumptions for hard coal and brown coal. For more details on the construction of the fossil fuel data set we refer to Appendixes D.1 and M.2.

Emission factors for CO_2

The emission factors for CO_2 essentially comply with the ones used in the GEIA inventory and the factors recommended by IPCC (1994). We use globally uniform factors combustion of coals, oil products and natural gas. In Table 5.1.2 these factors are summarized, including the conversion to other units. For CO_2, we treat the feedstock use of fuels and other non-energy use (such as for bitumen and lubricants) as a separate sector, with emission factors calculated as percentage (depending on the fate of the substances) of the factor for combustion as was done in the GEIA inventory (Table 5.2). These percentages differ slightly from the defaults recommended by IPCC. To calculate the net CO_2 emissions of the Other Transformation Sector (e.g. by coke ovens, blast furnaces, refineries) we used the same three values for coal, oil and gas, but now as negative factor, for the production of secondary fuels (coal products, gas works gas and oil products), to take into account that part of the carbon input is not oxidized in the sector, but in other sectors using these secondary fuels. If we did not make this net calculation, we would have counted double or neglected the losses in the transformation process itself.

The CO_2 emission factors for gas flaring in oil production were calculated on a per country basis from estimated emissions from Marland *et al.* (1994) and oil production data.

Table 5.1.2. Emission factors for CO_2 from fossil fuel combustion (in kg CO_2-C/GJ)

Sector/fuel	Emission factor [1]	Remark (related factor used in GEIA inventory)	Reference
SOLID FUELS	25.50	Factor used for solids in GEIA CO_2 inventory is: 0.73257 kg CO_2-C/kg solid fuel (= 0.746*0.982) [3] Acc. IPCC, 1994, p. 1.22 this is equivalent to 25.5 kg C/GJ LHV	IPCC, 1994 [6]
LIQUID FUELS	19.26	This factor is average of gasoline and diesel factor (both are the fuels mostly used within the OECD) [4] Factor used for liquids in GEIA CO_2 inventory is: 0.7803 kg CO_2-C/kg crude cons. (= 0.85*0.918) (for bunker fuels 2% higher)	IPCC, 1994 [6]
GASEOUS FUELS	15.3	Factor used for gas in GEIA CO_2 inventory: 13.426 kg CO_2-C/GJ gas (= 13.7*0.98) [5] [13.7/0.9 = 15.3]	IPCC, 1994 [6]
Exceptions [2]:			
Gas-Chem. feedst.& NE	8.86	= 66% of EF gas	Marland&Rotty, 1984
LPG, ethane-Chem. f.&NE	11.76	= 60% of EF oil	Marland&Rotty, 1984
Naphtha	3.92	= 20% of EF oil	Marland&Rotty, 1984
Bitumen	0.	= 0% of EF oil	Marland&Rotty, 1984
Lubricants	9.80	= 50% of EF oil	Marland&Rotty, 1984
International marine bunkers (int. shipping)	19.65	Factor used for bunkers is 2% higher than for inland consumption.	Andres, 1994

1) We have here ignored the unoxidized fraction from combustion, which compared to Marland and Rotty, 1984, is 1%, 1.5% and 1% for solids, liquids and gases, respectively (IPCC recommendations: 2%, 1% and 0.5%, respectively.) In addition, we assumed here that all oxidized carbon is converted into CO_2, neglecting fractions emitted as CO or other compounds.

2) For feedstock use of fuels (in chemical industry) an emission factor of 0 has been assumed, except for gas, LPG and ethane as indicated here and except for white spirit, paraffin waxes, petroluem coke and 'other petroleum products' as well as for liquid fuel for electricity output, where we assume full oxidation (in contrast with LPG-feedstock/NE, ethane-feedstock/NE, naphthta, bitumen and lubricants).

3) For coke production losses Marland and Rotty, 1984, assume 4.4% losses of coal throughput.

4) Since our calculation is on a fuel-specific consumption basis, we converted from kg to GJ using the weighted average of the gasoline and diesel factor (both are the fuels mostly used within the OECD: 513 Mton and 428 Mton in 1990, respectively) [LHV] (acc. IPCC, 1994, p. 1.21): 44.8 GJ/ton gasoline and 43.33 GJ/ton diesel oil [LHV]. Average conversion factor: (44.8*513+43.33*428)/941 = 44.129 GJ/ton; subsequently: 0.85/44.129 = 1.9260e+04 and 1.965e+04 for bunker fuels (1.926 + 2%).

5) According to IPCC, 1994, Marland and Pippin, 1990, used 15.3 kg C/GJ LHV. We used 13.7/0.9 = 1.522 and rounded it off to 15.3 C/GJ LHV to comply with Marland and Pippin, 1994; OECD, 1991; and with IPCC, 1994.

6) Based on Marland and Rotty, 1984.

Emission factors for nitrous oxide (N_2O)

For fossil fuel combustion, measured emission factors for nitrous oxide are still rather scarce. Default and globally uniform factors were derived for combustion of coals, oil products and natural gas, respectively, from the existing data (Olivier, 1994); these are also recommended by IPCC. However, it is also known that factors for gasoline cars equipped with catalytic convertors show substantially higher emission factors for N_2O. The use of these convertors is still limited to a few countries. Based on information on the penetration rate of gasoline cars with catalysts we have used a set of country specific factors to estimate these emissions from 1971 to 1992. In Table 5.1.3 we summarize the factors used for 1990. These are also the factors used in the GEIA N_2O inventory.

Table 5.1.3: Emission factors for N_2O from fossil fuel combustion in 1990 (in g N_2O-N/GJ)

Sector/fuel	Emission factor	Remark (range)	Reference
SOLID FUELS	0.8909	1.4 g N_2O/GJ x 28/44 = 0.890909 g N_2O-N/GJ (range for 1.4 is: 0-10 g/GJ)	IPCC, 1994 [5)]
LIQUID FUELS	0.3818	0.6 g N_2O/GJ x 28/44 = 0.381818 g N_2O-N/GJ (range for 0.6 is: 0-2.8 g/GJ).	IPCC, 1994 [5)]
GASEOUS FUELS	0.06364	0.1 g N_2O/GJ x 28/44 = 0.063636 g N_2O-N/GJ (range for 0.1 is: 0-1.1 g/GJ)	IPCC, 1994 [5)]
Exceptions:			
Road transport-gasoline [3)]	2.673	USA, Canada, Japan [1)]	Hawker, 1990
	1.145	Australia [2)]	Nat. GHG Ctee, 1994
	1.145	Germany (Fed. Rep.) [2)]	UBA, 1994
	0.8095	Former DDR [2)]	UBA, 1994
	0.7255	Netherlands [2)]	CBS, 1995
Domestic air-jet fuel [4)]	2.14	0.15 g N_2O/kg = 3.4 g/GJ = 2.14 g N_2O-N/GJ	Wiesen *et al.*, 1994
International air-jet fuel [4)]	2.14	0.15 g N_2O/kg = 3.4 g/GJ = 2.14 g N_2O-N/GJ	Wiesen *et al.*, 1994

1) In 1980 a global default value of 0.3818 for USA, CAN, JPN, increased linearly from 1980 to the 1990 value of 2.673 and keeping constant from 1990.
2) In 1985 a global default value of 0.3818 for AUS, DEU, DDR and NLD, increased linearly from 1985 to their 1990 values as listed here. From 1990 to 1992 these values increase to 1.527, 1.527, 1.023 and 0.9545, respectively.
3) Process code: E.TP1.TRA.MOG.ROA
4) Process codes: E.TP1.TRA.JET.AIR and E.TP1.TRA.JET.INT, respectively.

Emission factors for CH_4, NMVOC, CO, NO_x and SO_2

For reference purposes and for an impression of the factors used, and of the variation in terms of sectors, fuels and regions, we have listed in Appendix D.2 the calculated globally and regionally aggregated emission factors, both per main sector and fuel type.

Emissions from large combustion plants and residential combustion

For fossil fuel combustion a subdivision was made in industrial use, use for utilities and residential use; each category and detailed fuel type has its own emission factor. All factors except those for SO_2 are from the LOTOS database, which are assumed to be globally applicable. The SO_2 emission factor has been supplied by Berdowski (personal comm., 1995). An exception concerns NO_x and SO_2 for Japan, for which factors representing emission reducing measures for Japan from Kato and Akimoto (1992) have been applied. For countries within the LOTOS area and for the USA, the emission estimates from the respective LOTOS and US-EPA inventories for this source category have been converted into the EDGAR processes and entered directly into the EDGAR database.

Emissions from coke production
The emission factors for coke production have been taken from the LOTOS database. The reference for the emission profile is PHOXA report by Veldt (1994).

NMVOC profiles for fuel combustion and coke production
Profiles are available for:
- hard and brown coal for residential use and transportation
- hard and brown coal for industrial and utilities use
- (natural) gas for all uses
- liquid fuels for residential use
- liquid fuels for industrial and utilities use and residual oil in transportation
- coke production

The reference for the profiles mentioned above is the PHOXA report by Veldt (1994).
- peat (the profile for wood is used)

The reference for the wood profile is Veldt and Berdowski (1995).

Emissions from fossil fuel production, transmission and handling
1) Coal production.
The emission factors used in EDGAR to estimate CH_4 emissions due to 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 a global default values given in this reference were used. The emission factors used in Version 2.0 are listed in Table M.2.1 of Appendix M.2.
2) Crude oil production.
For the crude oil production industry, the emission factors for NMVOC and CH_4 have been calculated from emission estimates by Arthur D. Little (1989). The emissions have a geographical distribution according to Oil and Gas Journal energy database (OJG, 1991). The US-EPA proposed the NMVOC emission profile in US-EPA (1988). An exception concerns the USA for which the NMVOC emission factor as well as spacial distribution of the NMVOC emission estimate have been taken from the US-EPA inventory.
3) 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 Encyclopeadia. For this emission source category the general crude oil production profile has been assumed.
4) 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). TNO-MEP has proposed the NMVOC emission profiles from which the NMVOC emission factors are calculated. The geographical distribution of the emissions due to natural gas production has been evaluated from OGJ (1990/1994), International Petroleum Encyclopeadia.

5) Crude oil refining and storage at refinery site.
   The emission factors for petroleum refining for NMVOC, CH_4, CO, NO_x and SO_2 have been proposed by Veldt and Berdowski for the LOTOS database at TNO-MEP, Delft (TNO-MW, 1990). These emission factors account for all combustion and fugitive emissions occurring at the refinery site. A grid map for this emission source category has been compiled from the OGJ (1992), International Refining Survey. The NMVOC emission profile for crude oil refining is presented in Veldt (1994).
6) Distribution of gasoline.
   NMVOC emissions due to the distribution of gasoline have been estimated with emission factors taken from Williams (1986). The NMVOC emission profile has been taken from Veldt (1993).

Transport emissions
1) Road transport with gasoline, diesel oil and LPG as automotive fuel.
   For road transport and the evaporation of gasoline from automobiles, which is by far the most important contributor in this sector, the emission estimates for NMVOC, CO, NO_x, and CH_4 have been taken from Samaras (1991). An exception concerns the USA for which the NMVOC emission factors have been taken from the US-EPA inventory. All SO_2 emission factors for road transport have been proposed by Berdowski, personal comm. (1995). The NMVOC emission profiles for the different types of fuel used and for gasoline evaporation have been taken from Veldt (1993).
2) Jetfuel used in air transport.
   For jetfuel use by air transport, which is assumed to be the only transport sector with consumption of jetfuel, the aggregate emission factors for CO, NO_x and NMVOC were taken from emission and fuel consumption estimates of NASA (1993), as analyzed in Olivier (1995). The emission factors for CH_4 and SO_2 were taken from Olivier (1995), in which the factor for methane had been derived from the total VOC factor for the LTO cycle and a percentage of 10% in total VOC emissions in the LTO cycle. Above 1 kilometre methane emissions are assumed to be negligable, thus zero. We stress that these emission factors are the global aggregate of all air traffic, including military aircraft and general aviation. Aggregated emisison factors which apply for scheduled civil air traffic only may differ 10 to 50% (see Wuebbles *et al.*, 1993).
3) Other means of transport.
   All other means of transport have been regarded as small industrial combustion units for which the appropriate emission factors have been taken from the TNO-MW LOTOS database (TNO-MW, 1990).

Gridded maps

Table 5.1.4 summarizes the maps used for distribution of fossil fuel related emissions on grid. For fuel combustion in industry and power generation we used for 6 fossil fuel types (hard coal, brown coal, peat, coal products, oil products, gas) and 4 compounds (CO, NO_x, SO_2 and NMVOC) for Europe and USA compound-specific point- and area-source data combined with population density for other countries. For international transport we use a specific map for international shipping based on the main shipping routes and provisional estimates of relative intensities; for air traffic we use 19 maps (per altitude band of 1 km), separate for fuel consumption and emissions of NO_x, CO and NMVOC. The air traffic maps were provided by NASA (1993), which is kindly acknowledged for submitting these maps also as Version 1 of the GEIA inventory on aircraft emissions. More information on these maps can be found in Appendixes M.6 and M.7. Other combustion sources are distributed using population density as allocation function.

For production, handling and transmission of coal, oil and natural gas we compiled separate grid maps based on global compilations of point sources. Because of the different emission factors we made a distinction for coal production between hard coal and brown coal, and between surface and underground mining. In addition to production sites, we used specific gridded maps for tanker loading of crude oil and for oil refinings, based on a global compilation of point sources. More information on the construction of these maps can be found in Appendixes M.2 and M.3. Gas transport and distribution and coke production is spatially distributed according to population density.

Table 5.1.4: Gridded maps used for spatial distribution of fossil-fuel related emissions

Source sector	Code	LOTOS/NAPAP-USA [4]	Other countries	All countries
Fuel combustion				
F10. Industry	IND	4 maps [1] x 6 fuel types [2]	pop. dens.	pop. dens. [3]
F20. Power generation	POW	4 maps [1] x 6 fuel types [2]	pop. dens.	pop. dens. [3]
F30. Other transformation:	OTS			
- refineries:		-	-	refinery map [5]
- others:		-	-	pop. dens.
F40. Resid., comm., others	RCO	-	-	pop. dens.
F50. Transport:				
F51. - Road	ROA	-	-	pop. dens.
F54. - Rail, inland water, other	RIO	-	-	pop. dens.
F58. - International shipping	BUN	-	-	main shipping routes [6]
F57. - Air traffic	AIR	-	-	19 altitude bands of 1 km
Fuel production, handling and transmission				
F70. Coal production	PRO	-	-	4 coal prod. maps [7]
F81. Oil production	PRO	-	-	oil production map [5]
F83. Oil handling (tanker loading)	EXP	-	-	tanker loading map [5]
F91. Gas production	PRO	-	-	gas production map [5]
F92. Gas transmission	DOM	-	-	pop. dens.

Notes:

[1] For CO, NO_x, SO_2 and NMVOC.

[2] One map per compound for: hard coal (HDC), brown coal (BRS), peat (PEA), coal products (CP), gas (GAS), and oil products (TP1).

[3] For CO_2, CH_4 and N_2O. (pop. dens. = population density, according to Logan, 1993).

[4] Point and area sources summed on 1°x1° grid for LOTOS countries and the USA (TNO, 1990; EPA, 1993), combined with population density for other countries.

[5] For data sources see Appendix M.3.

[6] For data sources see Appendix M.6.

[7] For hard coal and brown coal, both for surface mining (open pit) and underground mining. For data sources see Appendix M.2

5.2 Biofuel combustion

Biofuels include wood, wood waste, charcoal, dung, crop residue, bagasse, a crop residue, but separately identified, ethanol and the IEA categories black liquor, an industrial waste, but separately identified, non-solid fuels (non-specified), industrial and municipal waste. 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. For all other countries the approach is stated below.

Activity data

The activity levels for total biomass use per country are from Hall *et al.* (1994), except for some industrialized countries [IEA statistics and as secondary source the PHOXA report by Veldt (1994), and Leach (1988) for countries in the Middle East], resulting in a global consumption estimate of 50 EJ for 1990. The subdivision of the total biomass consumption in the different biofuels is based on country studies, IEA and OLADE statistics. Where no subdivision was available for a country, the subdivision of a neighbour with the same kind of vegetation was used. Total biomass consumption was also split in residential and industrial use based on a number of country studies and OLADE statistics. Again, when no subdivision was available, the division of a neighbouring country was used. Appendix D.2 gives more details on the assumptions made for the sectoral and fuel split per country.

Emission factors

The references for the emission factors used to calculate the emission for the biofuels are: for CO_2 from fuelwood we assume 450 g C/kg fuel based on IPCC (1994) and 15 MJ/kg LHV (air dry; 20% moisture), resulting in (rounded-off) 30 kg C/GJ (Hall *et al.*, 1994). For combustion of charcoal, which has a much higher carbon content per kg, the same factor is used, since the emission factor expressed as kg C/GJ is almost the same as the factor for fuelwood. Other references are Veldt and Berdowski (1995) for CO, CH_4, N_2O and NMVOC; LOTOS (TNO-MW, 1990) for default emission factors for NO_x and NH_3; Smith *et al.* (1993) for N_2O from fuelwood, which was based on a pilot study for residential stoves; and Berdowski (personal comm., 1995) for SO_2. We note that the N_2O factor for fuelwood in IPCC (1994) is about 50% higher than ours.

Of course net CO_2 emissions depend on the degree of sustainable production of fuelwood etc. As a first estimate we assumed here that the biofuel consumption represents a 100% extraction without any replacement. This allows the user to make a correction, if other assumptions for this sector are to be used.

NMVOC profiles

Two profiles one for charcoal and one for wood. The latter is also used for all other biofuels, except ethanol and IEA category biofuels (Veldt and Berdowski, 1995).

Gridded maps

Table 5.2.1 summarizes the maps used for distribution of biofuel emissions on grid. As in the case of fossil fuel combustion we used for the sum of traditional biofuel and other biofuel use in industry and power generation compound-specific maps for European countries and the USA (when available), supplemented with population density for other countries and also when no specific emissions of CO, NO_x, SO_2 or NMVOC were available in the inventories of USA and the LOTOS area.

Table 5.2.1: Gridded maps used for spatial distribution of biofuel emissions

Source sector	Code	LOTOS/NAPAP-USA [4)]	Other countries	All countries
Fuel combustion				
F10. Industry	IND	4 maps [1)] x 2 fuel types [2)]	pop. dens.	pop. dens. [3)]
F20. Power generation	POW	4 maps [1)] x 2 fuel types [2)]	pop. dens.	pop. dens. [3)]
F30. Other transformation:	OTS			
- refineries:		-	-	refinery map[5)]
- others:		-	-	pop. dens. [3)]
F40. Residential, comm., others	RCO	-	-	pop. dens. [3)]

[1)] For CO, NO_x, SO_2 and NMVOC, respectively.

[2)] One map per compound for: other solids (OS) and traditional biofuels (TR).

[3)] For CO_2, CH_4 and N_2O. (pop. dens. = population density, according to Logan, 1993).

[4)] Point and area sources summed on 1°x1° grid for LOTOS countries and the USA (TNO, 1990; EPA, 1993), combined with population density for other countries.

[5)] OGJ (1992), International Refining Survey. For more information on data sources see Appendix M.3.

5.3 Industrial processes and solvent use

Depending on the knowledge of non-combustion emissions associated with the manufacturing of specific products or the application of certain processes or products, we included these as source categories. We categorize this source sector in about ten subsectors as shown in Table 5.3.1.

Table 5.3.1: Reporting sectors for industrial processes/solvent use

EDGAR sector	Code	Remark
I10. Iron & Steel	IRO	Production of pellets, pig iron, sinter, and steel (per process); hot and cold rolled steel; excluded is coke production (see fossil fuel sectors)
I20. Non-ferro metals	NFE	Production of copper, lead, zinc, aluminium, and molybdemum (primary and secondary)
I30. Chemicals	CHE	Production of organic and inorganic bulk chemicals (e.g. adipic acid, ammonia, nitric acid, sulphuric acid, N-fertilizers, polymers, monomers, etc.)
I40. Building materials	NME	Cement production
I50. Pulp & Paper	PAP	(not included in V2.0).
I60. Food	FOO	Bread, beer and wine production (bread not included in V2.0).
I70. Solvent use	SOL	Divided in 12 categories of solvent applications (chemical industry, paints, dry cleaning, degreasing, glues and adhesives, graphic arts (ink), leather, pesticides, rubber and plastics industry, vegetative oil extraction, household products, other solvent use)
I80. Transport evaporation	EVA	Evaporation of gasoline vehicles in road transport: in V2.0 included under combustion emissions
I90. Miscellaneous industry	MIS	Includes miscellaneous processes, not related to a specific type of industry; includes production and consumption of halocarbons and related compounds

Activity data

Most industrial production data were taken from UN (1993/1995), since it provides a time series from 1970 to 1990, except for a few products in the iron & steel industry which were taken from IISI (1994). For many commodities the time series were not complete up to 1990. In those cases we extrapolated at maximum five years backward and forward in time in estimating missing values, for 1990 mostly by assuming that the last known production level was kept constant in time. Also for solvent use and for the production of a number of chemical products no UN data were available. Instead, production data for 1990 were compiled from various sources. An overview of data sources used in the construction of the data set for solvent use is provided in Appendix D.3

Adipic acid and nitric acid
Adipic Acid (AA) production data are primarily based on the production capacity of plants given by Castellan *et al.* (1991). For manufacturing of nitric acid (HNO_3 or NA), which is mainly used as feedstock in fertilizer production, global production estimates from UN statistics (UN, 1993) and by the industry (McCulloch, 1993, pers. comm.) are inconsistent. Therefore, we adopted statistics of N-fertilizer production as a correlate for NA production (IFA, 1992).

Solvent use
Twelve categories are distinguished: chemical industry, dry cleaning, glues & adhesives, graphic arts (ink), household products, industrial degreasing, leather, paint, pesticides, rubber & plastics industry and other solvent use. For all categories, except chemical industry and household products, consumption or production data were gathered on global, regional and country levels. When no

country data were available, these were estimated on the basis of region or socio-economic group. For this purpose a socio-economic index for all countries in the world based on social and economic indicators, like GNP, birth rate, percentage working in the industry, etc., was developed. On the basis of this index the world is subdivided in four socio-economic groups.

Halocarbons

Global total production and consumption (sales) data of CFCs and HCFC-22 and 142b for reporting countries were taken from AFEAS (1995). For halons and methylchloroform (MCF) use, data were taken from from McCulloch (1992) and Midgley and McCulloch (1995), respectively. Production data of carbon tetrachloride (CTC) are based on the methodology described in Simmonds *et al.* (1983, 1988) combined with production data on CFC-11 and 12 from AFEAS (1995). Additional estimates were made for so-called non-reporting countries, which were calibrated to estimates for this group of countries made in AFEAS (1994), when available. Sales data are also available per application and per hemisphere. The global total production and consumption data are available for a time-series starting with the beginning of industrial production of these compounds (CFC-11 and 12, halons) or starting from a specific year (e.g. 1981 for other CFCs and 1970 for MCF). For methyl bromide data were used from Fisher *et al.* (1994) and from Reeves and Penkett (1993).

For CFCs these estimates for per country consumption were made based on the methodology described by McCulloch *et al.* (1994), extended for the time period 1980-1990 (for 1987-1990 only provisional, as no specific reduction rate per country was used) and for about 20 additional territories with a CFC consumption in 1986 of over 100 ton (to achieve a better global spatial distribution of these emissions). For MCF production the per country distribution for the period 1980-1993 was based on interpolation of data for 1980, 1986 and 1993 provided by Midgley and McCulloch (1994). For other compounds no attempt was made to distribute global total emissions on a per country basis.

Emission factors

Emission factors for CO_2 and N_2O

The emission factor of CO_2 for cement production is from Marland and Rotty (1984). Emission factors of N_2O for adipic acid and nitric acid production are based on Reimer *et al.* (1992).

Table 5.3.2: Emission factors for CO_2, CH_4 and N_2O from industrial processes in 1990

Sector/product	Emission factor	Unit	Region	Reference
Cement	136.0	kg CO_2-C/ton	World	Marland and Rotty, 1984
Ethene (ethylene)	247.5	g CH_4-C/ton	World	TNO, 1990 (LOTOS)
Styrene	22.5	g CH_4-C/ton	World	TNO, 1990 (LOTOS)
Coke production	13.171	kg CH_4-C/TJ	World	TNO, 1990 (LOTOS)
Sinter production	375.0	g CH_4-C/ton	World	TNO, 1990 (LOTOS)
Pig iron production (blast furnace)	675.0	g CH_4-C/ton	World	TNO, 1990 (LOTOS)
Adipic acid	147.1	kg N_2O-N/ton	World [1)]	Reimer *et al.*, 1992
Nitric acid	16.0	kg N_2O-N/ton N	World	Reimer *et al.*, 1992
[1)] **Exceptions:**				
Adipic acid	184.9	kg N_2O-N/ton	Canada	Reimer *et al.*, 1992
Adipic acid	110.0	kg N_2O-N/ton	USA	Reimer *et al.*, 1992

Emission factors for CH_4, CO and NO_x

For all countries the default emission factors for CH_4, CO and NO_x from the LOTOS database have been used in EDGAR (TNO-MW, 1990).

Emission factors for SO_2

Smelting of copper (Cu), lead (Pb), and zinc (Zn) are the main metallurgy industries contributing to sulfur emissions, with copper smelting been the largest contributor. Emission factors for these processes were computed assuming simple stoichiometric relationships to give the gross release in ton S per ton of metal based on Spiro *et al.* (1992) and Kato and Akimoto (1992). The gross factors for primary metal production were corrected for data on sulfur recovery for the metallurgical industry of BoM (1992) with the total recovery allocated proportional to the gross emissions from primary production of each metal. For some countries, for which this method resulted in negative net sulfur emissions, we used net factors calculated from the regional net emission factors.

The production of sulfuric acid (H_2SO_4) is another source of sulfur emissions, for which we used emisson factors based upon the conversion efficiency and application of flue gas controls. Assumptions were made based on, for example, Kato and Akimoto (1992) for specific countries or regions.

NMVOC: Solvent use

For some categories 'emission = use = sales' is valid, but for other categories the activity base levels are converted to emissions by multiplication by one or more emission factors. Many references, both for data and emission factors, were used for this category, the most important being: Passant (1993) and the journals: Eurocoat, PaintIndia, Farbe & Lack, European Chemical News, Chemical & Engineering News, Rubber Statistical Bulletin and FAO data on leather and seeds.

NMVOC: other processes

As many categories as possible have their own emission factor(s). For those categories which do not have an emission factor a default emission factor is used. The emission factors are from several references: TNO Emission Registration (1987, 1990 and 1992) and US EPA (AP-42, Stockton and Stelling and AIRCHIEF).

Halocarbons

Emissions of halocarbons are generally taken from the same data sources as the production data. This also applies for emissions per application or per hemisphere. For non-reporting countries emissions were estimated similar to the estimates made reporting countries.

For emission estimates on a per country basis the same method was applied as for production estimates per country.

NMVOC profiles

Each solvent subcategory, which has activity data, has its own NMVOC profile. These profiles are generated by TNO-MEP, using several references. For some of the industrial processes profiles are available. They have the same references as the NMVOC emission factor.

Gridded maps

Table 5.3.3 summarizes the maps used for distribution of emissions form industrial processes and solvent use emissions on grid and their references. Essentially, all country total emissions are distributed according to population density, except for the production of adipic acid and non-ferro metals. For these, gridded maps were compiled from global point source information, and for production of nitric and sulphuric acids gridded spatial distribution functions were compiled from point source data for USA and Europe, contained in the NAPAP and LOTOS inventory, and population density for other countries. More information on the construction of the grid maps for emissions from adipic acid and non-ferro metal production can be found in Appendixes M.4 to M.6.

Table 5.3.3: Gridded maps used for spatial distribution of emissions from industrial processes and solvent use.

Source sector	Code	LOTOS/NAPAP-USA	Other countries	All countries
I10. Iron & steel	IRO	-	-	pop. dens.
I20. Non-ferro metals:	NFE			
- Copper, lead, zinc		-	-	6 maps [1)]
- Others		-	-	pop. dens.
I30. Chemicals:	CHE			
- Adipic acid		-	-	AA map [2)]
- Nitric acid		NA production map [3)]	pop. dens.	
- Sulphuric acid		H_2SO_4 production map [3)]	pop. dens.	
- Other products		-	-	pop. dens.
I40. Building materials	NME	-	-	pop. dens.
I50. Pulp & paper	PAP	-	-	pop. dens.
I60. Food	FOO	-	-	pop. dens.
I70. Solvent use	SOL	-	-	pop. dens.
I80. Transport evaporation	EVA	-	-	pop. dens
I90. Miscellaneous industry	MIS	-	-	pop. dens

Notes:

1) For primary and secondary production of copper, lead and zinc, as well as primary production of aluminium (ICSG, pers. comm., 1995; ILZSG, 1994; BoM, 1993; Olivier, pers. comm., 1995)

2) Map for N_2O emissions from AA production (Castellan *et al.*, 1991; Olivier, pers. comm., 1995)

3) Point sources summed on 1°x1° grid for LOTOS countries and the USA (TNO, 1990; EPA, 1993).

N.B. pop. dens. = population density according to Logan, 1993.

5.4 Landuse and waste treatment

Landuse and waste treatment sources include the subprocesses rice paddies (CH_4), fertilizer use (N_2O), animals (CH_4 and N_2O), biomass burning, agricultural waste burning, uncontrolled waste burning and landfills (CH_4). Burning of biomass and waste causes emissions of a great number of trace gases. 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.

Activity data

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 (1991), except for caribous which were defined as numbers per grid cell (Lerner *et al.*, 1988).

Biomass burning consists of large-scale biomass burning (deforestation and savannah burning) and local fires of agricultural waste burning. Base levels for large-scale burning include the amount of carbon released in the tropics compiled by Hao et al. (1990) as distributions on a 5x5 grid, based on FAO statistics for the period 1975-1980. These distributions were converted to the EDGAR $1^{o}x1^{o}$ grid and used as base level for calculation of 1990 emissions. For agricultural waste burning 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). For more details we refer to Bouwman *et al.* (1995).

The waste handling sources include landfills and uncontrolled waste burning. The landfilled amounts of waste are based on per country estimates of waste production per capita and the fraction which is disposed of by landfilling as specified for the 13 IMAGE regions with data from SEI (1992) as described in Kreileman and Bouwman (1994). Amounts of uncontrolled waste burning are based on per country estimates of the amount combusted per capita.

Emission factors

For CO_2 from large biomass burning only deforestation is accounted for. Carbon losses from savannah burning and agricultural waste burning do not contribute to net emissions, since the vegetation is regrown in an average time period of one to two years.

For rice cultivation and landfills the emission factor for CH_4 was taken from Kreileman and Bouwman (1994), with factors for landfills derived from Subak *et al.* (1992). Factors for methane from enteric fermentation by ruminants were taken from Gibbs and Leng (1993). For biomass burning, including agricultural waste burning, the emission factor for N_2O was taken from Crutzen and Andreae (1990) as described in detail in Bouwman et al. (1995).

For biomass burning and agricultural waste burning, the NMVOC, CO and CH_4 emission factors and the NMVOC emission profile have all been taken from Veldt and Berdowski (1995), while for SO_2 and NO_x the factors are from Andreae (1991). To match with the global total emissions of the GEIA NMVOC inventory, the emission factor for NMVOC from deforestation and savannah burning has been scaled with a factor of 1.40 and 1.25, respectively. This was done to account for the different figures for the amounts of biomass burned in the EDGAR and the GEIA inventory.

NMVOC profiles

For all three large-scale biomass burning applications the same NMVOC profile is used, being that of wood and herbaceous matter.

Gridded maps

Table 5.4.1 lists the maps used for grid distribution of landuse and waste treatment emissions and their references.

Table 5.4.1: Gridded maps used for spatial distribution of landuse and waste treatment emissions

Source sector	Code	Map	Reference
L10. Agriculture:			
L11. - Arable land	AR_FE	arable land map	Bouwman *et al.*, 1995
L12. - Rice cultivation	CR_RI	wetland rice cultivation map	Asselmann and Crutzen, 1989
L20. Animals	AN	10 maps (one per animal type) 1)	Lerner *et al.*, 1988
L30. Biomass burning:			
L31. - Deforestation	BB_DEF	deforestation map 2)	Hao *et al.*, 1990
L32. - Savannah burning	BB_SAV	savannah burning map 2)	Hao *et al.*, 1990
L33. - Post-burn effects (deforest)	CR_DEF	deforestation map 2)	Hao *et al.*, 1990
L40. Waste handling:			
L41. - Agricultural waste burning	AWB	agricultural waste burning 2)	Bouwman *et al.*, 1995
L42. - Uncontrolled waste burning	UWB	pop. dens.	Logan, 1993
L43. - Landfills	LAF	pop. dens.	Logan, 1993

Notes:

1) For dairy cattle, non-dairy cattle, buffaloes, camels, horses, sheep, goats, pigs, chicken and caribous.

2) Used as base level on grid (amount of carbon combusted)

(pop. dens. = population density).

5.5 Natural sources

Natural sources are of very a different nature: natural soils, natural vegetation, wetlands, oceans, lightning and volcanoes are all sources of greenhouse gas emissions, for some of which emission estimates for specific compounds are available. Because of the complex nature of these sources most of them are either defined as base levels on grid or directly as emissions per grid cell.

Activity data and emission factors

For activity levels and emission factors for N_2O of natural soils, including grasslands, we used an adapted version of the gridded N_2O inventory (total of 6.6 Tg N_2O-N) produced by Bouwman et al. (1993) as described in Kreileman and Bouwman (1994). For natural vegetation and oceans, NMVOC emissions are avaible from the GEIA data centre (see below).

For wetland emissions we used gridded base levels and CH_4 emissions data from Asselmann and Crutzen (1989). Gridded emissions of N_2O from oceans was taken from Nevison (1994), which include areas with N_2O absorption (negative emissions) (net total of 3.6 Tg N_2O-N).

For CO_2 emitted and absorbed by vegatation and by oceans no representative emission estimates were available. Also, for emissions of CH_4, CO, NO_x and SO_2 from natural sources no spatial emissions data are included. The same holds for lightning and (irregular) volcanic activities, considered to be sources of NO_x and SO_2, respectively.

NMVOC and NMVOC profiles

The natural NMVOC data are estimated by Guenther *et al.* (1994). The world total is 1150 Tg C, composed of 44% isoprene, 11% monoterpenes, 22.5% other reactive VOC and 22.5% other VOC. The information is available on a 0.5° x 0.5° grid and has a temporal variation. In EDGAR we included the available GEIA data of isoprenes, monoterpenes and other reactive VOC as aggregated annual emissions on the 1°x1° grid, thus resulting in a global total of 890 Tg C (or 1182 Tg expressed as CH_4). Thus, the natural emissions of non-reactive NMVOC, with typical lifetimes greater than one day and contributing 260 Tg C (or 347 Tg as CH_4) to the global total budget, are not included in Version 2.0 of the database.

Gridded maps

Table 5.5.1 lists the maps used for distribution of natural emissions on grid and their references.

Table 5.5.1: Gridded maps used for spatial distribution of natural sources

Source sector	Code	Map	Reference
N10. Natural soils	NAT_SO	Natural soils: N_2O emission	Bouwman *et al.*, 1993
N20. Natural vegetation	NAT_VE	Natural veg.: NMVOC maps [1)]	Guenter *et al.*, 1994
N30. Wetlands	NAT_WL_xx	6 wetlands maps [2)]	Asselmann and Crutzen, 1989
N40. Oceans	NAT_OC	Oceans: N_2O emission	Nevison, 1994

Notes:

1) For three compound groups: isoprenes, terpenes and other reactive NMVOC. Other reactive NMVOC includes also oceanic emissions.

2) For bogs, fens, floodplains, lakes, marshes, and swamps.

6. RESULTS AND DISCUSSION

In this chapter we will present results extracted from EDGAR V2.0. Per compound we will include a summary table with the calculated anthropogenic emissions in 1990 given per main source and region, including a brief discussion of the main features. The results will then be compared with IPCC estimates, which we consider to be the aggregation of various scientific emission estimates (IPCC, 1992, and details presented in Pepper *et al.*, 1992; supplemented with, in some cases, IPCC, 1994). To illustrate regional and sectoral uncertainties, SO_2 and NO_x emissions from Asia and Europe were compared in more detail. An extensive validation of the database, for example with GEIA and FCCC inventories, is anticipated in a follow-up project. In addition, some gridded emission maps are included to illustrate the results of EDGAR calculations on grid.

Another application of the database is analysis of the historical development of emissions, either per region or per source. This is possible when historical emission factors are included in the database. Currently, this is the case for CO_2 and N_2O from fossil fuel combustion and industrial processes for which the emission factors were assumed to be constant in time (except for N_2O from road transport in some regions). For other sources and compounds, this may not be the case, and assumptions for historical emission factors need somewhat more detailed consideration. To illustrate the capability of providing historical trends, we will present some figures for emissions from fossil fuel combustion and cement production in the period 1970-1990 in the section on CO_2.

For atmospheric modellers the latitudinal 1-D distribution of the 2-D spatially distributed emissions is an important aspect to consider. EDGAR provides an option for projecting results of a calculation on $1^o x 1^o$ grid into the latitudinal distribution, either per degree, per 5 degrees, or in 19 latitudinal bands. In the section on CO_2 we will also present some figures for the latitudinal distribution of emissions from fossil fuel combustion sectors to show the profiles and contributions of different sources as well as the development in time.

6.1 Carbon dioxide (CO_2)

The results of the calculations of all anthropogenic sources for CO_2 are presented in Table 6.1.1. The total emissions in 1990 are 29.8 Pg CO_2 or 8.1 Pg C, including 5.5 Pg CO_2 biofuel consumption if we assume that all woodfuel etc. collection as well as wood waste generation in OECD regions is done in a non-sustainable way. In addition, the calculated CO_2 emissions assume that all carbon is fully oxidized during combustion to CO_2. When correcting for the fraction that not fully oxidized (e.g. to CO), fossil fuel emisisons would be 0.5 to 1% lower, whereas biofuel and deforestation emissions would be about 10% lower. We recall that CO_2 emissions from savannah burning and agricultural waste burning are not accounted for, since the regrowth in one or two years time compensates for this.

Most emissions are energy related: roughly speaking 70% of this total stems from fossil fuel combustion, 3% from non-energetic use of fossil fuels (e.g. as lubricants, bitumen, or as chemical feedstock), 1% from associated gas flaring (in oil production) and almost 20% from biofuel use (prodominantly fuelwood). In addition, 2% originates from cement production and about 6% is the net contribution from large-scale biomass burning (deforestation).

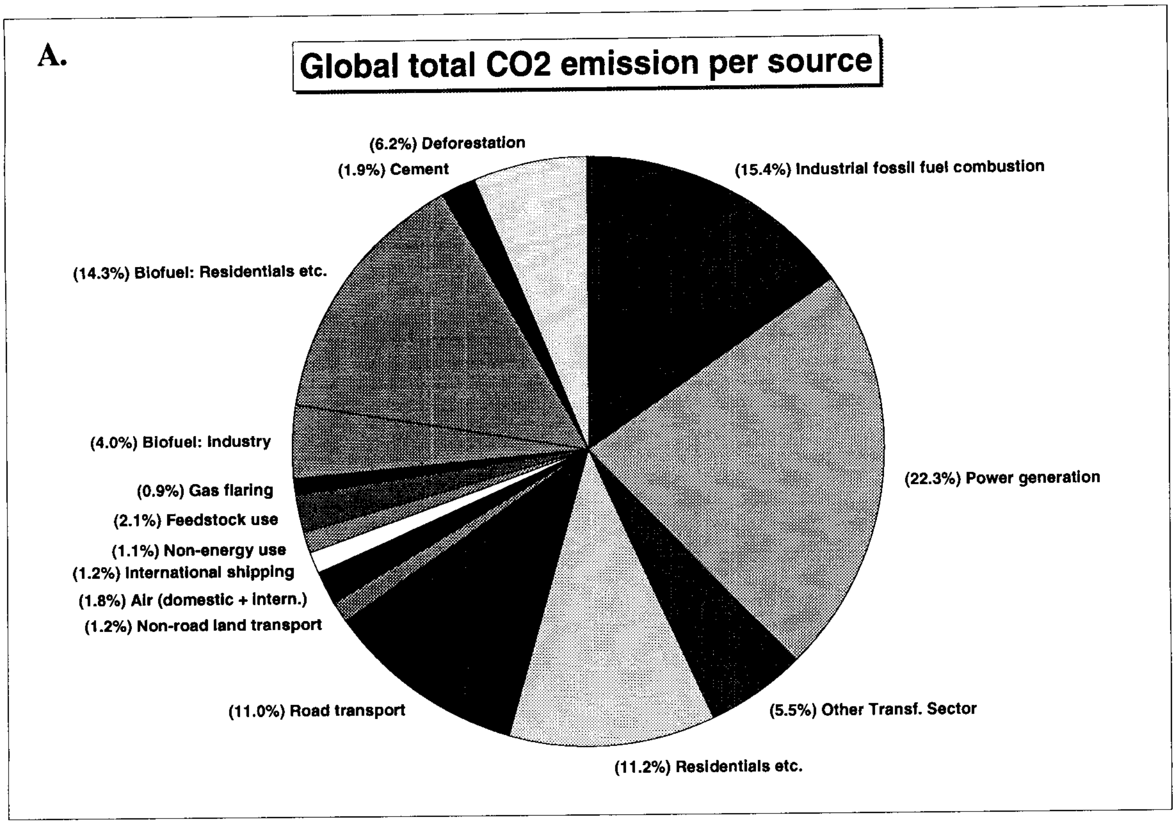
Table 6.1.1: Global anthropogenic emissions of CO_2 per region and source in 1990 (Tg CO_2)

Global anthropogenic CO2 emissions in 1990 (assuming 100% oxidation to CO2 during combustion)
Unit: Tg CO2

Source/sub-sector	TOTAL	CAN.	USA	LAT. AM.	AFRICA	W. EUR.	E. EUR.	CIS	M. EAST	INDIA+	CHINA+	E ASIA	OCEAN.	JAPAN	INT. SHIP
Total	**29765.3**	**563.7**	**5618.7**	**2316.6**	**2322.2**	**3791.7**	**1073.9**	**3628.0**	**1007.2**	**2228.3**	**3978.9**	**1350.2**	**347.9**	**1188.2**	**349.8**
o.w.															
Fossil fuel: combustion	**20694.6**	**423.7**	**4761.6**	**945.7**	**680.1**	**3202.2**	**1000.3**	**3400.3**	**759.5**	**668.6**	**2599.5**	**571.5**	**289.3**	**1042.6**	**349.8**
o.w. Industry	4590.2	75.5	689.0	207.9	118.9	554.8	170.8	884.4	107.2	225.5	1137.7	135.0	42.4	241.2	0.0
o.w. Power generation	6638.3	92.9	1773.4	153.1	249.5	945.9	444.4	1296.8	180.6	257.7	677.1	125.3	128.0	313.7	0.0
o.w. Other Transf. Sector	1623.6	47.0	258.2	135.6	138.8	256.9	156.0	183.9	103.0	28.1	113.4	55.0	24.7	123.1	0.0
o.w. Residentials etc.	3343.3	80.0	603.3	130.2	59.7	660.8	151.0	644.6	207.3	57.2	492.6	110.3	15.2	131.0	0.0
o.w. Road transport	3261.1	97.2	1160.7	282.2	97.1	659.7	68.0	222.2	131.4	75.1	103.9	114.1	63.0	186.3	0.0
o.w. Non-road land transport	343.4	18.1	50.6	11.6	2.0	33.1	5.0	101.7	1.4	17.5	61.9	9.7	5.9	24.9	0.0
o.w. Air (domestic + intern.)	544.9	13.0	226.5	24.9	14.2	90.9	5.1	66.8	28.6	7.6	12.9	22.2	10.0	22.3	0.0
o.w. International shipping	349.8														349.8
Fossil fuel: non-combustion	**1206.8**	**44.8**	**331.5**	**64.6**	**73.3**	**268.6**	**21.1**	**104.3**	**77.3**	**30.6**	**22.8**	**50.5**	**14.9**	**102.7**	**0.0**
o.w. Non-energy use	334.0	14.9	180.5	0.9	0.0	87.9	11.6	0.0	3.1	0.0	0.0	0.0	8.4	26.5	0.0
o.w. Feedstock use	613.0	25.6	143.2	42.5	5.8	155.4	8.4	80.5	18.7	18.5	10.6	23.3	4.2	76.1	0.0
o.w. Gas flaring	259.9	4.3	7.8	21.2	67.5	25.3	1.1	23.8	55.4	12.1	12.1	27.2	2.2	0.0	0.0
Biofuel	**5456.3**	**89.4**	**490.3**	**402.4**	**971.0**	**220.8**	**27.8**	**55.0**	**132.0**	**1368.9**	**1158.6**	**499.4**	**39.8**	**0.9**	**0.0**
o.w. Industry	1177.8	84.2	397.9	72.6	58.2	208.4	25.3	49.5	16.5	123.7	54.1	58.4	28.3	0.8	0.0
o.w. Other Transf. Sector	9.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0	0.0	0.0	0.0
o.w. Residentials etc.	4269.5	5.2	92.4	329.9	912.8	12.4	2.5	5.5	115.4	1245.2	1104.5	432.0	11.5	0.1	0.0
Industrial processes	**570.1**	**5.9**	**35.4**	**42.1**	**25.9**	**100.0**	**24.7**	**68.5**	**38.2**	**27.5**	**115.1**	**40.9**	**3.9**	**42.1**	**0.0**
o.w. Cement	570.1	5.9	35.4	42.1	25.9	100.0	24.7	68.5	38.2	27.5	115.1	40.9	3.9	42.1	0.0
Landuse/waste treatment	**1837.4**	**0.0**	**0.0**	**861.8**	**571.9**	**0.0**	**0.0**	**0.0**	**0.3**	**132.7**	**82.9**	**187.8**	**0.0**	**0.0**	**0.0**
o.w. Deforestation	1837.4	0.0	0.0	861.8	571.9	0.0	0.0	0.0	0.3	132.7	82.9	187.8	0.0	0.0	0.0
o.w. Savannah burning	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note:All sectors:	100% Oxidation to CO2 was assumed, except for Non-energy and Feedstock use of fuels; to be corrected for the fraction not oxidized to CO2, which is typically 0.5-1% for fossil fuel combustion, and about 10% for biofuel combustion & large scale biomass burning; to be converted for the fraction of oxidized carbon not converted to CO2 but to other compounds such as CO.
Other Transf. Sector:	Notably refineries, coke ovens, blast furnaces, etc., including fuel combustion for fuel extraction. The net CO2 emission from this sector has been calculated from carbon content in fuel inputs minus content in fuels produced, plus emission from fuel combustion.
Biofuel:	100% Non-sustainable production was assumed here; to be corrected for actual percentage of sustainable consumption.
Non-energy use:	Consumption of lubricants, waxes etc. in industry, transport etc.
Feedstock use:	Consumption of naphtha etc. as chemical feedstock in industry.
Savannah burning:	Do not contribute to net CO2 emissions, since the vegetation is regrown in an average time period of 1 to 2 years; the same holds for agricultural waste burning

Figures 6.1.1/2: Share in global total anthropogenic emissions of CO_2, split according to source categories (A) and regions (B).



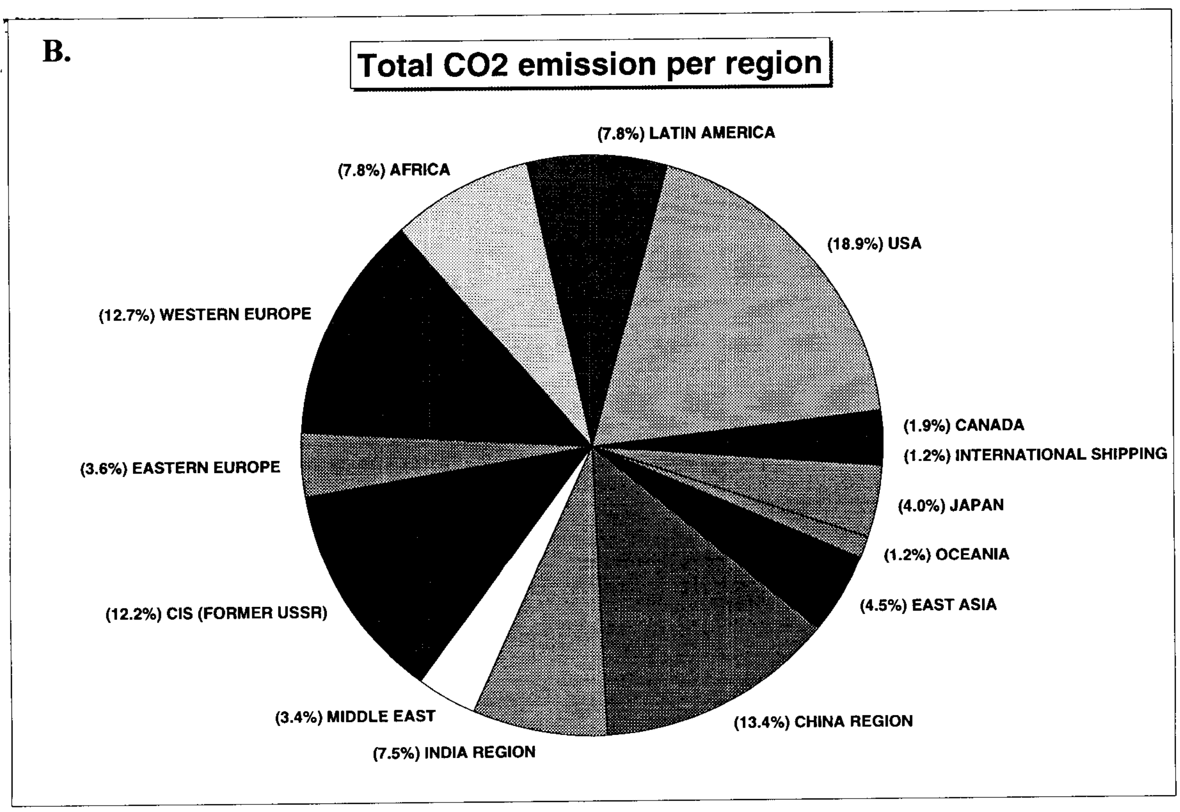
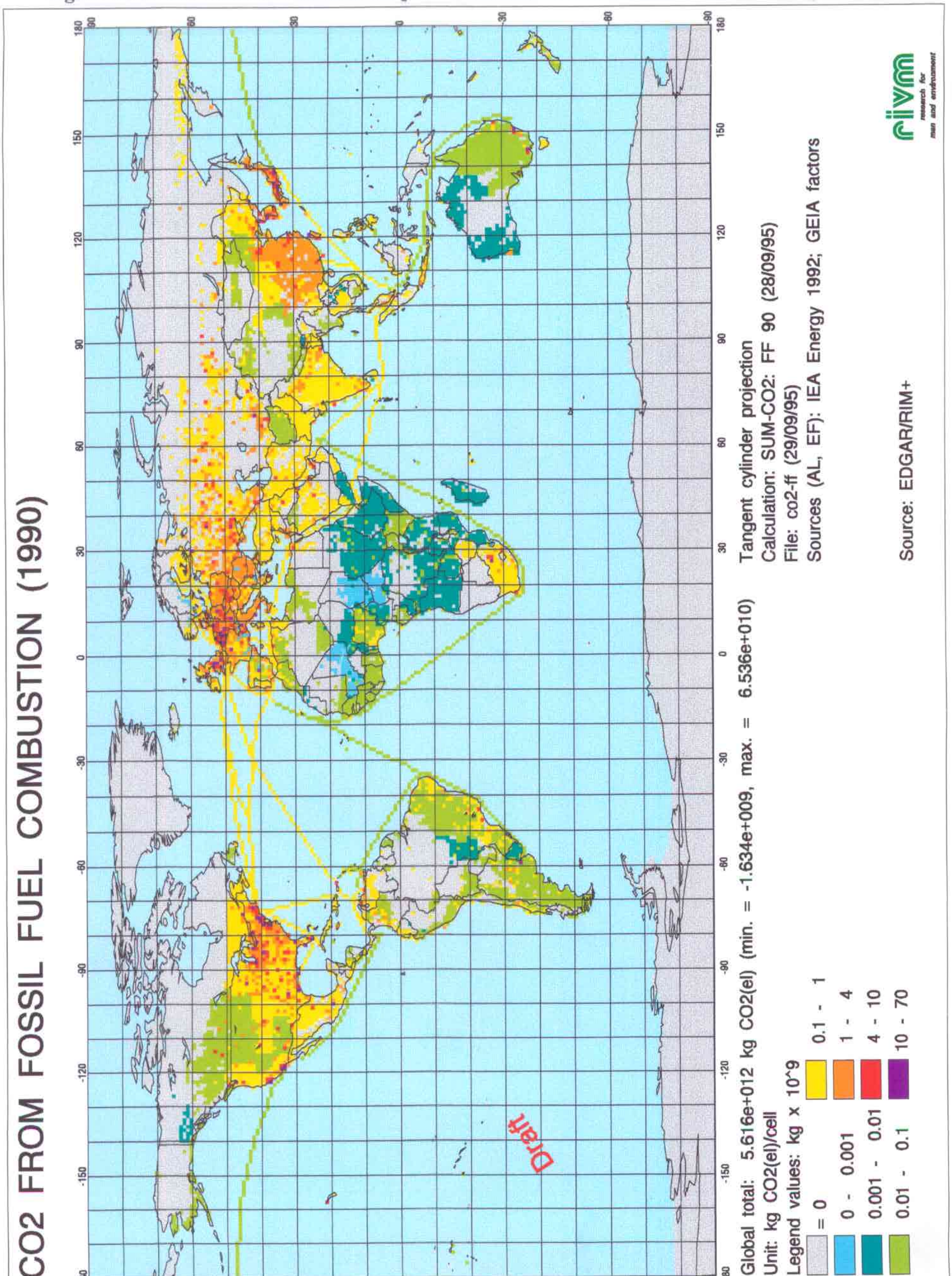


Figure 6.1.3: Global distribution of CO_2 emissions from fossil fuel combustion in 1990.



Within fossil fuel use electric power generation is responsible for 1/3 the CO_2 emissions with other industrial sources as the second largest. This can be explained from the fact that in most regions coal is predominantly used in these sectors. Fuel combustion in the residential sector accounts for almost a quarter of total anthropogenic emissions if we include emissions from biofuel use, which occurs predominantly in India, China and Africa. Cement emissions are concentrated in China, Western Europe and the former USSR, whereas large-scale biomass burning emissions stem mainly from Latin America and Africa.

The total emissions are graphically presented in Figures 6.1.1 and 6.1.2, where we made a split into contributions per source and per region. In addition, in Figure 6.1.3 we show the CO_2 emissions from fossil fuel use on a 1°x1° grid. As expected, industrialized regions such as the USA, OECD Europe and the former USSR have the largest shares of 12 to 19% in global total CO_2 emissions. The China region also contributes substantially (13%), which is due to the high share in global coal consumption and in residential biofuel use. However, due to the large amounts of large-scale biomass burning and biofuel use, Africa, Latin America and the India region also have rather large shares of about 8% each.

Comparison of our emission estimates with the IPCC(1992) inventory for 1990 gives the following picture:

Source	EDGAR (Pg C)	IPCC (Pg C)
Energy (fossil)	5.9	6.0 (5.5-6.5)
Cement	0.2	0.2
Biomass burning	2.0 [1)]	1.6 [1)] (0.6-2.6)
Global total	8.1	7.8

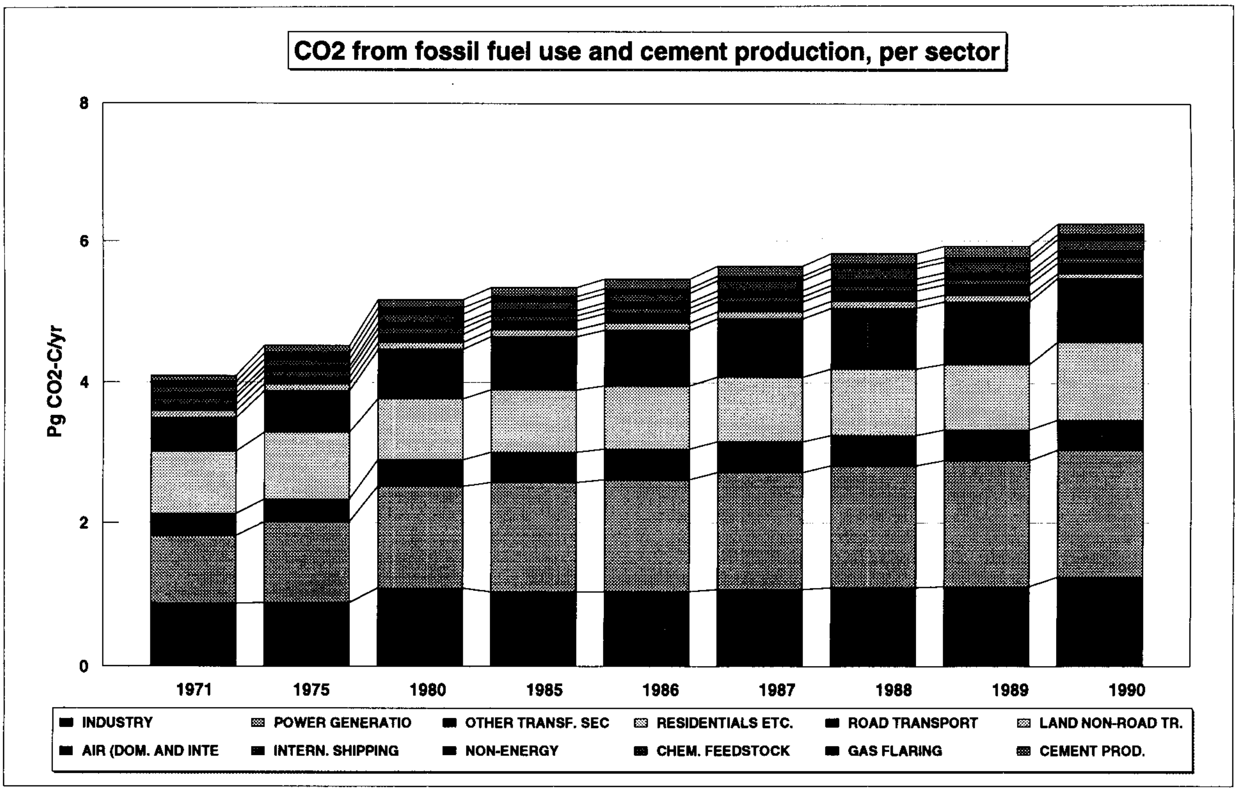
[1)] Including 1.5 and 0.9 Pg C for biofuels for EDGAR and IPCC, respectively.

It can be concluded that there is good agreement for fossil fuel use and cement production. This is also the case when we compare these emissions with the inventory prepared by Marland *et al.* (1994). Biomass burning emissions also fall within the uncertainty range of IPCC; biofuel emissions, however, appear to be substantially higher than estimated by the IPCC as part of their biomass burning figure. This difference may be partially caused by our assumption - for reporting purposes - of 100% non-sustainable use. Summarizing, we can conclude that the EDGAR data correspond well with the IPCC estimates.

Historical development of CO_2 emissions

For CO_2 from fossil fuel combustion and industrial processes, we may assume the emission factors to be constant in time. For sources for which historical data for activity levels are available, such as energy consumption and many industrial production processes, an analysis can be made, either per region or per source, of the historical development of emissions. In Figure 6.1.4/5 historical trends for the period 1971-1990 are shown for CO_2 emissions from fossil fuel combustion and cement production, both per region and per source category. As an illustration, Figure 6.1.6 shows the historical development of emissions per region for a few specific sectors: electric power generation, road transport and cement production. Calculation of historical emissions on a 1°x1° grid is also possible using the 1990 maps for distributing country emissions for other years if no specific map is available for that year, which will often be the case.

Figure 6.1.4/5: Historical development of CO_2 emissions from fossil fuel use and cement production per sector and per region.



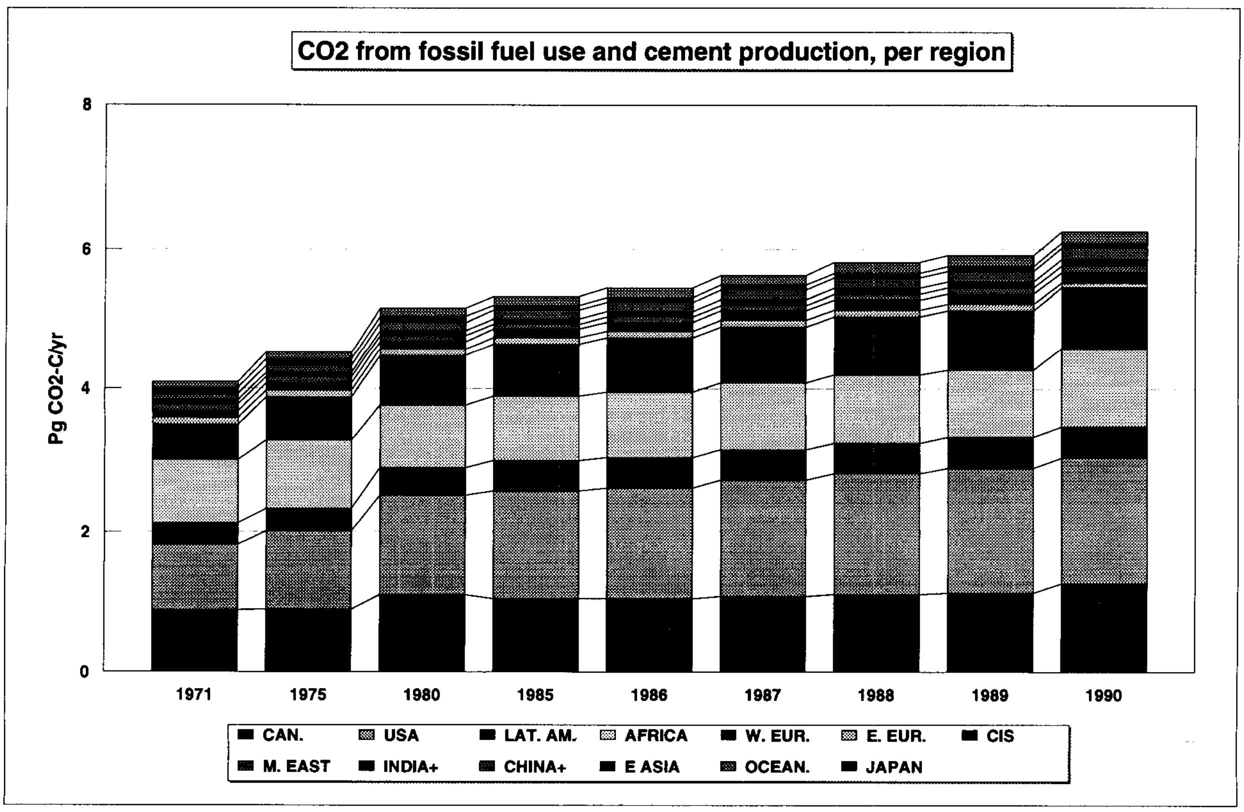
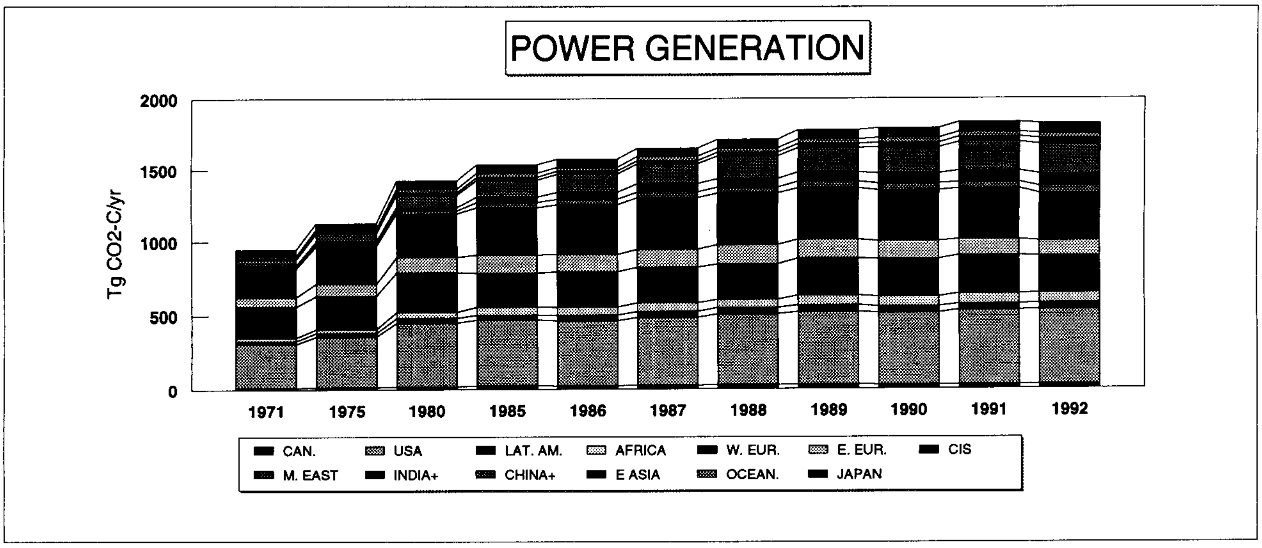
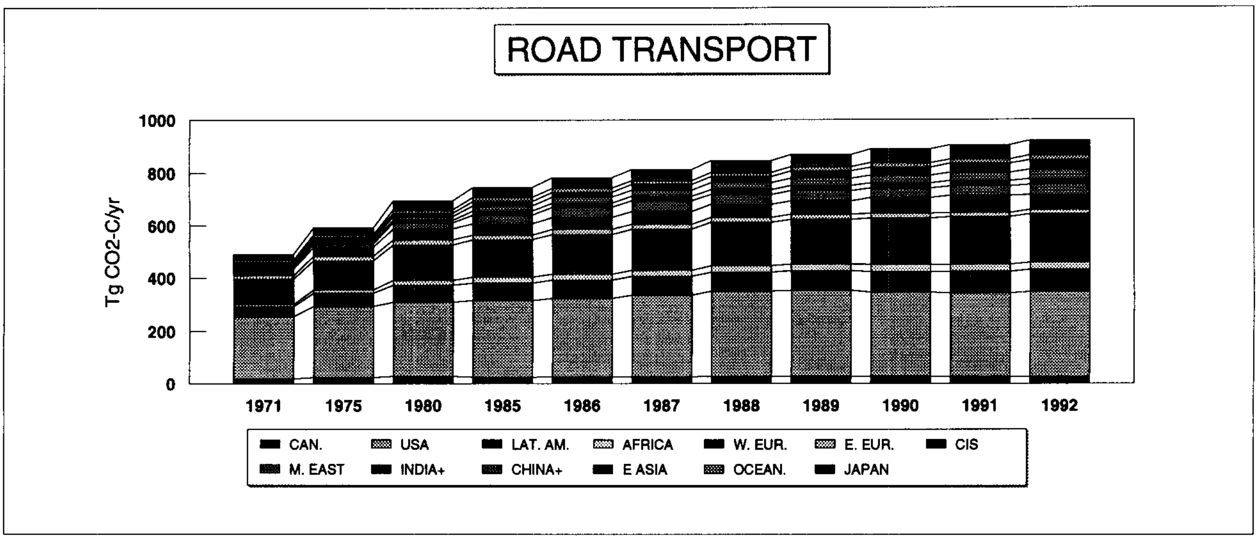
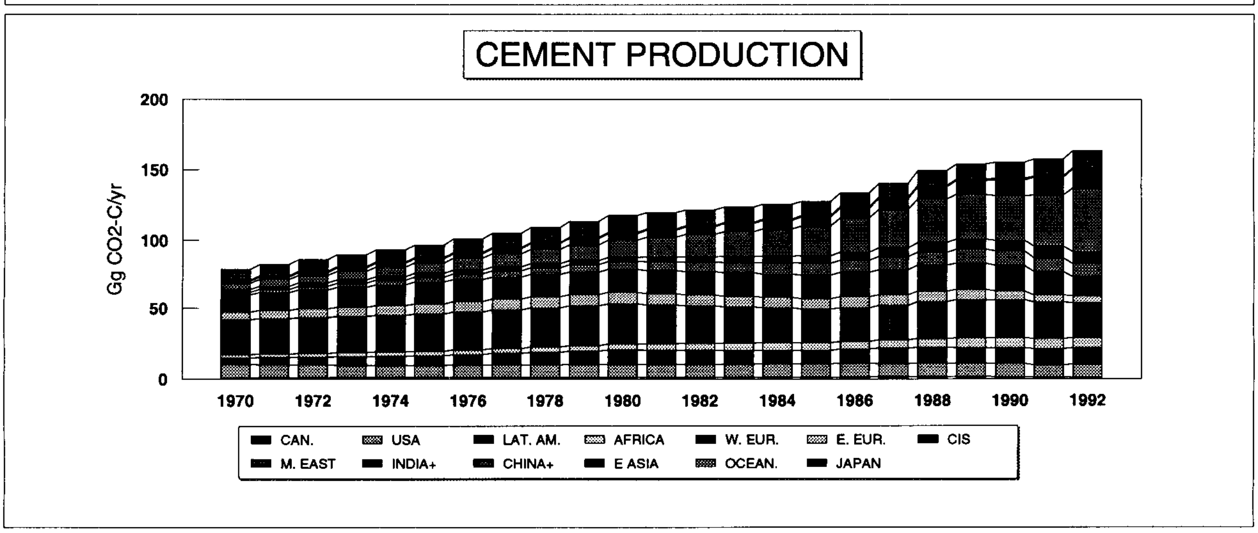


Figure 6.1.6: Regional historical development of CO_2 emissions of specific sectors: power generation, road transport and cement production.







Latitudinal distribution of CO_2 emissions

Latitudinal distributions, resulting from projecting 2-D results of grid calculations into 1-D latitude bands, are a powerful way to compare the spatial contribution and profile of different sources as well as trends in the spatial distribution and their underlying causes. To illustrate these aspects, Figure 6.1.7 shows the latitudinal distribution in 1990 of emissions from different fossil fuel combustion sectors. Figures 6.1.8 presents the historical development in time for these sectors.

To interpret the distributions we have listed the latitude of a number of number of major cities in the world and the region they belong to in Table 6.1.2. Clearly, some latitude peaks can be explained by a few major cities in the larger source regions of the former USSR, Western Europe, USA and Japan: Moscow, Essen-Düsseldorf, London, Paris, Rome, Chicago, San Francisco, Tokyo, and Los Angeles. Of course, with the data available in the database other cross-sections (such as per region) can also easily be made.

Figure 6.1.7: Latitudinal distribution of CO_2 emissions from fossil fuel use in 1990.

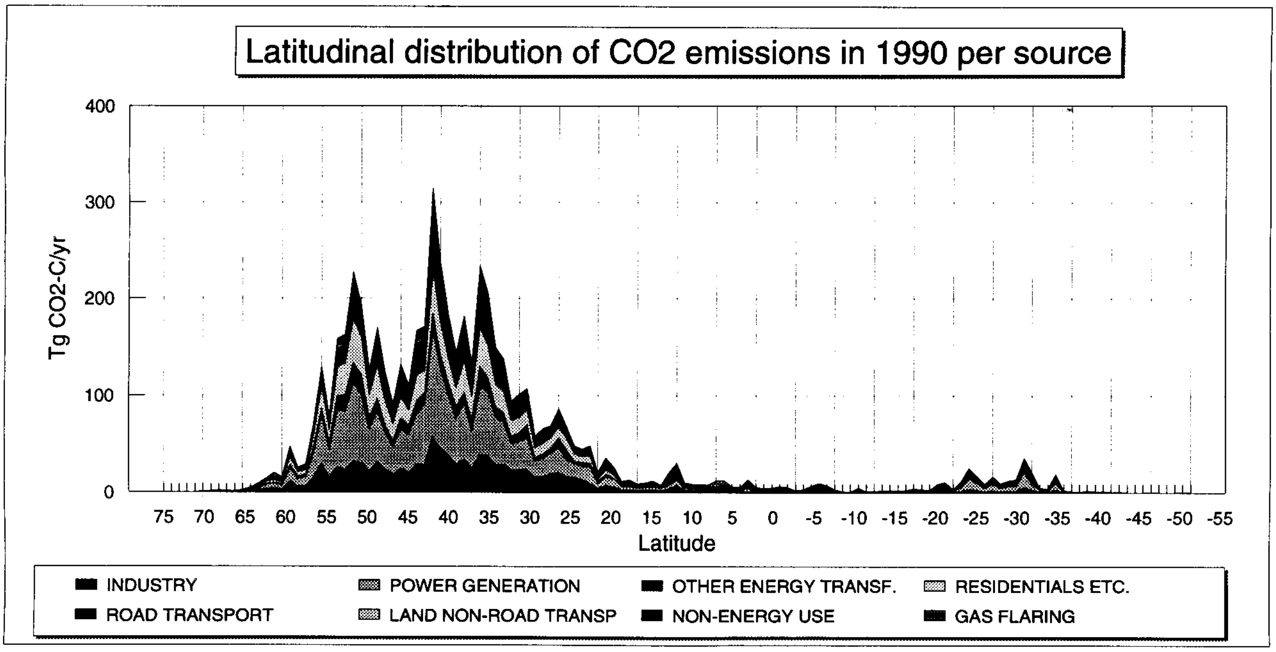


Table 6.1.2: Latitude of highly populated areas: major cities, ordered per latitude, grouped per region and in alphabetical order.

ORDER: LATITUDE, REGION, CITY

LATITUDE	City	Region
59	St Petersburg	CIS
56	Gorky	CIS
55	Moscow	CIS
52	Berlin	OECD EUROPE
51	Essen-Duesseldorf	OECD EUROPE
51	London	OECD EUROPE
48	Paris	OECD EUROPE
41	Rome	OECD EUROPE
41	Chicago	USA
40	New York	USA
39	Beijing	CHINA REGION
39	Tianjin	CHINA REGION
38	Washington DC	USA
37	Seoul	EAST ASIA
37	San Francisco	USA
35	Tokyo-Osaka-Yokohama	JAPAN
34	Los Angeles	USA
31	Shanghai	CHINA REGION
30	Chengdu	CHINA REGION
30	Wuhan	CHINA REGION
29	Chongqing	CHINA REGION
29	Houston	USA
28	New Delhi	INDIA REGION
25	Taipei	EAST ASIA
23	Guangzhou	CHINA REGION
22	Calcutta	INDIA REGION
19	Mexico City	LAT. AM.
18	Bombay	INDIA REGION
17	Hyderabad	INDIA REGION
14	Manila	EAST ASIA
13	Madras	INDIA REGION
12	Bangalore	INDIA REGION
10	Caracas	LAT. AM.
1	Singapore	EAST ASIA
-7	Jakarta	EAST ASIA
-23	Rio de Janeiro	LAT. AM.
-24	Sao Paulo	LAT. AM.
-27	Johannnesburg	AFRICA
-30	Durban	AFRICA
-34	Cape Town	AFRICA
-34	Sydney	OCEANIA
-38	Melbourne	OCEANIA

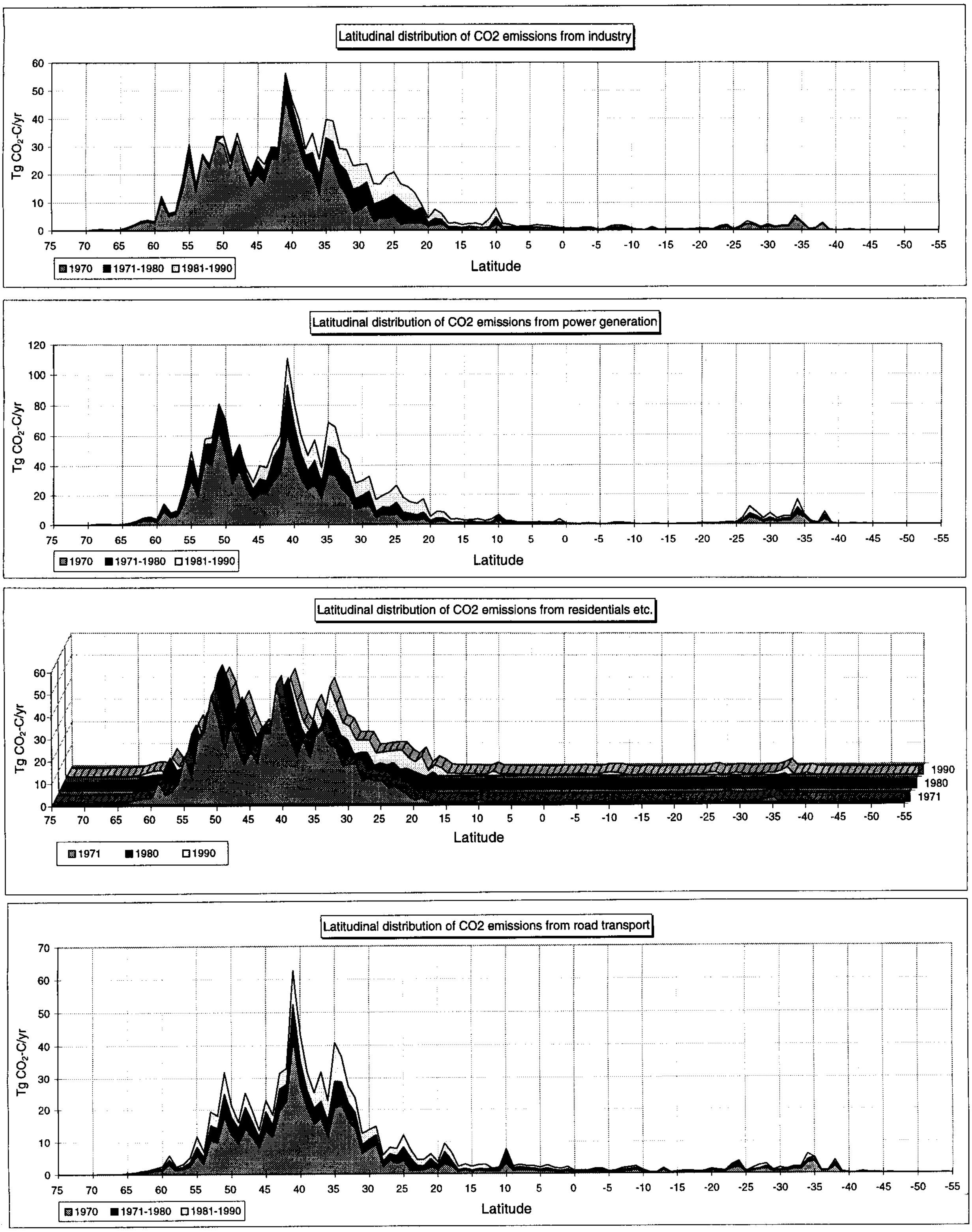
ORDER: REGION, LATITUDE, CITY

REGION	Latitude	City
USA	41	Chicago
USA	40	New York
USA	38	Washington DC
USA	37	San Francisco
USA	34	Los Angeles
USA	29	Houston
LAT. AM.	19	Mexico City
LAT. AM.	10	Caracas
LAT. AM.	-23	Rio de Janeiro
LAT. AM.	-24	Sao Paulo
OECD EUROPE	52	Berlin
OECD EUROPE	51	Essen-Duesseldorf
OECD EUROPE	51	London
OECD EUROPE	48	Paris
OECD EUROPE	41	Rome
AFRICA	-27	Johannnesburg
AFRICA	-34	Cape Town
AFRICA	-30	Durban
CIS	59	St Petersburg
CIS	56	Gorky
CIS	55	Moscow
INDIA REGION	28	New Delhi
INDIA REGION	22	Calcutta
INDIA REGION	18	Bombay
INDIA REGION	17	Hyderabad
INDIA REGION	13	Madras
INDIA REGION	12	Bangalore
CHINA REGION	39	Beijing
CHINA REGION	39	Tianjin
CHINA REGION	31	Shanghai
CHINA REGION	30	Chengdu
CHINA REGION	30	Wuhan
CHINA REGION	29	Chongqing
CHINA REGION	23	Guangzhou
EAST ASIA	37	Seoul
EAST ASIA	25	Taipei
EAST ASIA	14	Manila
EAST ASIA	1	Singapore
EAST ASIA	-7	Jakarta
JAPAN	35	Tokyo-Osaka-Yokohama
OCEANIA	-34	Sydney
OCEANIA	-38	Melbourne

ORDER: CITY

Latitude	CITY	Region
12	Bangalore	INDIA REGION
39	Beijing	CHINA REGION
52	Berlin	OECD EUROPE
18	Bombay	INDIA REGION
22	Calcutta	INDIA REGION
-34	Cape Town	AFRICA
10	Caracas	LAT. AM.
30	Chengdu	CHINA REGION
41	Chicago	USA
29	Chongqing	CHINA REGION
-30	Durban	AFRICA
51	Essen-Duesseldorf	OECD EUROPE
56	Gorky	CIS
23	Guangzhou	CHINA REGION
29	Houston	USA
17	Hyderabad	INDIA REGION
-7	Jakarta	EAST ASIA
-27	Johannnesburg	AFRICA
51	London	OECD EUROPE
34	Los Angeles	USA
13	Madras	INDIA REGION
14	Manila	EAST ASIA
-38	Melbourne	OCEANIA
19	Mexico City	LAT. AM.
55	Moscow	CIS
28	New Delhi	INDIA REGION
40	New York	USA
48	Paris	OECD EUROPE
-23	Rio de Janeiro	LAT. AM.
41	Rome	OECD EUROPE
37	San Francisco	USA
-24	Sao Paulo	LAT. AM.
37	Seoul	EAST ASIA
31	Shanghai	CHINA REGION
1	Singapore	EAST ASIA
59	St Petersburg	CIS
-34	Sydney	OCEANIA
25	Taipei	EAST ASIA
39	Tianjin	CHINA REGION
35	Tokyo-Osaka-Yokohama	JAPAN
38	Washington DC	USA
30	Wuhan	CHINA REGION

Figure 6.1.8: Historical trends in the latitudinal distribution of CO_2 emissions for four fossil fuel combustion sectors.



6.2 Methane (CH_4)

The results from the EDGAR calculations for CH_4 are conveniently arranged in Table 6.2.1. In the EDGAR database the global total for anthropogenic CH_4 emissions amounts to 320 Tg for 1990. This figure is consistent with that stated by the IPCC (320 vs. 360 Tg). As also shown in Figures 6.2.1 and 6.2.2, it can be seen from this table that although the division over the different emission source categories differs between the regions, there are no obvious dominant regions in terms of total CH_4 emissions. When the different emission source categories from the table are considered, six major categories can be distinguished. In order of decreasing importance these include: enteric fermentation, rice paddies, landfills, the natural gas industry, coal mining and biomass burning. To compare the emission estimates with the IPCC (1992) inventory for 1990, the emission source categories were rearranged to yield the following:

Source	EDGAR (Tg)	IPCC (Tg)
Enteric Fermentation & Animal Waste	93	105 (85-130)
Energy Production and Use	94	100 (70-120)
Rice Cultivation	60	60 (20-150)
Landfills	36	30 (20-70)
Biomass Burning	37 [1)]	40 (20-80) [1)]
Domestic Sewage	-	25
Global total	320	360

[1)] Including 14 and 9 Tg for biofuel use for EDGAR and IPCC, respectively.

All categories fall well within the uncertainty range estimated by IPCC. Differences for energy production and use might be explained by the relatively high global default emission factor for coal mining proposed by Smith and Sloss (1992). Also the high uncertainties for natural gas losses in the former USSR's massive production area, West Siberia, might give rise to differences in the emission estimates. In Figure 6.2.3 the spatial distribution of methane emissions from anthropogenic sources is shown on the 1°x1° grid. Differences for biomass burning might be explained by the large uncertainties which exist in the activity estimates large-scale biomass burning. Also, a different emission factor might have been used. Summarizing, it can be stated that EDGAR shows good consistency with the IPCC inventory.

Table 6.2.1: Global anthropogenic emissions of CH_4 per region and source in 1990 (Tg CH_4)

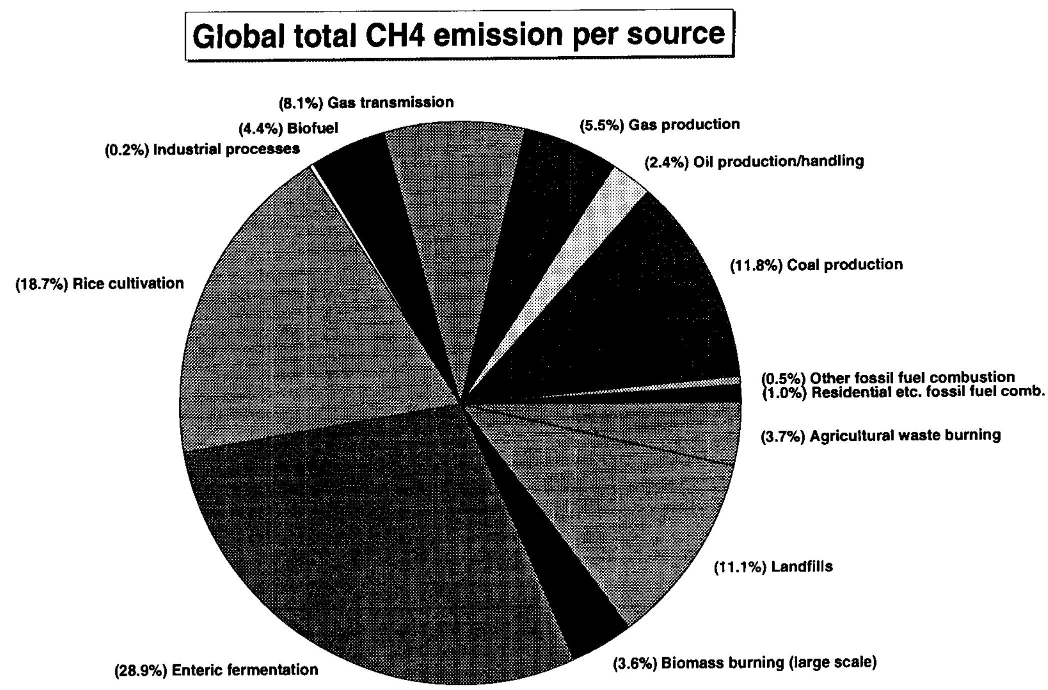
Global anthropogenic CH4 emissions in 1990
Unit: Tg CH4

Source/sub-sector	TOTAL	CAN.	USA	LAT. AM.	AFRICA	W. EUR.	E. EUR.	CIS	M. EAST	INDIA+	CHINA+	E ASIA	OCEAN.	JAPAN	INT. SHIP
Total	**320.2**	**3.9**	**41.6**	**32.4**	**26.8**	**23.4**	**10.8**	**47.0**	**10.3**	**49.9**	**46.7**	**18.6**	**5.7**	**3.2**	**0.02**
o.w.															
Fossil fuel: combustion	**4.80**	**0.04**	**0.52**	**0.13**	**0.08**	**0.64**	**0.35**	**0.94**	**0.11**	**0.07**	**1.57**	**0.19**	**0.03**	**0.11**	**0.02**
o.w. Industry	0.38	0.01	0.06	0.01	0.01	0.04	0.01	0.07	0.01	0.02	0.11	0.01	0.00	0.02	0.00
o.w. Power generation	0.10	0.00	0.02	0.00	0.00	0.01	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.00
o.w. Other Transf. Sector	0.35	0.01	0.06	0.02	0.01	0.06	0.02	0.04	0.02	0.01	0.05	0.01	0.00	0.03	0.00
o.w. Residentials etc.	3.13	0.00	0.13	0.02	0.04	0.36	0.29	0.73	0.05	0.01	1.36	0.12	0.01	0.01	0.00
o.w. Road transport	0.73	0.02	0.23	0.07	0.02	0.14	0.02	0.06	0.03	0.02	0.03	0.04	0.02	0.03	0.00
o.w. Non-road land transport	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00
o.w. Air (domestic + intern.)	0.05	0.00	0.02	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
o.w. International shipping	0.02														0.02
Fossil fuel: production	**89.28**	**1.62**	**21.34**	**2.68**	**2.90**	**4.75**	**5.29**	**30.97**	**4.46**	**1.34**	**9.80**	**2.27**	**1.21**	**0.64**	**0.00**
o.w. Coal production	37.84	0.25	11.96	0.41	1.32	3.57	3.35	5.56	0.14	0.86	9.14	0.19	0.88	0.22	0.00
o.w. Oil production	7.62	0.19	0.99	1.30	1.09	0.10	0.05	1.89	0.94	0.12	0.47	0.38	0.09	0.00	0.00
o.w. Oil handling	0.20	0.00	0.00	0.02	0.03	0.02	0.00	0.02	0.09	0.00	0.00	0.01	0.00	0.00	0.00
o.w. Gas production	17.57	0.27	1.26	0.22	0.17	0.13	0.50	10.86	2.51	0.12	0.04	1.42	0.06	0.01	0.00
o.w. Gas transmission	26.06	0.91	7.13	0.72	0.29	0.94	1.39	12.65	0.79	0.23	0.14	0.28	0.18	0.41	0.00
Biofuel	**14.07**	**0.02**	**0.37**	**1.04**	**3.78**	**0.06**	**0.01**	**0.02**	**0.31**	**4.02**	**2.78**	**1.64**	**0.03**	**0.00**	**0.00**
o.w. Industry	0.13	0.00	0.04	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.04	0.00	0.00	0.00
o.w. Residentials etc.	13.94	0.02	0.34	1.03	3.77	0.04	0.01	0.02	0.31	4.01	2.77	1.59	0.02	0.00	0.00
Industrial processes	**0.80**	**0.01**	**0.06**	**0.04**	**0.01**	**0.15**	**0.05**	**0.17**	**0.03**	**0.02**	**0.11**	**0.03**	**0.01**	**0.12**	**0.00**
o.w. Iron & steel	0.78	0.01	0.05	0.04	0.01	0.15	0.05	0.17	0.03	0.02	0.11	0.03	0.01	0.12	0.00
o.w. Chemicals	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Landuse/waste treatment	**211.45**	**2.17**	**19.22**	**28.50**	**20.04**	**17.81**	**5.09**	**14.99**	**5.36**	**44.49**	**32.49**	**14.44**	**4.38**	**2.47**	**0.00**
o.w. Rice cultivation	59.81	0.00	0.52	2.40	1.41	0.17	0.03	0.28	0.41	24.63	18.92	10.04	0.05	0.94	0.00
o.w. Enteric fermentation	92.57	0.83	7.75	18.40	9.63	10.36	3.33	10.49	2.14	14.65	9.22	1.85	3.18	0.74	0.00
o.w. Biomass burning	11.49	0.00	0.00	4.00	6.14	0.00	0.00	0.00	0.00	0.43	0.30	0.63	0.00	0.00	0.00
o.w. Landfills	35.72	1.09	9.96	2.68	1.76	6.30	1.49	3.08	1.91	1.97	2.57	1.14	1.04	0.72	0.00
o.w. Agricultural waste burning	11.86	0.24	0.99	1.02	1.11	0.98	0.24	1.14	0.89	2.82	1.48	0.78	0.11	0.06	0.00

Note: Other Transf. Sector: Notably refineries, coke ovens, blast furnaces, etc., including fuel combustion for fuel extraction. The CH4 emissions from this sector are the sum of combustion and non-combustion emissions.
Oil handling: Tanker loading
Gas transmission: Sum of transport and distribution
Biomass burning: Sum of deforestation and savannah burning.
Enteric fermentation: Emissions from ruminants

Figures 6.2.1/2: Share in global total anthropogenic emissions of CH_4, split according to source categories (A) and regions (B).

A.



B.

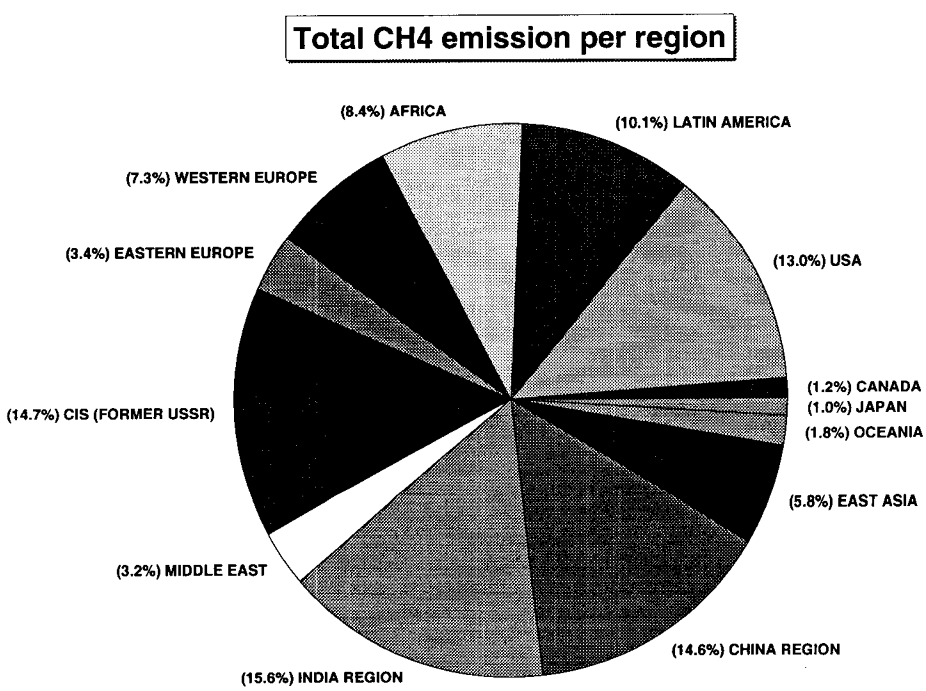
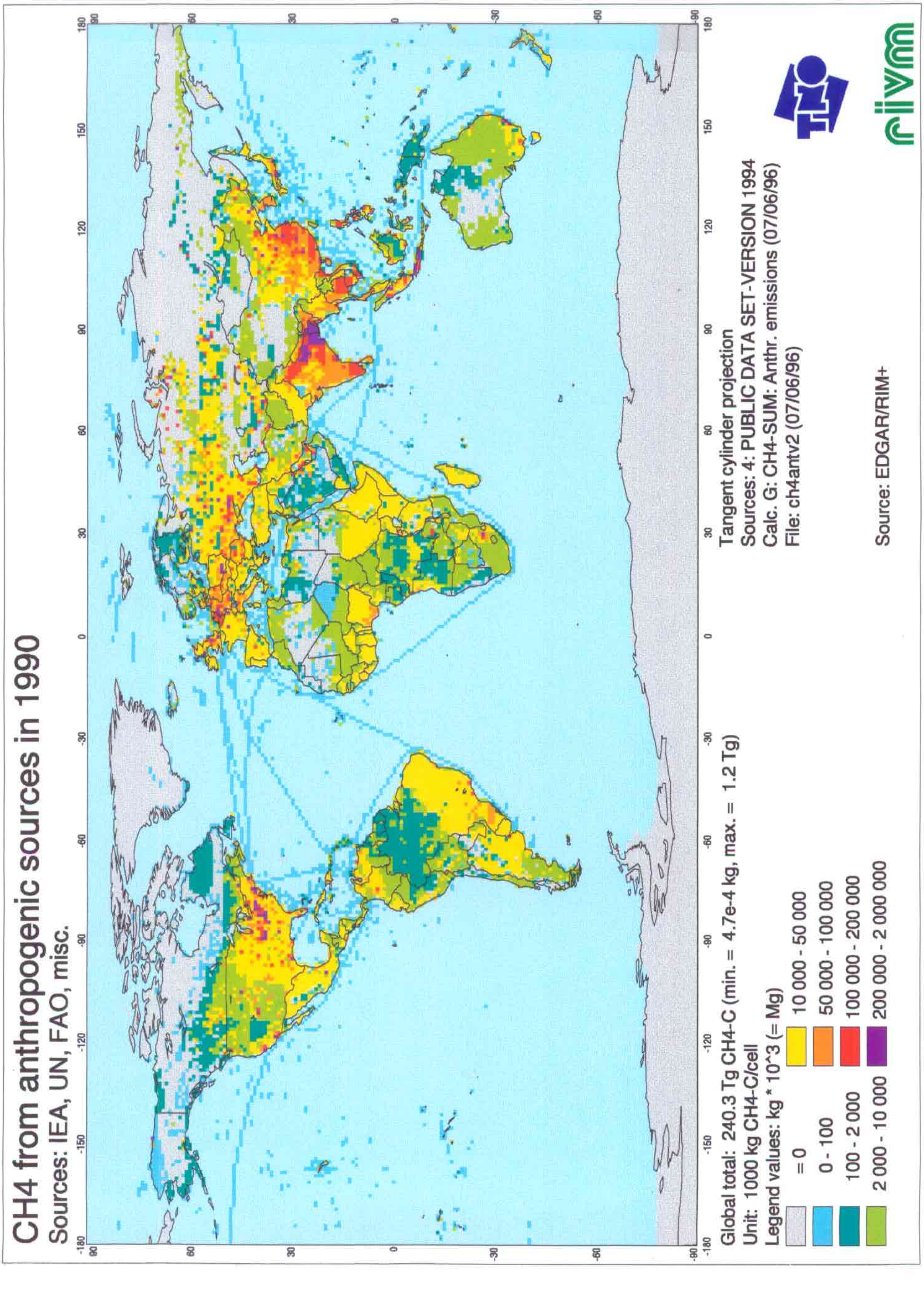


Figure 6.2.3: Global distribution of CH_4 emissions from all anthropogenic sources in 1990.



6.3 Nitrous oxide (N_2O)

The results for N_2O of the calculations of all anthropogenic sources are presented in Table 6.3.1. The total emissions in 1990 of these sources are 5.0 Tg N_2O or 3.2 Tg N_2O-N, including emissions related to the post-burning effects of deforestation. Most emissions are related to land use and waste treatment: about 3/4 of the total stems from fertilizer use on arable lands, animal excreta and from biomass burning (predominantly deforestation, as we include an estimate of post-burning emissions of 0.4 Tg N_2O-N). Industrial processes account for 14% and the remainder is mainly related to fuel combustion.

The total emissions are graphically presented in Figures 6.3.1 and 6.3.2, where we made a split in contributions by source and by region. Figure 6.3.3 shows the total N2O emissions from all sources on a 1°x1° grid. Because of the high fraction of emissions from agriculture and other land use sources, it is not surprising that the India, Latin America and China regions have the highest shares in the regional split. The second largest group consists of OECD Europe, Africa, USA and the former USSR, which all contribute about 10% in anthropogenic N_2O emissions. Other regions have relatively small emissions.

When we compare our anthropogenic emission estimates with the IPCC(1992) inventory for 1990 we get the following picture:

Source	EDGAR (Tg N)	IPCC (Tg N)
Fossil fuels	0.2	0.4 (0.3-0.9)
Biofuels	0.1	0.1
Adipic acid	0.3	0.5 (0.4-0.6)
Nitric acid	0.2	0.2 (0.1-0.3)
Arable lands	1.0	2.2 (0.03-3.0) [1)]
Animal excreta	1.0	- (-)
Biomass burning	0.2	0.5 (0.2-1.0)
Post-burning effects	0.4	- (-)
Global total	3.2	3.9

[1)] Including a background emission of about 0.9.

From this comparison it can be concluded that, given the high degree of uncertainty of these N_2O emissions, our estimates per source category compare rather well with the global totals estimated by IPCC. Emissions from arable lands (due to fertilizer use) also fall within the uncertainty range of IPCC, although the IPCC estimate includes the fertilizer-induced N_2O emission only. Emissions from animal excreta were not recognized by IPCC (1992), and were included in the second assessment on the basis of this study. For a more extensive validation we refer to Bouwman *et al.* (1995). Summarizing, we conclude that the EDGAR data correspond well with the IPCC estimates.

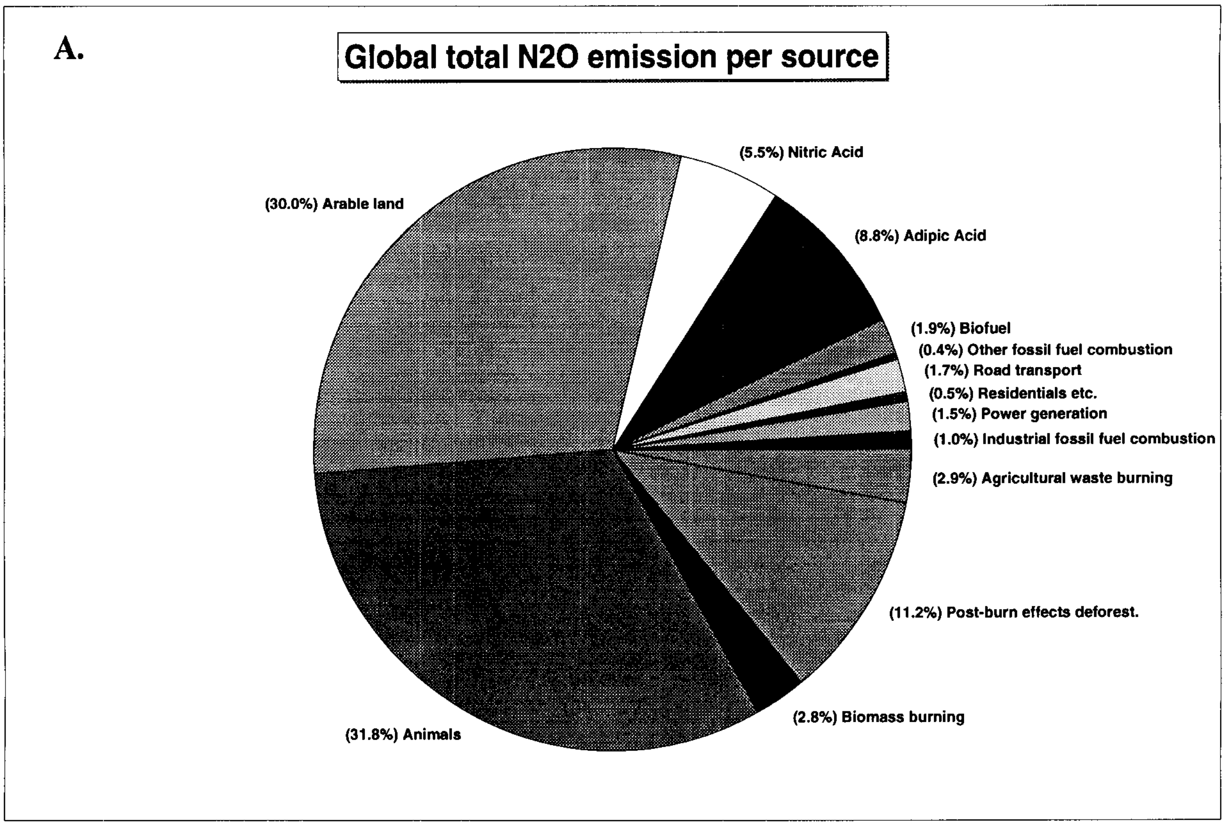
Table 6.3.1: Global anthropogenic emissions of N_2O per region and source in 1990 (Gg N_2O-N).

Global anthropogenic N2O emissions in 1990
Unit: Gg N2O-N

Source/sub-sector	TOTAL	CAN.	USA	LAT. AM.	AFRICA	W. EUR.	E. EUR.	CIS	M. EAST	INDIA+	CHINA+	E ASIA	OCEAN.	JAPAN	NT. SHIP
Total	**3214.2**	**50.5**	**353.7**	**462.1**	**357.7**	**366.2**	**122.8**	**294.3**	**85.1**	**400.0**	**501.2**	**134.7**	**50.0**	**34.0**	**1.9**
o.w.															
Fossil fuel	**165.9**	**4.8**	**60.3**	**4.5**	**4.0**	**20.9**	**6.9**	**17.5**	**3.4**	**5.2**	**22.0**	**3.4**	**2.4**	**8.7**	**1.9**
o.w. Industry	31.0	0.4	3.7	1.2	0.9	3.8	0.9	4.5	0.5	1.9	10.0	1.0	0.2	2.0	0.0
o.w. Power generation	49.6	0.8	15.3	0.8	2.0	7.7	3.7	7.0	0.7	2.2	6.1	0.8	1.1	1.3	0.0
o.w. Other Transf. Sector	4.9	0.1	1.0	0.3	0.1	1.1	0.8	0.4	0.3	0.1	0.3	0.1	0.1	0.2	0.0
o.w. Residentials etc.	17.5	0.2	1.8	0.6	0.3	3.0	1.1	3.4	1.0	0.3	4.4	0.7	0.1	0.6	0.0
o.w. Road transport	55.8	3.1	37.1	1.5	0.5	4.6	0.4	1.1	0.7	0.4	0.6	0.6	0.8	4.4	0.0
o.w. Non-road land transport	2.1	0.1	0.3	0.1	0.0	0.2	0.0	0.6	0.0	0.1	0.5	0.1	0.0	0.1	0.0
o.w. Air (domestic + intern.)	2.9	0.1	1.2	0.1	0.1	0.5	0.0	0.4	0.2	0.0	0.1	0.1	0.1	0.1	0.0
o.w. International shipping	1.9														1.9
Biofuel	**60.3**	**0.7**	**3.9**	**4.5**	**11.5**	**1.5**	**0.2**	**0.5**	**1.5**	**16.0**	**13.8**	**5.9**	**0.3**	**0.0**	**0.0**
o.w. Industry	8.6	0.6	2.8	0.5	0.5	1.3	0.2	0.4	0.1	1.0	0.4	0.7	0.1	0.0	0.0
o.w. Residentials etc.	51.6	0.1	1.1	4.0	11.0	0.2	0.0	0.1	1.4	15.1	13.4	5.2	0.1	0.0	0.0
Industrial processes	**458.3**	**20.7**	**90.2**	**21.1**	**5.0**	**122.5**	**40.4**	**58.3**	**7.5**	**19.5**	**48.6**	**12.4**	**0.6**	**11.5**	**0.0**
o.w. Adipic Acid	282.3	14.8	66.7	14.1	0.0	99.7	29.4	29.4	0.0	0.0	14.1	4.7	0.0	9.4	0.0
o.w. Nitric Acid	176.0	5.9	23.5	7.0	5.0	22.9	11.0	28.9	7.5	19.5	34.4	7.6	0.6	2.1	0.0
Landuse/waste treatment	**2529.7**	**24.3**	**199.2**	**432.0**	**337.3**	**221.3**	**75.4**	**218.0**	**72.7**	**359.2**	**416.8**	**113.0**	**46.7**	**13.7**	**0.0**
o.w. Arable land	963.4	14.5	126.8	47.2	26.3	129.8	41.9	109.2	30.8	123.1	257.8	42.0	6.2	7.7	0.0
o.w. Animals	1021.3	8.0	64.7	177.9	137.6	83.7	31.6	99.8	34.8	185.1	129.1	23.8	39.6	5.6	0.0
o.w. Biomass burning	90.7	0.0	0.0	29.5	52.3	0.0	0.0	0.0	0.0	2.8	2.0	4.1	0.0	0.0	0.0
o.w. Post-burn effects def.	360.9	0.0	0.0	169.3	112.3	0.0	0.0	0.0	0.1	26.1	16.3	36.9	0.0	0.0	0.0
o.w. Agricultural waste burning	93.4	1.9	7.8	8.0	8.7	7.7	1.9	9.0	7.0	22.2	11.6	6.1	0.9	0.5	0.0

Note: Other Transf. Sector: Notably refineries, coke ovens, blast furnaces, etc., including fuel combustion for fuel extraction.
Arable land: Emissions due to fertilizers use, excluding background emission of N2O of about 0.9 Tg N globally.
Animals: Animal waste
Biomass burning: Sum of deforestation and savannah burning.
Post-burn effects: Delayed emissions related to deforestation.
Natural emissions: Natural soils: global total emissions 6.6 Tg N2O-N (including 1.4 Tg N2O-N background emissions from grasslands).
Oceans: global total net emissions 3.6 Tg N2O-N (net, i.e. including negative oceanic sinks).

Figures 6.3.1/2: Share in global total anthropogenic emissions of N_2O, split according to source categories (A) and regions (B).



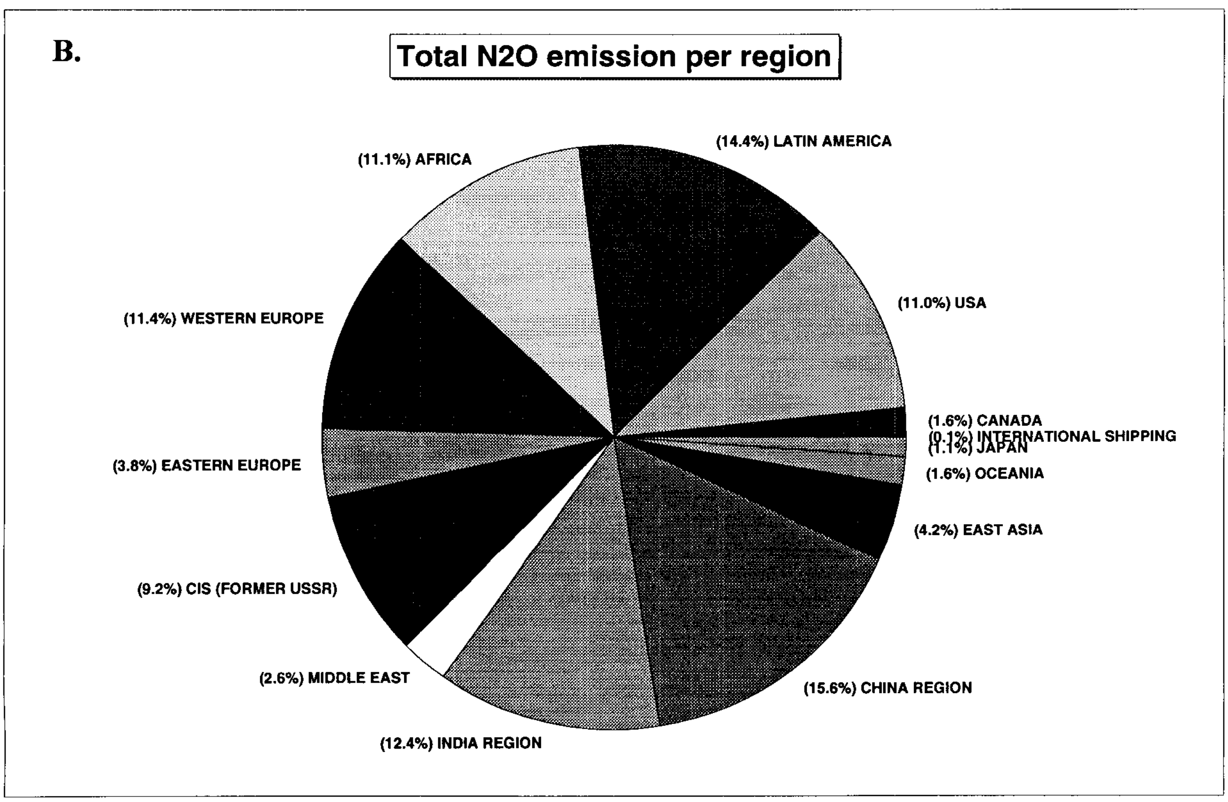
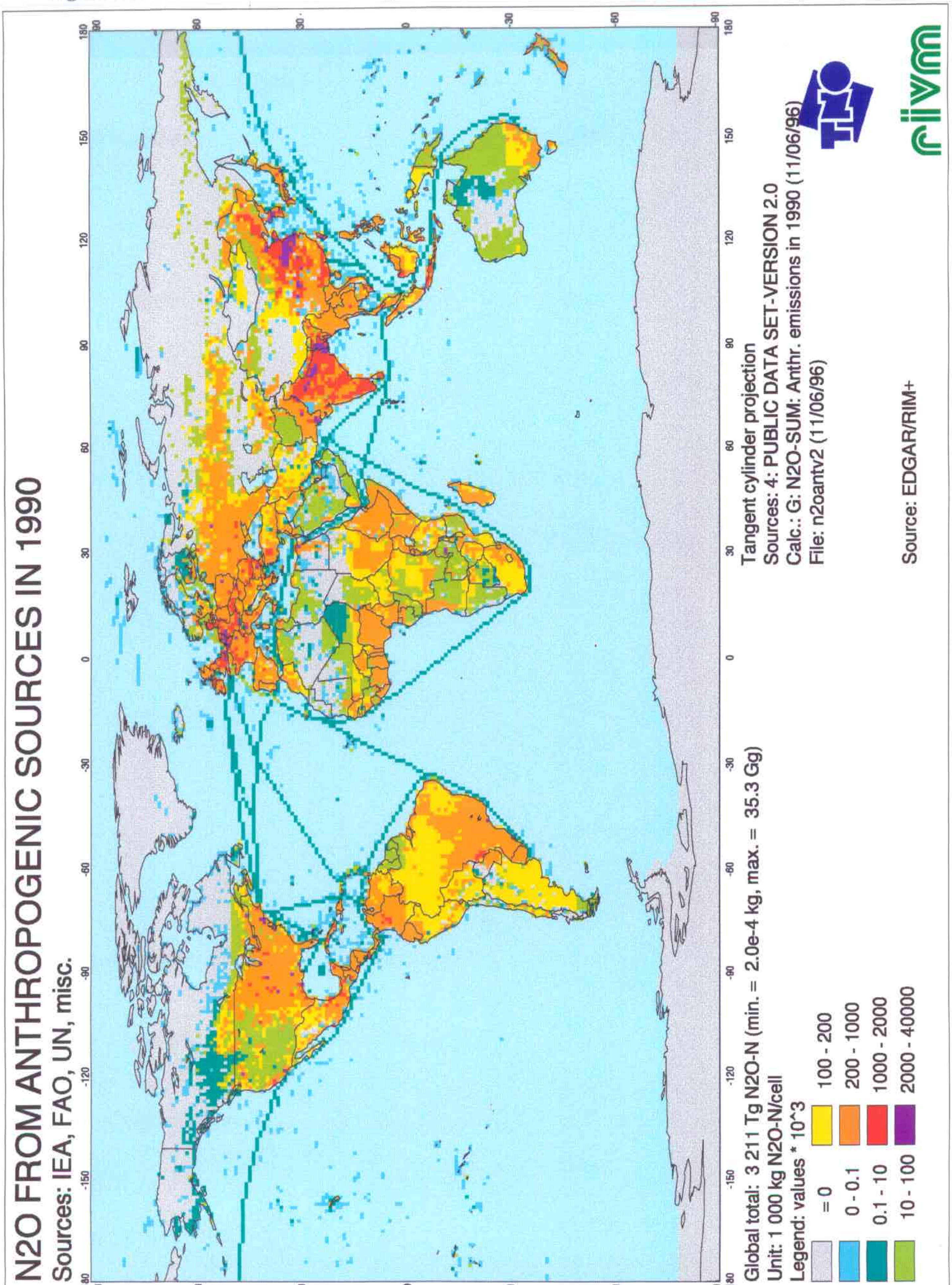


Figure 6.3.3: Global distribution of N_2O emissions from all anthropogenic sources in 1990.



6.4 Carbon monoxide (CO)

The results from the EDGAR calculations for CO are arranged in Table 6.4.1. In the EDGAR database the global total for anthropogenic CO emissions amounts to 974 Tg for 1990. This figure is consistent with the about 1020 Tg reported by IPCC (1992). As shown in Figures 6.4.1 and 6.4.2, the major part of the global anthropogenic CO emission stems from agricultural waste burning, savannah burning and deforestation. Also, road transport and biofuel use are major CO contributors. As a result of this, roughly 1/4 of the global CO emissions occur in Africa, for which the activity levels for savannah burning are the highest of all regions. Figure 6.4.3 shows the total CO emissions from anthropogenic sources on a 1°x1° grid. Comparison with the IPCC inventory (1992 and 1995) results in the following:

Source	EDGAR (Tg)	IPCC (Tg)
Biomass burning	677 [1)]	693 (300-700) [1)]
Energy production and use	297	303 (300-550)
Wildfires	-	30
Global total	974	1026

[1)] Including about 180 Tg for biofuel use.

For biomass burning as well as for energy use, the EDGAR emission estimates are in good agreement with the IPCC inventory, in particular when taking account of the rather large uncertainty estimates involved.

Table 6.4.1: Global anthropogenic emissions of CO per region and source in 1990 (Tg CO)

Global anthropogenic CO emissions in 1990
Unit: Tg CO

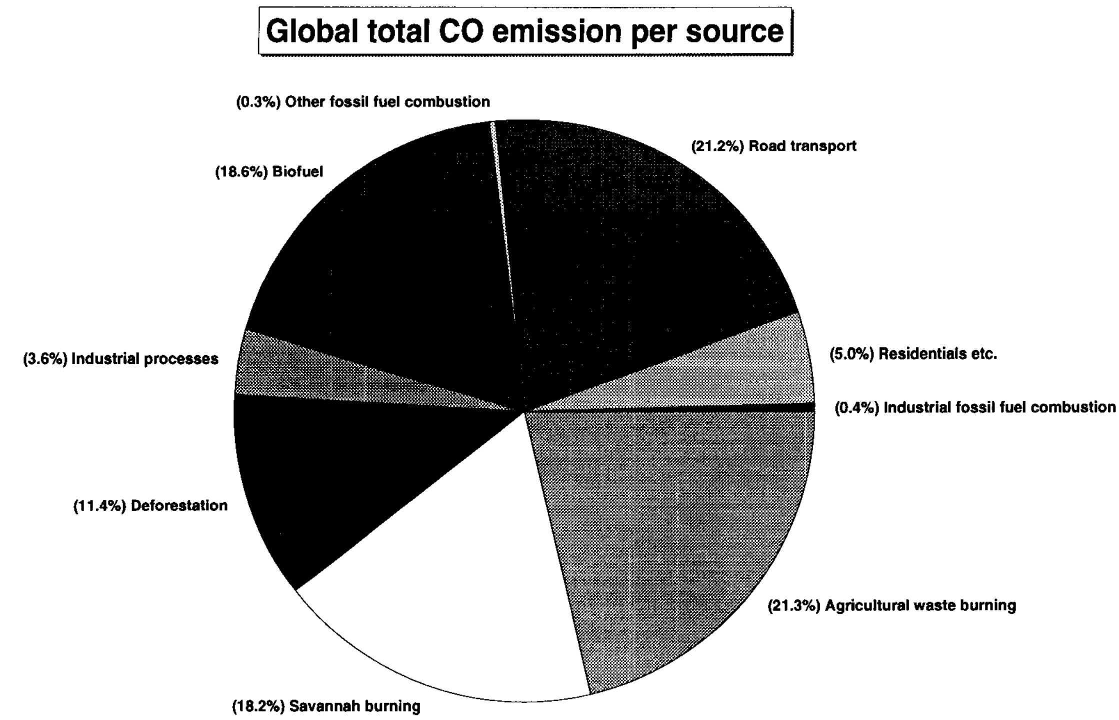
Source/sub-sector	TOTAL	CAN.	USA	LAT. AM.	AFRICA	W. EUR.	E. EUR.	CIS	M. EAST	INDIA+	CHINA+	E ASIA	OCEAN.	JAPAN	INT. SHIP
Total	**974.3**	**10.9**	**95.1**	**148.5**	**239.2**	**68.5**	**16.9**	**65.6**	**32.3**	**110.0**	**111.5**	**57.0**	**6.8**	**11.8**	**0.1**
o.w.															
Fossil fuel	**262.6**	**5.6**	**68.0**	**22.4**	**8.3**	**43.2**	**10.1**	**35.2**	**11.9**	**3.9**	**34.4**	**9.7**	**3.9**	**6.0**	**0.1**
o.w. Industry	4.1	0.0	0.4	0.1	0.1	0.3	0.1	0.7	0.1	0.3	1.6	0.1	0.0	0.2	0.0
o.w. Power generation	1.3	0.0	0.3	0.0	0.1	0.2	0.1	0.3	0.0	0.1	0.1	0.0	0.0	0.1	0.0
o.w. Other Transf. Sector	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
o.w. Residentials etc.	48.7	0.0	1.8	0.2	0.5	5.7	3.7	11.1	0.8	0.2	22.5	1.9	0.1	0.1	0.0
o.w. Road transport	206.7	5.4	64.8	22.0	7.6	36.7	6.3	22.9	10.9	3.3	9.9	7.6	3.8	5.6	0.0
o.w. Non-road land transport	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
o.w. Air (domestic + intern.)	1.4	0.0	0.6	0.1	0.0	0.2	0.0	0.2	0.1	0.0	0.0	0.1	0.0	0.1	0.0
o.w. International shipping	0.1														0.1
Biofuel	**181.0**	**0.8**	**7.7**	**13.1**	**44.6**	**2.0**	**0.4**	**0.8**	**4.2**	**47.2**	**40.1**	**19.4**	**0.5**	**0.0**	**0.0**
o.w. Industry	10.8	0.6	3.8	0.7	0.6	1.5	0.2	0.5	0.1	1.3	0.6	0.6	0.1	0.0	0.0
o.w. Residentials etc.	170.2	0.2	3.9	12.4	44.0	0.5	0.1	0.2	4.1	45.9	39.5	18.8	0.4	0.0	0.0
Industrial processes	**34.8**	**0.3**	**2.1**	**1.4**	**0.4**	**6.1**	**2.3**	**9.7**	**0.7**	**0.8**	**4.7**	**1.2**	**0.3**	**4.7**	**0.0**
o.w. Iron & steel	34.7	0.3	2.1	1.4	0.4	6.1	2.3	9.7	0.7	0.8	4.7	1.2	0.3	4.7	0.0
o.w. Aluminium	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Landuse/waste treatment	**495.9**	**4.2**	**17.3**	**111.6**	**185.8**	**17.2**	**4.2**	**19.9**	**15.6**	**58.1**	**32.3**	**26.7**	**2.0**	**1.1**	**0.0**
o.w. Deforestation	111.4	0.0	0.0	52.3	34.7	0.0	0.0	0.0	0.0	8.0	5.0	11.4	0.0	0.0	0.0
o.w. Savannah burning	177.0	0.0	0.0	41.5	131.7	0.0	0.0	0.0	0.0	0.7	1.4	1.6	0.0	0.0	0.0
o.w. Agricultural waste burning	207.6	4.2	17.3	17.9	19.4	17.2	4.2	19.9	15.6	49.4	25.9	13.7	2.0	1.1	0.0

Note: Other Transf. Sector: Notably refineries, coke ovens, blast furnaces, etc., including fuel combustion for fuel extraction. The CO emissions from this sector are the sum of combustion and non-combustion emissions.

Iron & steel: Sum of sinter, pig iron and crude steel production.

Figures 6.4.1/2: Share in global total anthropogenic emissions of CO, split according to source categories (A) and regions (B).

A.



B.

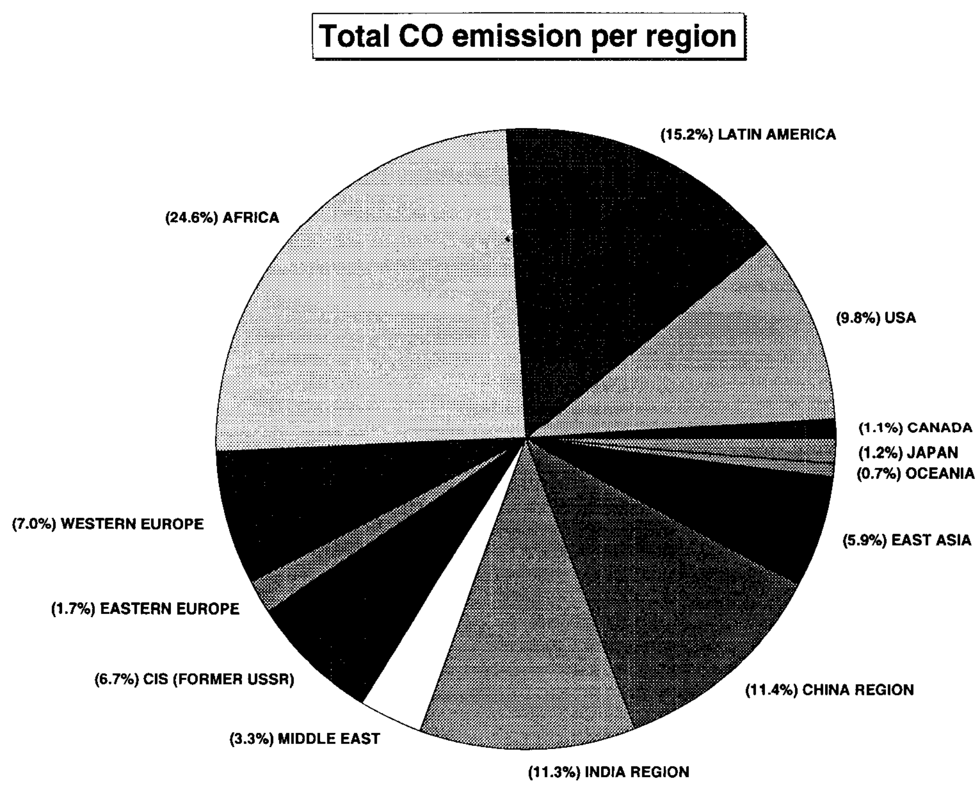
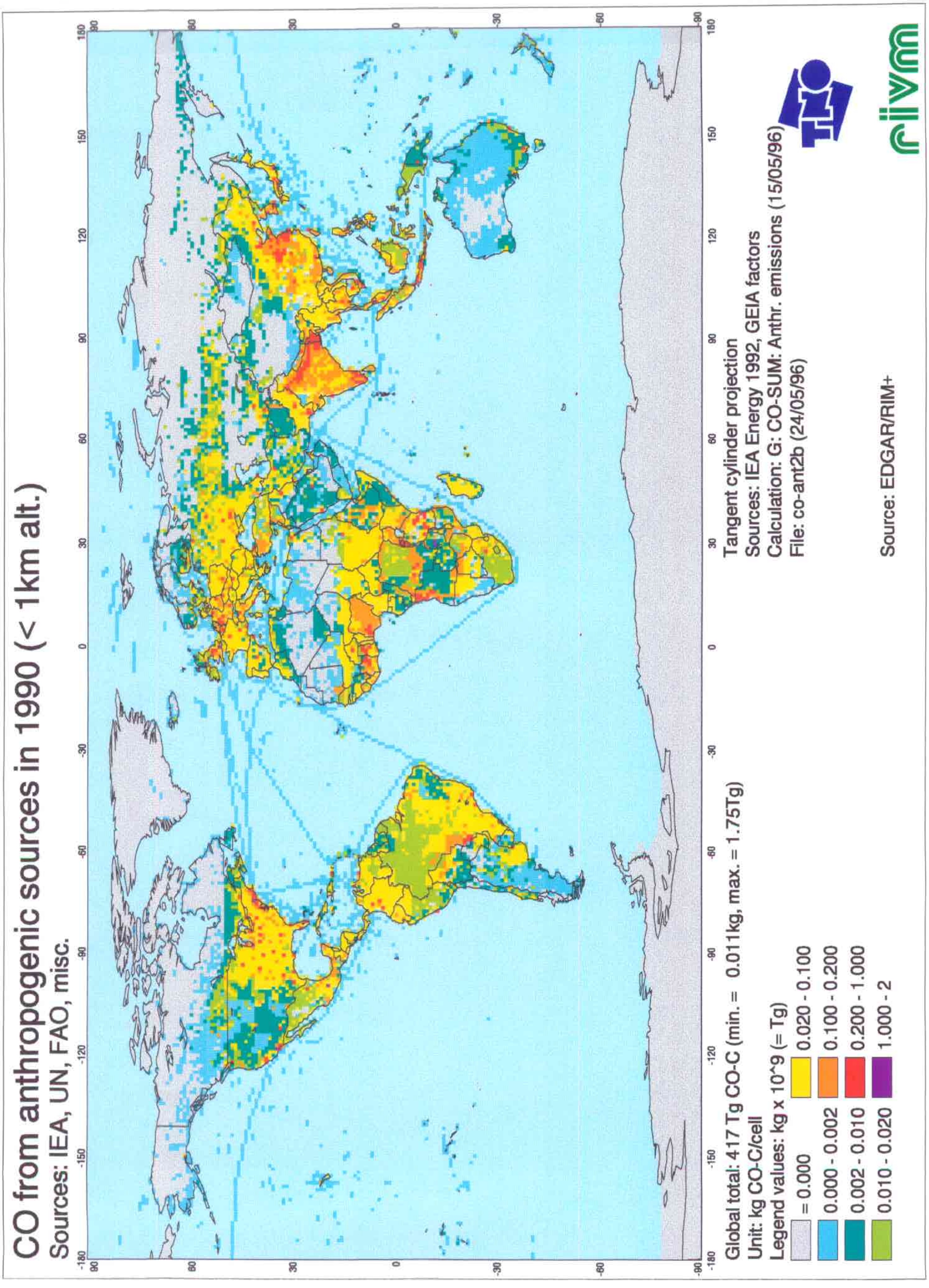


Figure 6.4.3: Global distribution of CO emissions from all anthropogenic sources in 1990.



6.5 Nitrogen oxides (NO_x)

The results for NO_x from the EDGAR database are represented in Table 6.5.1. Globally, the emission total for NO_x is consistent with the IPCC (1990) total (102 vs. 111 Tg). From the pie charts presented in Figures 6.5.1 and 6.5.2 it is clear that for anthropogenic NO_x emissions fossil fuel combustion (especially road transport and power generation) and biomass burning are the dominating emission sources. Hence, regions with either a high energy consumption, such as the USA, OECD Europe and the former USSR, or regions where large amounts of biomass are burned, such as Africa, Latin America or China, are the major contributors. In addition, Figure 6.5.3 shows the total NO_x emissions from anthropogenic sources on a 1°x1° grid

Comparison with the IPCC (1992) yields the following picture:

Source	EDGAR (Tg)	IPCC (Tg)
Energy production and use	77 [1]	82 (57-107)
Biomass burning	25 [2]	29 (8-43) [2]
Global total	102	111

[1] Including industrial processes.
[2] Including 5.1 and 7.6 Tg for biofuels for EDGAR and IPCC, respectively.

The results of the independently realized NO_x inventories from EDGAR and the IPCC (1990) show a good consistency for energy production and use as well as for biomass burning.

On a regional level, differences become more pronounced, as can be observed when looking at Asian regions. Grouping of the data per source category also reveals substantial differences as shown in Table 6.5.2, where we compare the results of this study with data of Kato *et al.* (1992). The differences in emissions can be largely traced back to different assumptions for the amount of biomass fuel use in different categories and more differentiation in vehicle fleets. In addition, some differences in emission factors and increased fuel consumption in 1990 can explain some of the differences. A similar comparison was made for emissions in Europe in Table 6.5.3, where we compare our results with data from the preliminary CORINAIR'90 inventory (McInnes, 1995, pers. comm.) and from Berlyand (1990).

Table 6.5.2: Comparison of NO_x emissions in Asia by region and by sector (Tg NO_2)

Asia: regional split	EDGAR ('90)	Kato *et al.* ('87)	E/K
China region	9.4	8.5	1.1
India region	5.9	3.0	2.0
East Asia	3.4	2.0	1.7
Japan	2.8	1.9	1.5
Asia: sectoral split	**EDGAR ('90)**	**Kato *et al.* ('87)**	**E/K**
Electricity generation	4.4	4.1	1.1
Industrial combustion	4.6	5.4	0.9
Non-industrial combustion	1.4	2.1	0.7
Road transport	4.0	2.8	1.4
Other transport	0.6	1.1	0.5

Table 6.5.3: Comparison of NO_x emissions in Europe by region and by sector (Tg NO_2)

Regional split:	EDGAR ('90)	CORINAIR[1]	Berlyand	E/C, E/B
OECD Europe	13.2	13.80		0.96
Eastern Europe	2.4	3.93		0.63
CIS[2]	10.9		6.8[3]	1.60
Sectoral split:	**EDGAR ('90)**	**CORINAIR[1]**	**Berlyand**	**E/C, E/B**
* **OECD Europe:**				
Electricity generation	2.19	2.49		0.88
Industrial combustion	1.58	1.70		0.98
Non-industrial combustion	0.65	0.52		1.25
Road transport	6.70	6.97		0.96
* **Eastern Europe:**				
Electricity generation	0.77	1.27		0.61
Industrial combustion	0.43	0.74		0.58
Non-industrial combustion	0.11	0.24		0.46
Road transport	0.67	0.88		0.76
* **CIS [2]:**				
Electricity generation and industrial combustion	7.26		4.77	1.52
Road transport	1.85		2.05	0.90

[1] Excluding Switzerland.

[2] Including Asian territory.

[3] 'Industry' and automobiles.

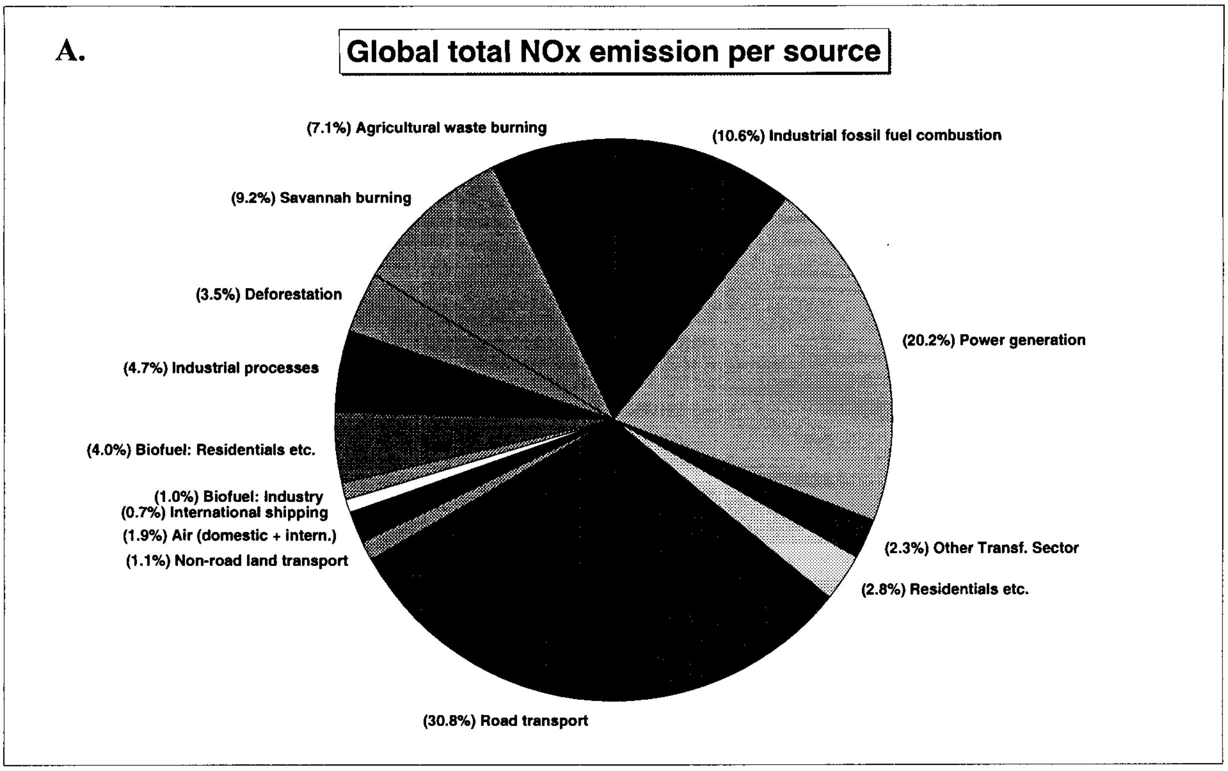
Table 6.5.1: Global anthropogenic emissions of NO_x per region and source in 1990 (Tg NO_2)

Global anthropogenic NOx emissions in 1990
Unit: Gg NO2

Source/sub-sector	TOTAL	CAN.	USA	LAT. AM.	AFRICA	W. EUR.	E. EUR.	CIS	M. EAST	INDIA+	CHINA+	E ASIA	OCEAN.	JAPAN	INT. SHIP
Total	**102183**	**1913**	**24065**	**9037**	**12247**	**13171**	**2432**	**10883**	**3191**	**5947**	**10785**	**3642**	**1366**	**2751**	**753**
o.w															
Fossil fuel	**71997**	**1653**	**22695**	**3960**	**2428**	**11560**	**2017**	**9407**	**2243**	**2596**	**7147**	**2014**	**1233**	**2292**	**753**
o.w Industry	10877	154	2587	359	240	1163	343	1951	169	554	2697	210	90	360	0
o.w Power generation	20655	304	6445	490	949	2186	765	4167	452	1011	2749	415	450	272	0
o.w Other Transf. Sector	2325	63	502	177	69	423	90	319	155	51	187	100	28	161	0
o.w Residentials etc.	2839	65	504	96	45	654	112	537	153	42	436	86	12	97	0
o.w Road transport	31519	982	11689	2710	1069	6701	675	1854	1209	857	849	1092	596	1237	0
o.w Non-road land transport	1124	40	177	41	7	115	15	345	5	55	184	34	20	87	0
o.w Air (domestic + intern.)	1904	45	791	87	50	318	18	233	100	27	45	78	35	78	0
o.w International shipping	753														753
Biofuel	**5105**	**54**	**445**	**260**	**854**	**157**	**22**	**49**	**151**	**1134**	**1549**	**400**	**30**	**1**	**0**
o.w Industry	1005	50	378	58	55	146	20	45	6	132	49	53	12	0	0
o.w Residentials etc.	4101	4	67	202	799	11	2	4	144	1002	1500	8	19	0	0
Industrial processes	**4821**	**59**	**317**	**316**	**168**	**851**	**247**	**728**	**250**	**190**	**944**	**297**	**34**	**421**	**0**
o.w Iron & steel	959	5	32	43	5	193	65	224	9	16	152	46	10	159	0
o.w Chemicals	433	19	72	20	7	56	34	93	11	9	100	5	0	8	0
o.w Cement	3430	35	213	253	156	602	148	412	230	165	693	246	24	253	0
Landuse/waste treatment	**20260**	**148**	**608**	**4502**	**8797**	**604**	**146**	**699**	**547**	**2027**	**1145**	**931**	**69**	**37**	**0**
o.w Deforestation	3557	0	0	1668	1107	0	0	0	1	257	160	364	0	0	0
o.w Savannah burning	9417	0	0	2206	7009	0	0	0	0	37	77	88	0	0	0
o.w Agricultural waste burning	7286	148	608	628	681	604	146	699	546	1733	908	479	69	37	0

Note: Other Transf. Sector: Notably refineries, coke ovens, blast furnaces, etc., including fuel combustion for fuel extraction.
Iron & steel: Sum of sinter and crude steel production.
Chemicals: Sum of nitric acid and ammonia

Figures 6.5.1/2: Share in global total anthropogenic emissions of NO_x, split according to source categories (A) and regions (B).



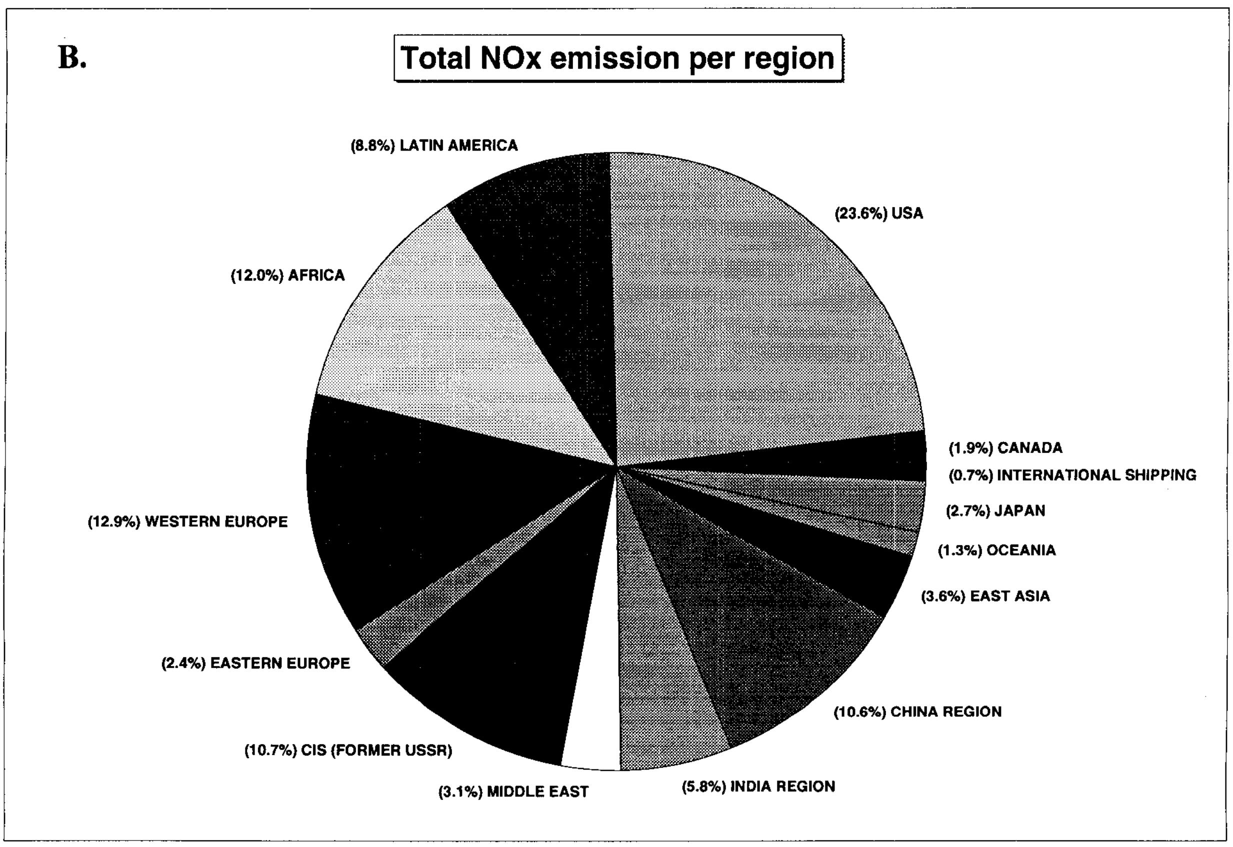
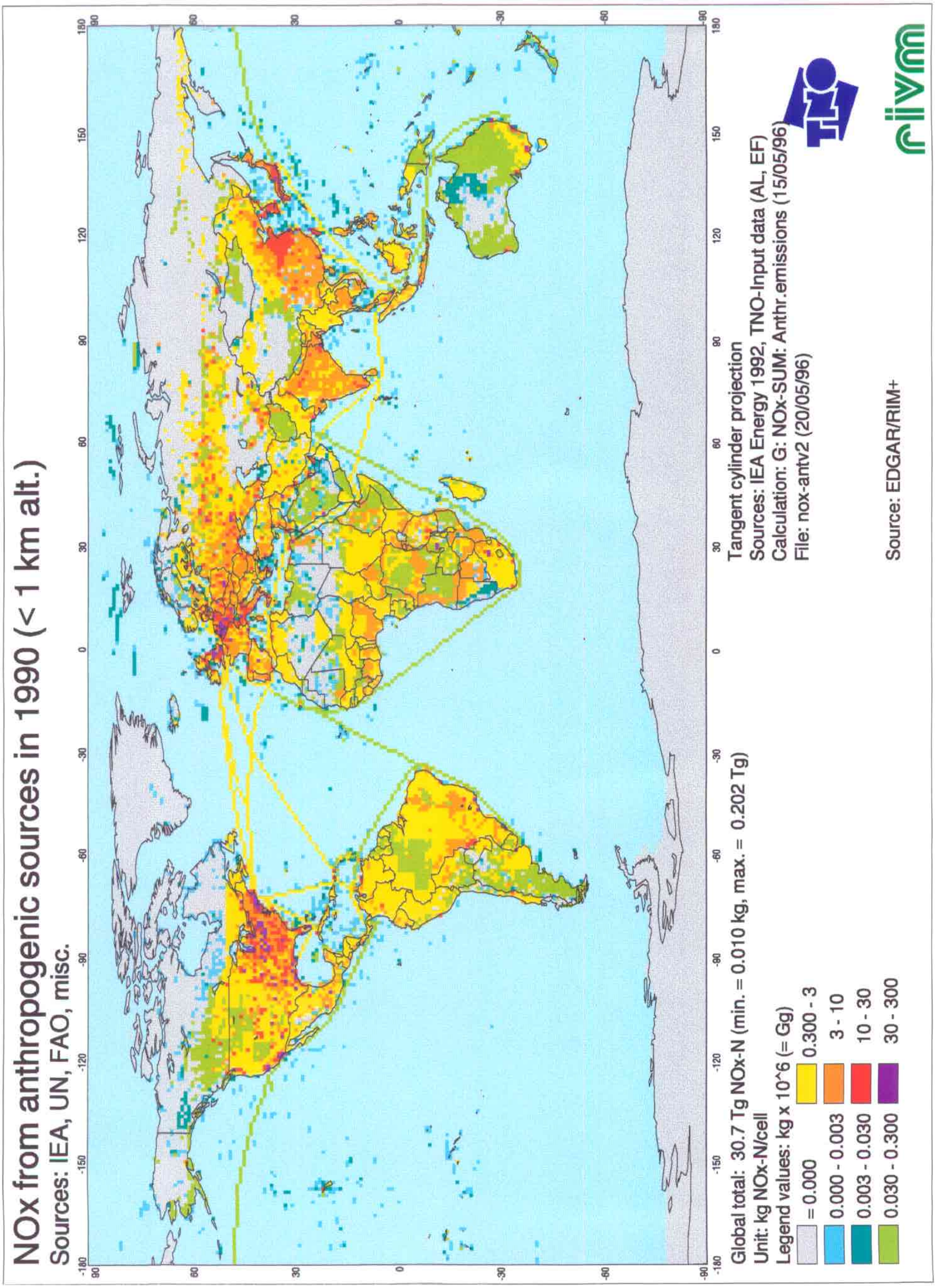


Figure 6.5.3: Global distribution of NO_x emissions from all anthropogenic sources in 1990.



6.6 Sulphur dioxide (SO_2)

The main features of the 1990 emissions are presented in Table 6.6.1, in which the regional emissions are reported per main region and per main category. The world total of EDGAR for SO_2 emissions in 1990 is 148 Tg SO_2. Industrial process sources of SO_2 emissions consist of metal production (copper, zinc, lead, iron, steel) and the production of H_2SO_4 and cement, of which more than half stem from primary and secondary copper production. Landuse emissions relate to large-scale biomass burning (savannah burning and deforestation) as well as local fires (agricultural waste burning).

It shows clearly from Figures 6.6.1 and 6.6.2 that of the total estimated emission of about 148 Tg SO_2, emissions from fossil fuel combustion (about 120 Tg SO_2) are responsible for more than 80% of the global total, of which more than half originates from the China, USA, OECD Europe and the former USSR regions. Industrial processes are the second important source, contributing 15% to total emissions, with the former USSR, OECD Europe and Latin America as the largest contributors. The smallest sources are landuse and biofuel use. In Figure 6.6.3 the total SO_2 emissions from all anthropogenic sources are presented on a 1°x1° grid

Comparison with the IPCC (1992) inventory results in the following:

Source	EDGAR (Tg)	IPCC (Tg)
Energy production and use	120	130 (140-160) [1)]
Industrial sources	23	16 (see above)
Biomass burning	5 [2)]	4 (2-5) [2)]
Global total	148	150

[1)] Uncertainty range of energy use includes industrial sources.
[2)] Including 1.6 and 1.2 Tg for biofuels for EDGAR and IPCC, respectively.

For energy production and use and for biomass burning, the EDGAR emission estimates are in good agreement with the IPCC inventory. The industrial sources are estimated in EDGAR to be 1/3 higher than these of the IPCC. However, we conclude that our global total for energy and industry is well within the specified uncertainty range.

Regionally, however, differences with other estimates can be larger, as is shown for Asia in Table 6.6.2. As was the case for NO_x, summing emissions per sector reveals some of the causes for these differences. Here, the largest difference occurs in the non-ferro metal production sector. The industrial combustion and transport sectors also show a substantial difference of 30%. The discrepancies in the non-ferro and industrial sectors are probably caused by differences in emission factors. In the transport sector, more differentiation in vehicle fleets in Kato *et al.* (1992) may explain the dissimilarities. In addition, the increased fuel consumption in 1990 should be taken into account. For Europe, we compared EDGAR results with the preliminary CORINAIR '90 inventory (McInnes, 1995, pers. comm.) (Table 6.6.3).

Table 6.6.1: Global anthropogenic emissions of SO_2 per region and source in 1990 (Tg SO_2)

Global anthropogenic SO2 emissions in 1990

Unit: Gg SO2

Source/sub-sector	TOTAL	CAN.	USA	LAT. AM.	AFRICA	W. EUR.	E. EUR.	CIS	M. EAST	INDIA+	CHINA+	E ASIA	OCEAN.	JAPAN	INT. SHIP
Total	**148495**	**2741**	**21826**	**9205**	**6928**	**22506**	**10831**	**23007**	**4810**	**4866**	**28292**	**5118**	**1531**	**1904**	**4930**
o.w															
Fossil fuel	**119594**	**2105**	**20684**	**4713**	**3459**	**17170**	**9225**	**17797**	**4359**	**4013**	**24970**	**3715**	**970**	**1484**	**4930**
o.w Industry	29556	292	2371	1469	896	3256	871	4747	922	1429	11494	1113	126	570	0
o.w Power generation	55848	1376	14373	1512	1841	8814	6812	8741	1420	1552	7243	1377	619	169	0
o.w Other Transf. Sector	10963	265	1967	1053	427	2006	376	1716	1040	320	868	604	126	195	0
o.w Residentials etc.	13199	75	798	334	170	2245	1066	2194	816	145	4733	451	24	151	0
o.w Road transport	4001	89	1088	334	116	808	87	211	151	459	145	160	61	293	0
o.w Non-road land transport	925	4	16	4	5	12	12	167	1	106	483	3	13	100	0
o.w Air (domestic + intern.)	173	4	72	8	5	29	2	21	9	2	4	7	3	7	0
o.w International shipping	4930														4930
Biofuel	**1635**	**383**	**47**	**35**	**135**	**439**	**3**	**5**	**28**	**183**	**279**	**53**	**48**	**0**	**0**
o.w Industry	955	383	38	9	6	437	2	5	2	18	5	7	44	0	0
o.w Residentials etc.	680	0	8	26	129	2	0	1	26	165	274	45	4	0	0
Industrial processes	**23409**	**228**	**990**	**3574**	**1595**	**4793**	**1578**	**5083**	**329**	**311**	**2838**	**1177**	**501**	**413**	**0**
o.w Iron & steel	868	3	20	38	0	173	60	214	7	15	143	42	9	145	0
o.w Non-ferro: Copper	12267	94	227	2655	1254	2198	920	2671	171	39	1100	655	255	26	0
o.w Non-ferro: Lead	740	13	45	71	32	221	50	152	3	5	93	20	31	5	0
o.w Non-ferro: Zinc	4206	49	36	250	64	1419	255	896	0	49	724	283	172	9	0
o.w Chemicals	3499	50	549	425	161	461	214	930	26	115	408	46	20	94	0
o.w Cement	1829	19	114	135	83	321	79	220	122	88	369	131	13	135	0
Landuse/waste treatment	**3856**	**26**	**105**	**883**	**1740**	**105**	**25**	**121**	**95**	**359**	**205**	**173**	**12**	**6**	**0**
o.w Deforestation	712	0	0	334	221	0	0	0	0	51	32	73	0	0	0
o.w Savannah burning	1881	0	0	441	1400	0	0	0	0	7	15	18	0	0	0
o.w Agricultural waste burning	1263	26	105	109	118	105	25	121	95	300	157	83	12	6	0

Note: Other Transf. Sector: Notably refineries, coke ovens, blast furnaces, etc., including fuel combustion for fuel extraction.
Iron & steel: Sinter production.
Non-ferro: Sum of primary and secondary production.
Chemicals: H2SO4 production.

Table 6.6.2: Comparison of SO_2 emissions in Asia by region and by sector (Tg SO_2)

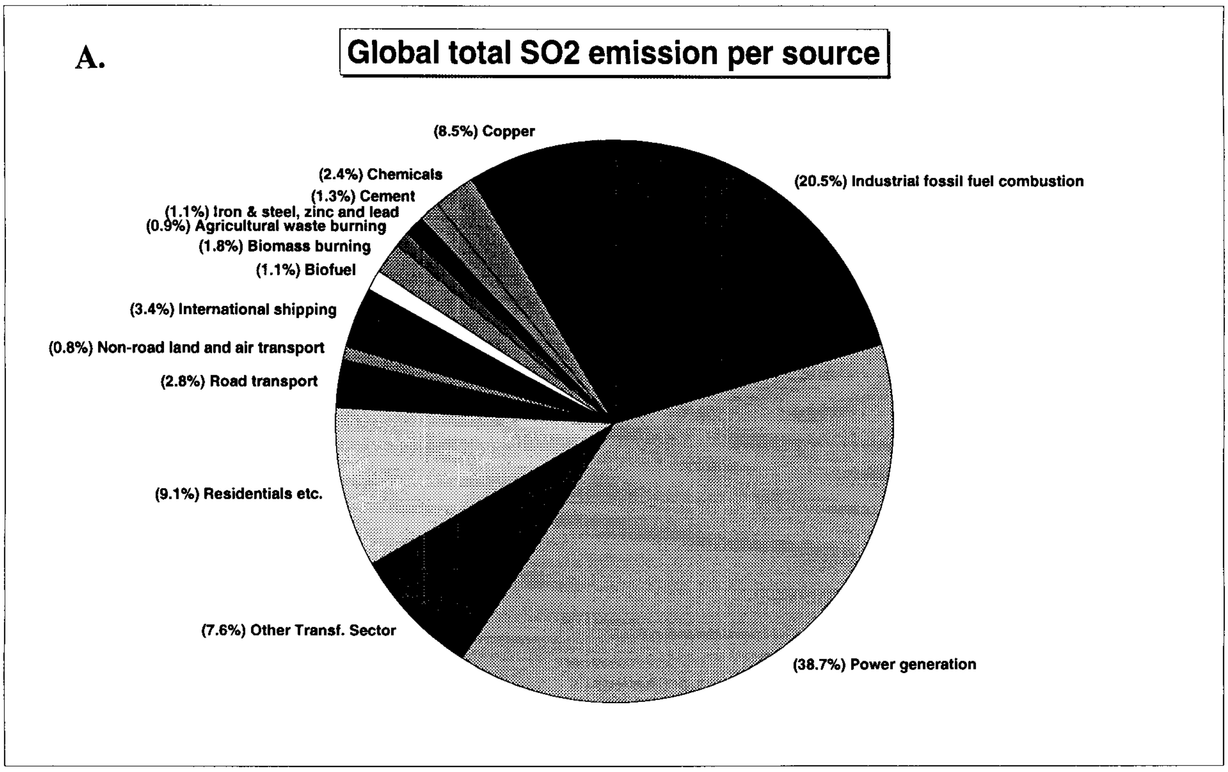
Asia: regional split	EDGAR ('90)	Kato et al. ('87)	E/K
China region	28.3	21.1	1.3
India region	4.86	3.57	1.4
East Asia	5.12	3.18	1.6
Japan	1.90	1.14	1.9
Asia: sectoral split	EDGAR ('90)	Kato et al. ('87)	E/K
Electricity generation	10.3	8.76	1.2
Industry	18.4	12.3	1.5
Non-ferro metal production	3.01	1.12	2.7
Road transport	1.06	0.70	1.5
Other transport	0.71	0.98	0.7
Non-industrial combustion	5.96	5.12	1.2

Table 6.6.3: Comparison of SO_2 emissions in Europe by region and by sector (Tg SO_2)

Europe: regional split	EDGAR ('90)	CORINAIR[1)]	Berlyand	E/C, E/B
OECD Europe	22.5	17.1		1.32
Eastern Europe	10.8	10.7		1.01
CIS[2)]	23.0		16.5[3)]	1.39
Europe: sectoral split	EDGAR ('90)	CORINAIR[1)]	Berlyand	E/C, E/B
* **OECD Europe:**				
Electricity generation	8.81	8.61		1.02
Industrial combustion	5.27	4.97		1.06
Non-industrial combustion[4)]	2.24		1.29	1.74
* **Eastern Europe:**				
Electricity generation	6.81	6.34		1.07
Industrial combustion	1.24	2.00		0.62
Non-industrial combustion[4)]	1.07	1.76		0.61
* **CIS [2)]:**				
Electricity generation and industrial combustion	16.18		16.5	0.98

[1)] Excluding Switzerland.
[2)] Including Asian territory.
[3)] 'Industry'.
[4)] Including combustion of biomass fuels, municipal waste and black liquor in EDGAR.

Figures 6.6.1/2: Share in global total anthropogenic emissions of SO_2, split according to source categories (A) and regions (B).



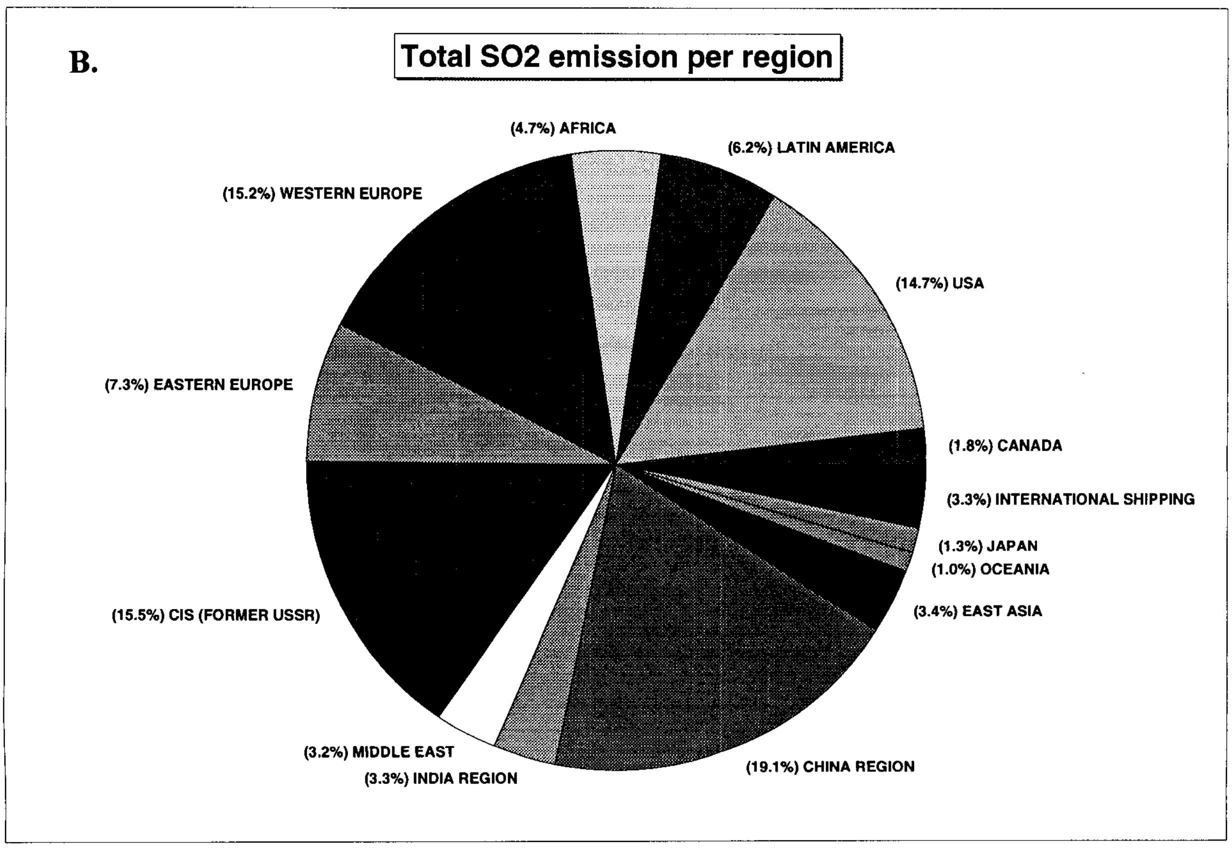
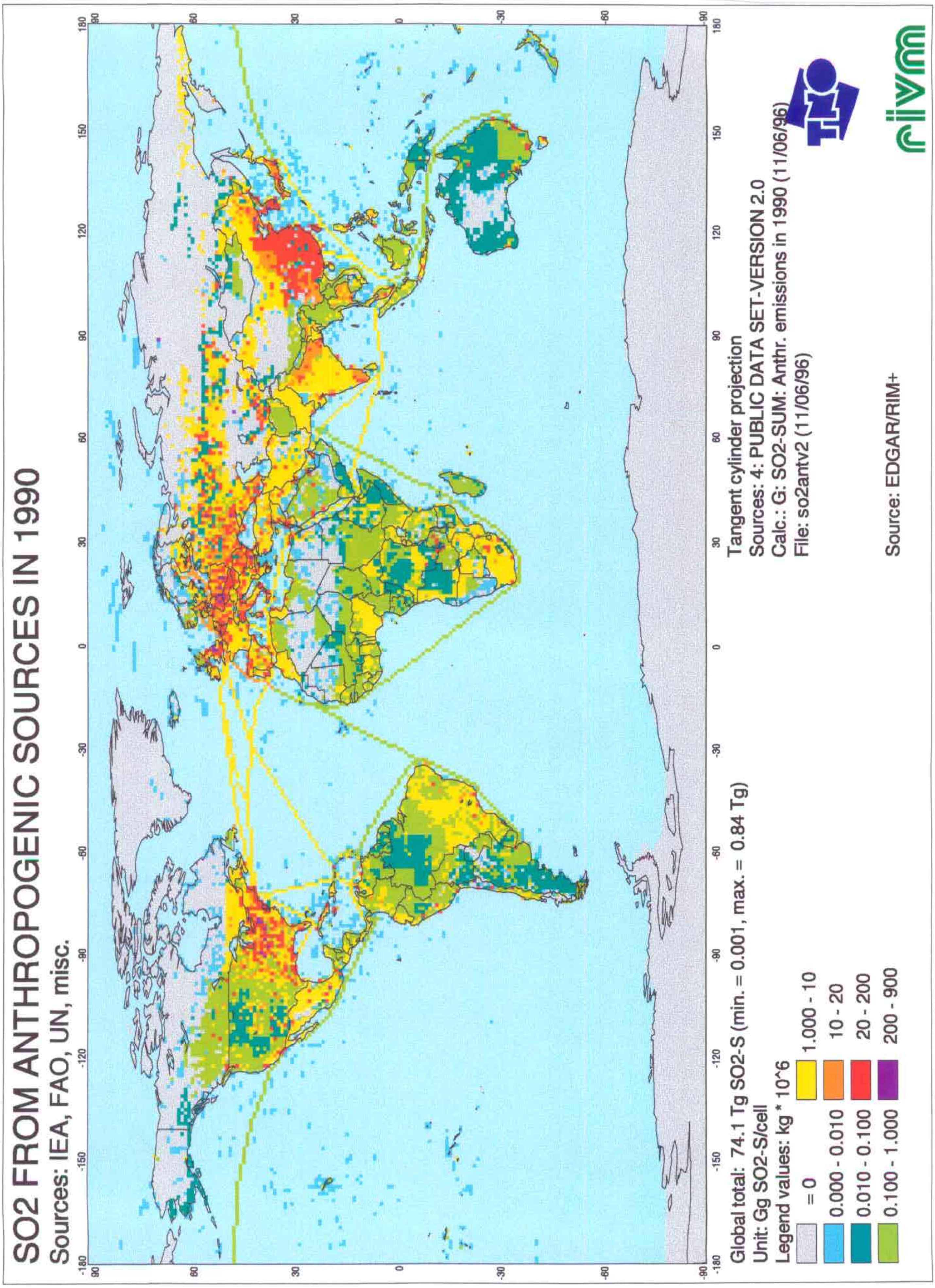


Figure 6.6.3: Global distribution of SO_2 emissions from all anthropogenic sources in 1990.



6.7 NMVOC and NMVOC profiles

The results of the the EDGAR calculations for NMVOC are represented in Table 6.7.1. The EDGAR NMVOC world total for 1990 is 178 Tg. This is higher than that of Veldt (1993), who reports 145 Tg for1990, and that of Piccot *et al.* (1992), who report 110 Tg for 1985. Our total is almost 50% higher than the IPCC figure for 1990, which is 121 Tg. The reason for this difference is that in EDGAR the energy production and use category is much higher than that of the IPCC (see Table 6.7.4). Our figure is in compliance with the literature found on this category (Samaras, 1993; TNO-MW, 1990; Ebert *et al.* 1993; Arthur D. Little, 1989).

In the Tables 6.7.1 through 6.7.4, the NMVOC world total is split in different ways. In Tables 6.7.1 and 6.7.2 a regional split is made with some extra comment on which compounds (groups) are important (Table 6.7.1) or which source categories are important (Table 6.7.2). The dominating source categories in a region determine which compound groups are regionally important. In Tables 6.7.3 and 6.7.4 our results are compared with those of the IPCC.

Table 6.7.1: Regional contribution to the global total NMVOC emissions: major compound groups

Region	%	Three most important compound groups
Africa	16.0	acids, alcohols & ethene
Asia excl. Japan	34.5	acids, hexanes+ & others
Japan	3.1	hexanes+, ethene & pentanes
Oceania	0.9	hexanes+, butanes & pentanes
Canada + USA	12.6	hexanes+, pentanes & butanes
Latin America	11.2	acids, hexanes+ & alcohols
Western Europe	10.1	hexanes+, pentanes & butanes
Eastern Europe	1.8	ethene, hexanes+ & ethane
Former USSR	9.8	hexanes+, butanes & pentanes

Table 6.7.2: Regional contribution to the global total NMVOC emissions: major sources

Region	%	Most important source categories
Africa	16.0	biomass burning, biofuels & oil production industry
Canada	1.7	road transport, oil production industry & solvent use
China region	10.4	biofuels, biomass burning & miscellaneous
Former USSR	9.8	oil production industry, road transport & solvent use
East Asia	6.3	biofuels, road transport & biomass burning
Eastern Europe	1.8	road transport, solvent use & biomass burning
India region	10.7	biofuels, biomass burning & miscellaneous
Japan	3.1	road transport & solvent use
Latin America	11.2	biomass burning, road transport & oil prod. industry
Middle East	7.1	oil prod. industry, road transport & biomass burning
Oceania	0.9	road transport, solvent use & oil production industry
Western Europe	10.1	road transport, solvent use & oil production industry
USA	10.9	road transport, solvent use & biomass burning

Table 6.7.3: The contribution of compound groups to the world total

Compound (group)	EDGAR (Tg)	IPCC (Tg)
Alcohols	11	[1])
Alkanes	67	56
Esters	2	[1])
Alkenes and alkynes	29	42
Chlorinated HC's	2	[1])
Aromatics	22	15 [2])
Ethers	4	[1])
Acids	19	[1])
Aldehydes	7	[1])
Ketones	3	[1])
Others and unknown	11 [3])	8
Global total	178	121

[1]) Included in 'Others and unknown'.
[2]) Only benzene, toluene and xylenes.
[3]) EDGAR sum of non-alkanes, non-alkenes and non-aromatics is 59 Tg.

Since our world NMVOC total (178 Tg) is much higher than that of the IPCC (121 Tg), differences will occur. One remarkable aspect is that our alkenes estimate is lower than that of the IPCC. The IPCC total for energy production and use (27 Tg) is too low in comparison with the EDGAR estimate. The transportation sector alone already has a higher NMVOC emission, but the oil and gas sectors also contribute substantially to fossil fuel related emissions. We believe that our recently compiled inventory, which is summarized per source and per region in Table 6.7.6, is likely to be more realistic than the IPCC estimate for this category. In Figures 6.7.1 and 6.7.2 the source and regional contributions are shown as pie charts. Figure 6.7.3 illustrates the total NMVOC emission from all anthropogenic sources on the $1^{o}x1^{o}$ grid.

Table 6.7.4: The contribution of source categories to the world total

Source category	EDGAR (Tg)	IPCC (Tg)	Dominant compound groups in EDGAR
Oil & gas production & refining	27	[1])	butanes, hexanes+ & propane
Large combustion plants	5	[1])	xylenes, hexanes+ & pentanes
Transport & gasoline distribution	35	27	hexanes+, pentanes & butanes
Solvent use	22	23	hexanes+, esters & chlorinated HC's
Chemical bulk products	1	[2])	unknown
Biomass burning (non-fuel use)	36	53	acids, alcohols & ethene
Biofuels	31	[3])	acids, alcohols & ethene
Other processes	20	18	unknowns, ethene & ethane
Global total	178	121	

[1]) Included in transport and gasoline distribution.
[2]) Included in solvent use.
[3]) Included in biomass burning.

Data with which a reliable comparison can be made are scarce. As an example, in Table 6.7.5 we compare the EDGAR results with CORINAIR '90 data for main contributing sources.

Table 6.7.5: The main contributions for NMVOC for European countries according to EDGAR and CORINAIR '90

	OECD Europe:			Eastern Europe:		
Sector	EDGAR	CORINAIR	E/C	EDGAR	CORINAIR	E/C
Road transport	7.39	6.60	1.12	1.00	0.69	1.45
Solvent use	4.77	4.19	1.14	0.75	0.66	1.14
Fossil fuel prod./distr.	1.80	1.15	1.57	0.30	0.21	1.43

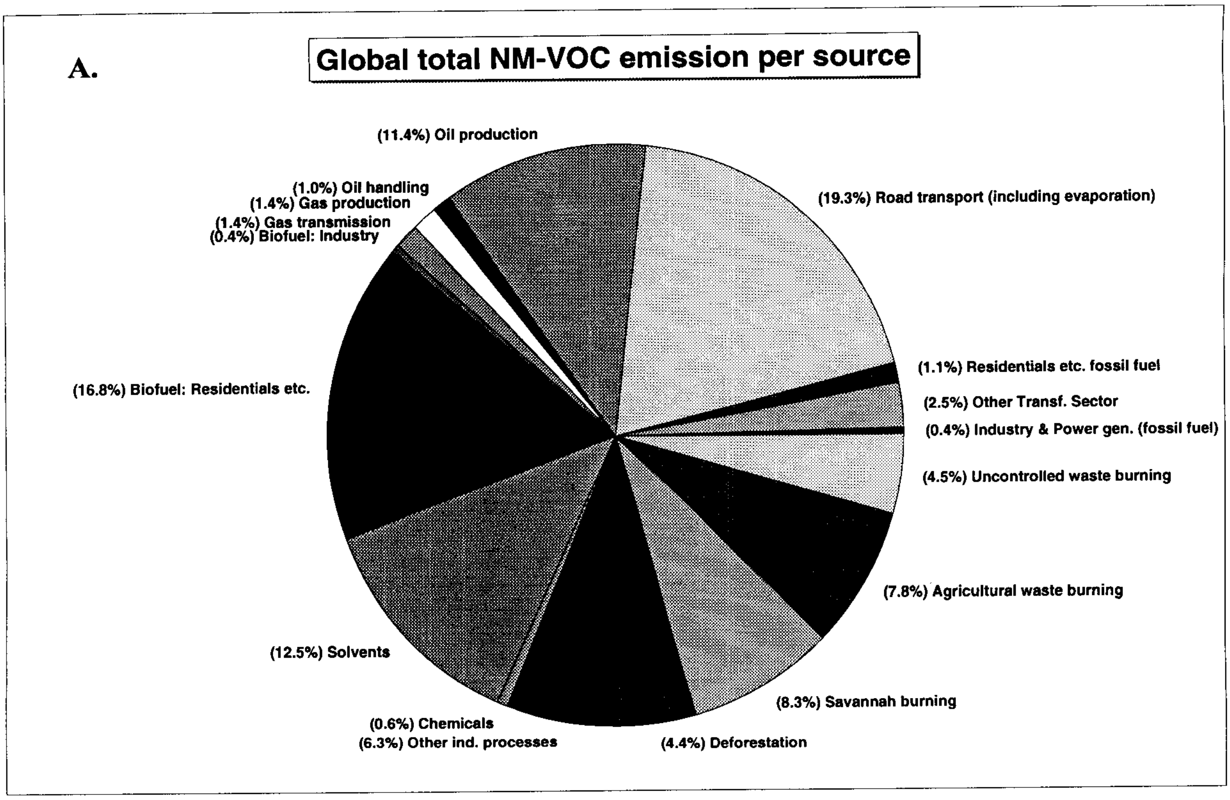
Table 6.7.6: Global anthropogenic emissions of total NMVOC per region and source in 1990 (Tg)

Global anthropogenic NM-VOC emissions in 1990
Unit: Tg

Source/sub-sector	TOTAL	CAN.	USA	LAT. AM.	AFRICA	W. EUR.	E. EUR.	CIS	M. EAST	INDIA+	CHINA+	E ASIA	OCEAN.	JAPAN	INT. SHIP
Total	**177.5**	**2.9**	**19.0**	**20.3**	**30.2**	**17.7**	**3.1**	**17.0**	**12.3**	**18.7**	**18.2**	**11.0**	**1.6**	**5.4**	**0.0**
o.w															
Fossil fuel: combustion	**41.6**	**1.2**	**8.8**	**3.7**	**1.4**	**8.1**	**1.3**	**5.3**	**2.0**	**1.2**	**2.7**	**2.5**	**0.8**	**2.5**	**0.0**
o.w Industry	0.6	0.0	0.1	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.2	0.0	0.0	0.0	0.0
o.w Power generation	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
o.w Other Transf. Sector	4.4	0.1	0.5	0.3	0.1	0.4	0.1	2.1	0.3	0.1	0.2	0.2	0.0	0.2	0.0
o.w Residentials etc.	2.0	0.0	0.1	0.0	0.0	0.3	0.1	0.4	0.0	0.0	0.9	0.1	0.0	0.0	0.0
o.w Road transport	34.4	1.2	8.2	3.4	1.2	7.4	1.0	2.7	1.7	1.1	1.4	2.2	0.8	2.3	0.0
o.w Non-road land transport	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
o.w Air (domestic + intern.)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
o.w International shipping	0.0														0.0
Fossil fuel: non-combustion	**27.3**	**0.8**	**1.4**	**3.1**	**2.8**	**1.8**	**0.3**	**6.9**	**7.4**	**0.3**	**1.2**	**1.0**	**0.3**	**0.0**	**0.0**
o.w Oil production	20.4	0.5	0.1	2.7	2.4	1.5	0.1	4.2	6.4	0.3	1.1	0.9	0.2	0.0	0.0
o.w Oil handling	1.9	0.0	0.0	0.2	0.3	0.2	0.0	0.2	0.8	0.0	0.0	0.1	0.0	0.0	0.0
o.w Gas production	2.6	0.1	0.6	0.1	0.1	0.1	0.1	1.4	0.1	0.0	0.0	0.1	0.0	0.0	0.0
o.w Gas transmission	2.4	0.1	0.7	0.1	0.0	0.1	0.1	1.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Biofuel	**30.7**	**0.1**	**0.9**	**2.3**	**8.3**	**0.2**	**0.0**	**0.1**	**0.7**	**8.5**	**6.3**	**3.3**	**0.1**	**0.0**	**0.0**
o.w Industry	0.8	0.0	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
o.w Residentials etc.	30.0	0.0	0.7	2.2	8.3	0.1	0.0	0.0	0.7	8.4	6.3	3.3	0.1	0.0	0.0
Industrial processes/solvents	**33.5**	**0.5**	**6.4**	**2.3**	**2.0**	**5.9**	**1.0**	**2.9**	**0.9**	**2.9**	**3.9**	**1.8**	**0.3**	**2.6**	**0.0**
o.w Solvents	22.2	0.4	5.6	1.4	0.7	4.8	0.8	2.3	0.6	0.8	1.5	1.0	0.2	2.1	0.0
o.w. Iron & steel	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
o.w Chemicals	1.0	0.0	0.3	0.0	0.0	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.0
o.w Miscellaneous industry	10.0	0.0	0.5	0.8	1.2	0.7	0.2	0.5	0.4	2.2	2.4	0.7	0.0	0.2	0.0
Landuse/waste treatment	**44.4**	**0.3**	**1.5**	**9.0**	**15.7**	**1.7**	**0.5**	**1.8**	**1.3**	**5.7**	**4.1**	**2.4**	**0.2**	**0.3**	**0.0**
o.w Deforestation	7.8	0.0	0.0	3.7	2.4	0.0	0.0	0.0	0.0	0.6	0.4	0.8	0.0	0.0	0.0
o.w Savannah burning	14.8	0.0	0.0	3.5	11.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0
o.w Agricultural waste burning	13.8	0.3	1.2	1.2	1.3	1.1	0.3	1.3	1.0	3.3	1.7	0.9	0.1	0.1	0.0
o.w. Uncontrolled waste burning	8.0	0.0	0.4	0.7	1.0	0.6	0.2	0.4	0.3	1.7	1.9	0.6	0.0	0.2	0.0

Note:Other Transf. Sector: Notably refineries, coke ovens, blast furnaces, etc., including fuel combustion for fuel extraction.
The NMVOC emissions from this sector are the sum of combustion and non-combustion emissions.
Road transport: Including evaporative emissions.
Oil handling: Tanker loading
Gas transmission: Sum of transport and distribution
Solvents: Sum of 11 solvent applications.
Iron & steel: Sum of sinter, pig iron, crude steel production, and mills.
Chemicals: Sum of production of bulk chemicals and specialties.
Miscellaneous industry Miscellaneous emissions, not attributable to a specific industrial sub-sector.
Deforestation&savannah burnin To comply with the GEIA NMVOC inventory, totals were calibrated to the totals calculated from the total biomass burning estimate by Andreae (1991).
Natural sources: Global total emission of reactive species from vegetation and oceans (not shown in this table) are estimated to be 1182 Tg NMVOC, when expressed as CH4 (or 890 Tg C).

Figures 6.7.1/2: Share in global total anthropogenic emissions of total NMVOC, split according to source categories (A) and regions (B).



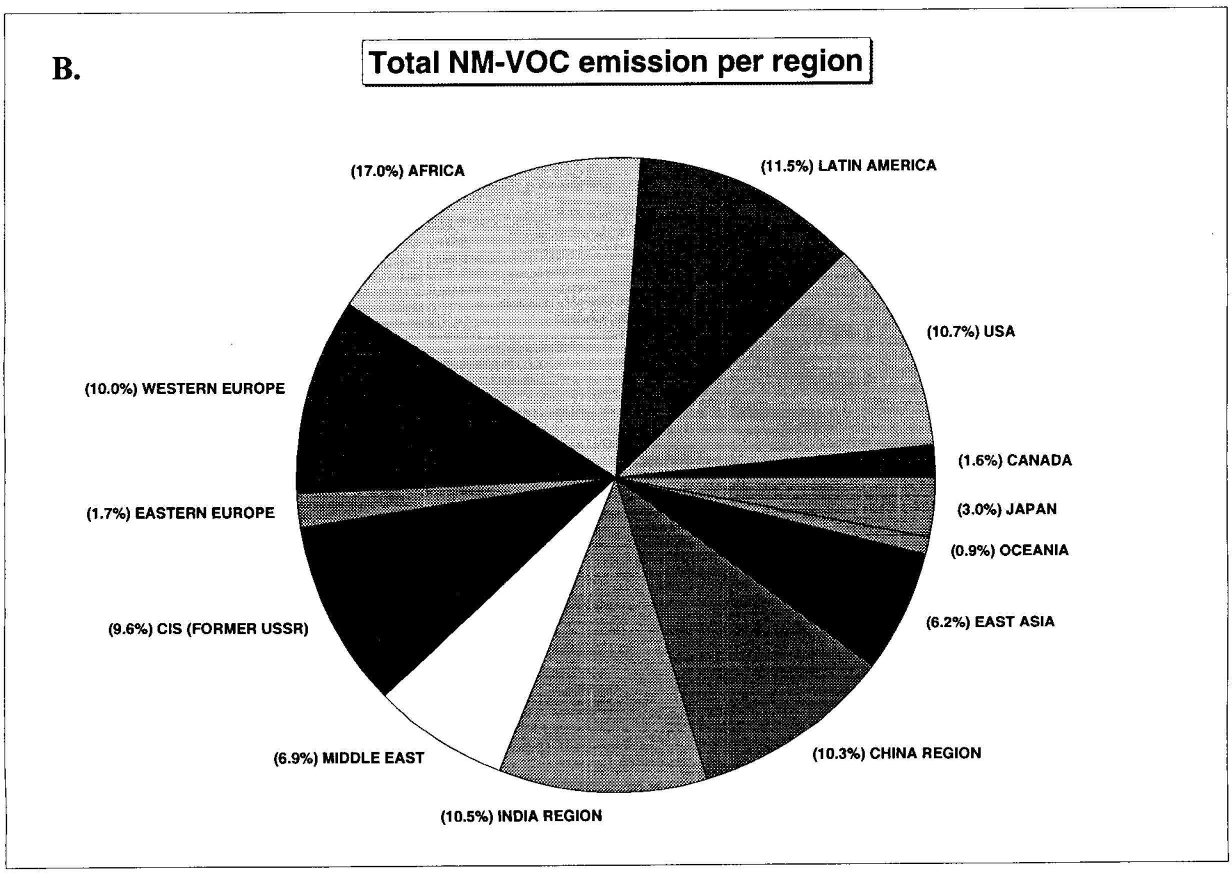
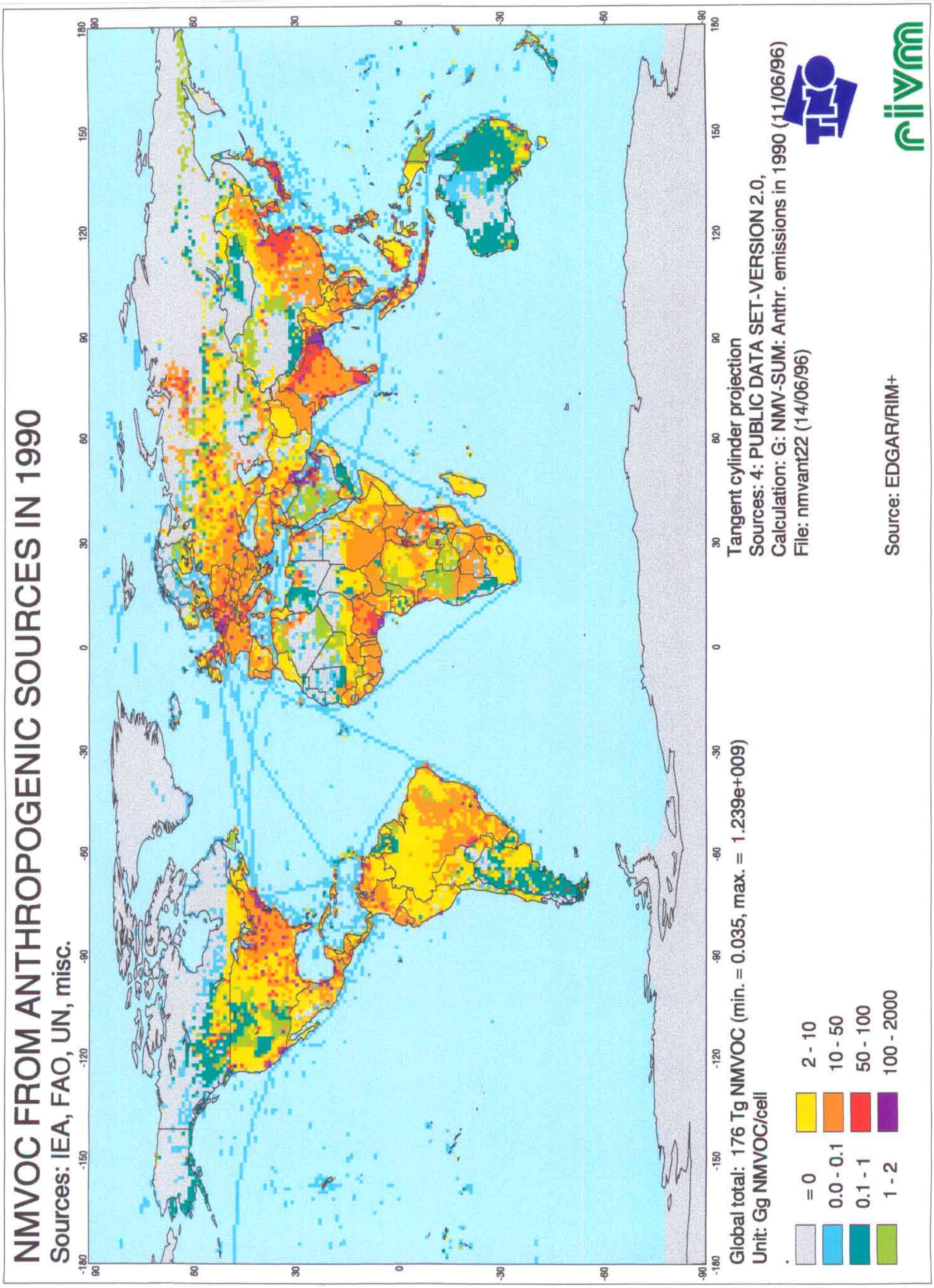


Figure 6.7.3: Global distribution of total NMVOC emissions from anthropogenic sources in 1990.



6.8 Halocarbons and related compounds

For halocarbons, production, consumption and emission estimates are made for time-series, based on well-known data sources with reported data, supplemented with an estimate for the non-reporting regions. Results are available per compound for these two groups. Figure 6.8.1 shows the historical development of global total halocarbon emissions for the period 1950-1990. The clear decrease in emissions of CFC-11 and CFC-12 and of CCl_4 after 1986 [and of methyl chloroform (MCF) after 1990, which is not shown here] is a result of the phase-out of CFC use as agreed upon in the Montreal Protocol.

For CFCs and methyl chloroform a per country estimate was made for the period 1980-1990. Table 6.8.1 shows the regional subdivision of the emissions of these compounds in 1986, whereas in Figure 6.8.2 the regional shares in halocarbon emissions are presented as pie charts. From the data presented here it can be concluded that there are large differences in regional shares for different compounds. While Europe and the USA are by far the largest source regions of halocarbon emissions in 1986, for CFC-113 and MCF Japan is also among the dominant source regions.

From the per country emissions of CFCs and MCF, gridded emissions can be derived using population density to distribute total country emissions. Figure 6.8.3 shows an example for CFC-11-equivalent emissions of CFCs in 1986. We note that emissions from international shipping (e.g. from refrigeration devices on food transport vessels) were not separately taken into account. Also, regional and gridded distributions of emissions in the years after 1986, the reference year for the Montreal Protocol, can be calculated only provisionally since countries do not respond to the phase-out described by the Montreal Protocol and its later revisions of London and Copenhagen in an uniform way. In fact, countries which are non-parties to the protocol will show a different consumption pattern than those which are parties.

Figure 6.8.1: Historical development of global total halocarbon emissions.

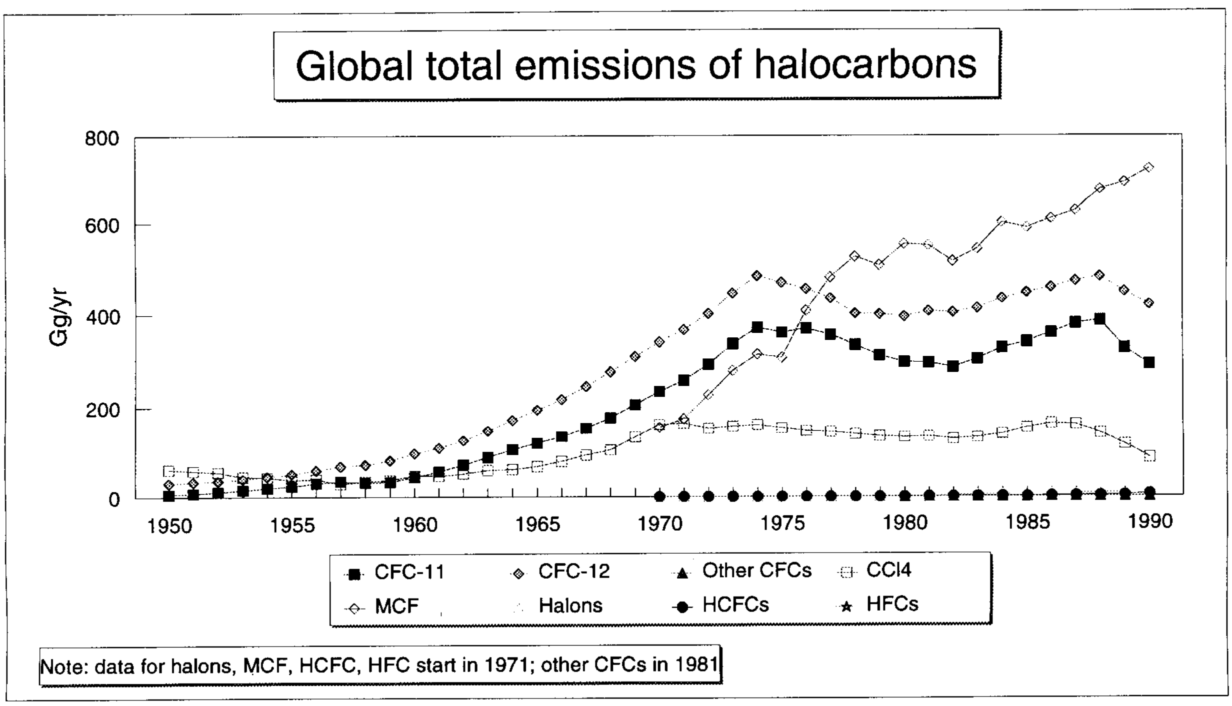


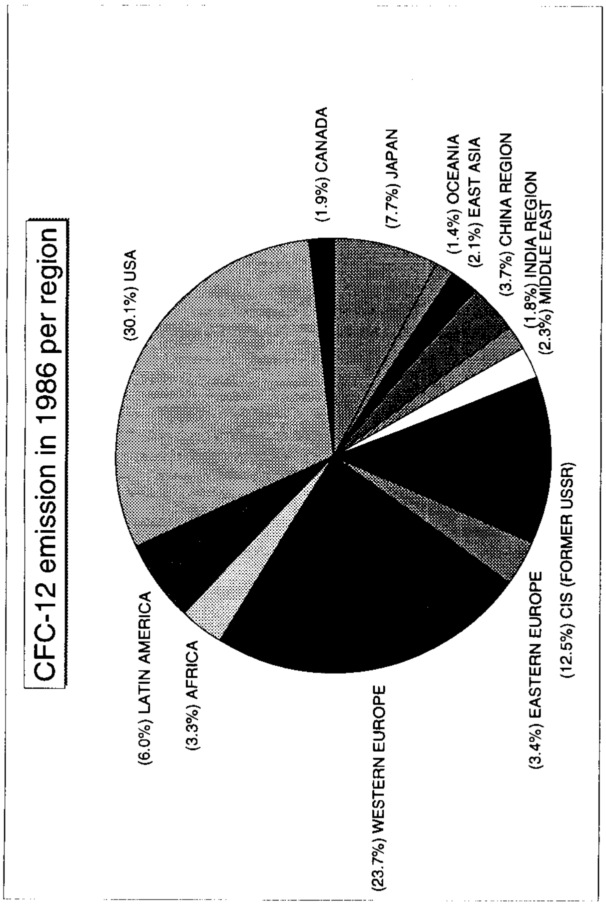
Table 6.8.1: Global anthropogenic emissions of CFC-11, 12, 113, 114, 115 and of MCF in 1986 by region and by compound (Gg)

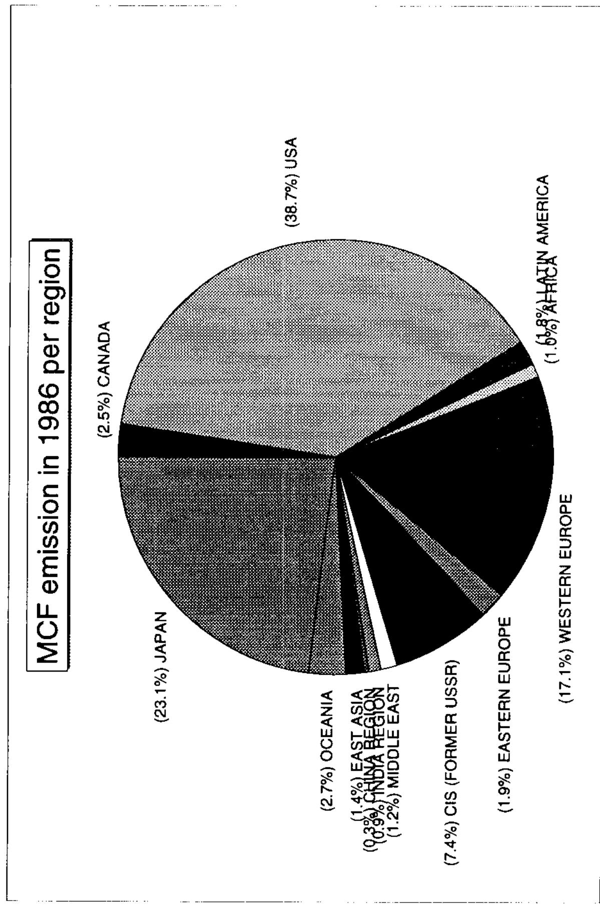
Global anthropogenic emissions of selected halocarbons in 1986.

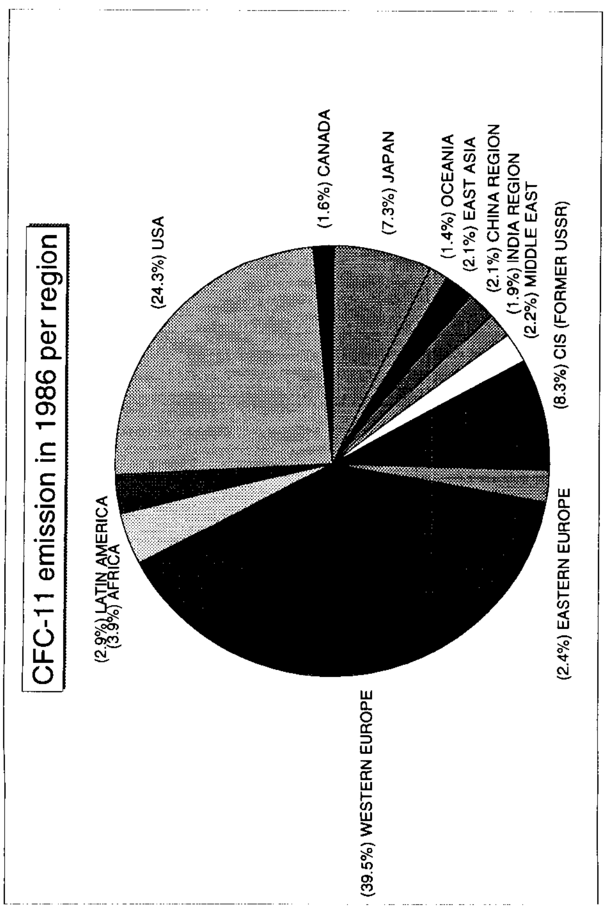
Compound	Unit	TOTAL	CAN.	USA	LAT. AM.	AFRICA	W. EUR.	E. EUR.	CIS	M. EAST	INDIA+	CHINA+	E. ASIA	OCEAN.	JAPAN
Total	**Gg**	**1413.4**	**29.2**	**455.8**	**49.0**	**35.0**	**352.1**	**35.6**	**130.9**	**25.8**	**20.3**	**26.7**	**25.7**	**27.5**	**199.6**
o.w. CFC-11	Gg	358.5	5.6	87.1	10.5	14.1	141.7	8.6	29.8	8.0	6.7	7.7	7.7	5.1	26.2
o.w. CFC-12	Gg	457.4	8.8	137.7	27.6	15.0	108.4	15.5	57.1	10.7	8.3	17.0	9.5	6.3	35.4
o.w. CFC-113	Gg	202.8	3.6	55.9	2.2	2.7	39.6	4.8	16.4	5.5	4.7	4.2	5.4	3.5	54.2
o.w. CFC-114	Gg	18.9	0.3	4.6	0.3	1.5	6.4	0.2	0.5	0.5	0.4	2.1	0.4	0.3	1.5
o.w. CFC-115	Gg	11.1	0.3	4.4	0.2	1.5	2.6	0.1	0.2	0.3	0.2	1.1	0.2	0.1	0.1
o.w. MCF	Gg	597.1	14.8	231.0	11.0	5.9	101.9	11.5	44.0	7.0	5.3	2.0	8.5	16.1	138.0

Note: As reference year for this table 1986 is used instead of 1990, since the regional development of per country emissions is not available (only provisional estimates based on GNP developments).
Emissions from international shipping (e.g.from refrigeration) are included in national, thus regional, emission estimates.
The total is the direct sum of the regional emissions included in the table, i.e. not weighted according to the Ozone Depleting Potential of each compound.
For other halocarbons (halons, CTC, HCFCs, HFCs, methyl bromide) no subdivision per country/region is available.

Figures 6.8.2: Share in global total emissions of CFC-11, 12, 113, 114, 115 and of MCF in 1986, split according to region.







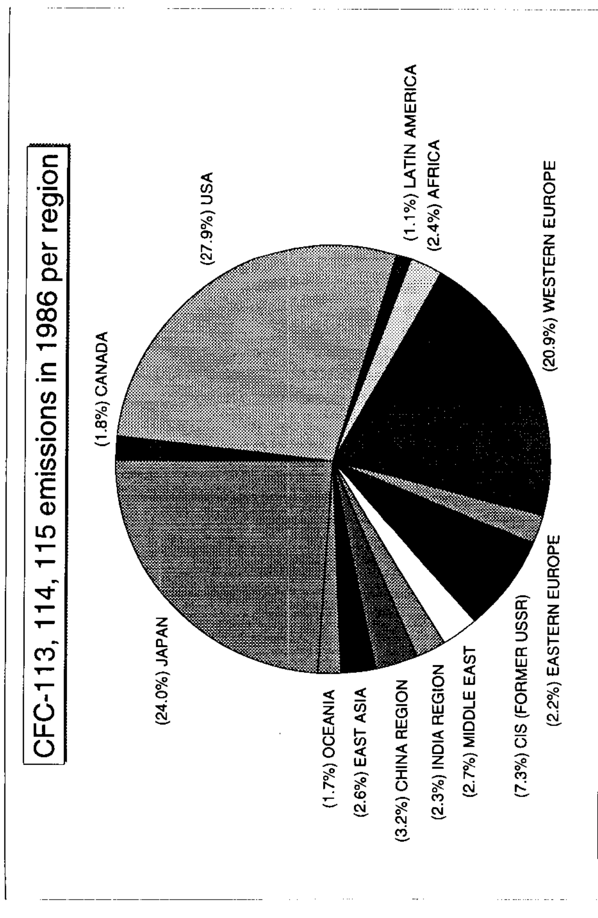
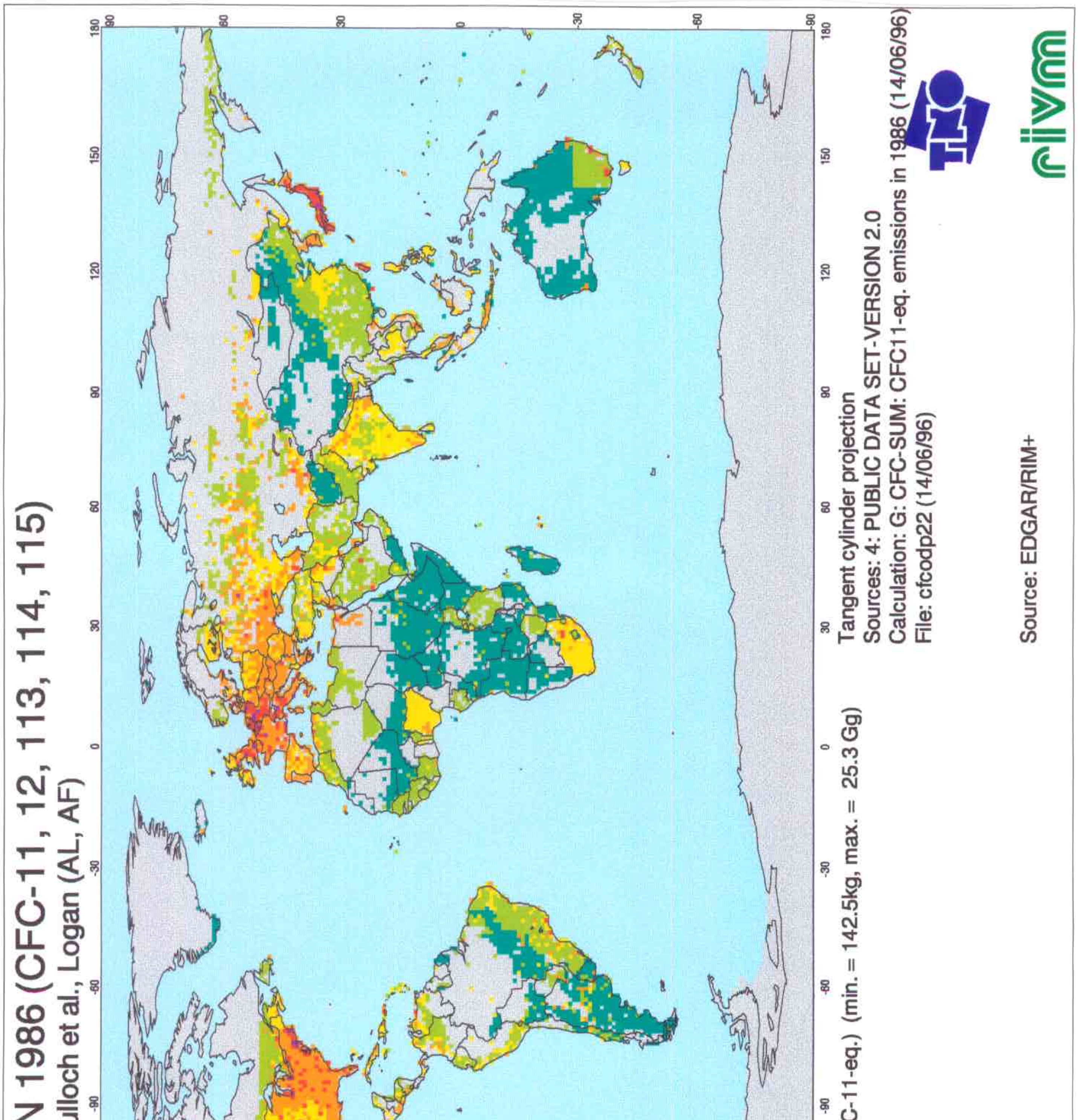


Figure 6.8.3: Global distribution of CFC-11-equivalent emissions of CFCs in 1986



7. LIMITATIONS AND UNCERTAINTIES

Version 2.0 of EDGAR, which has become available in November 1995, includes a data set for 1990 covering all major emission sources, both on a per region/country basis and a 1°x1° grid. It has a limited function in modelling and calculating past and future emissions. Neither are time profiles to distribute emissions over seasons or calender months provided in this version. Modellers may use their own estimates based on seasonal information, for example, as estimated in other inventories. In the previous chapter we discussed the global total and regional results of EDGAR by showing the results per main source, and compared the global totals of EDGAR with IPCC best 'middle' estimates and uncertainty ranges for global total emissions provided by IPCC. We concluded our estimates in Version 2.0 to be generally well in line with 'best estimates' of IPCC, and certainly within the uncertainty ranges described in Chapter 6. Further validation of EDGAR results, either in comparison with other inventories, or in more regional detail, has not been done.

Though it is important to know the accuracy of the estimates, Version 2.0 does not include fully assessed uncertainty estimates, since these are often very difficult to deduce. Nevertheless, an indication of the overall uncertainty per compound and per major source is provided in Table 7.1. Here, at least the order of magnitude of the uncertainties at the regional level is given. Uncertainty assessments can be made at different levels:

- spatial: for global, regional or country totals or, alternatively, at the grid-cell level; and
- source: for all, major or detailed, sources.

In both cases one should analyse the intrinsic uncertainty in activity levels, emission factors and grid maps used to allocate per country emissions to the 1°x1° grid. In the table we provide indications for the activities and emission factors at a high aggregation level as well as for the resulting global total and regional emissions. Next, we will discuss briefly and subsequently the character of the uncertainties as encountered in constructing the database: key activity levels, emission factors, grid maps used and map selection.

Table 7.1.1: Indication of uncertainty in activity levels, emission factors and resulting overall global and regional emissions

Main source	Sub-category	Activity data	Emission factors CO2	CH4	N2O	CO	NOx	SO2	NMVOC	Hal. HCs	Global total and regional emissions CO2	CH4	N2O	CO	NOx	SO2	NMVOC	Hal. HCs
Fossil fuel use	Fossil fuel combustion	S	S	M	M	M	M	S	M	-	S	M	M	M	M	S	M	-
	Fossil fuel production	S	M	M	-	-	-	-	M	-	M	M	-	-	-	-	M	-
Biofuel	Biofuel combustion	L	S	M	L	M	M	M	M	-	L	L	L	L	L	L	L	-
Industry/ solvent use	Iron & steel production	S		S		M	M	M	L	-		S	-	M	M	M	L	-
	Non-ferro production	S		S	L	M	M	L	L	-		S	-	M	M	L	L	-
	Chemicals production	S		S	L	M	M	L	L	-		S	M	M	M	L	L	-
	Cement production	S	S	-	-	-	-	-	-	-	S	-	-	-	-	-	-	-
	Solvent use	M	-	-	-	-	-	-	M	M	-	-	-	-	-	-	M	M
	Halocarbon use	S	-	-	-	-	-	-	-	S	-	-	-	-	-	-	-	S
	Miscellaneous	V							V	-							V	-
Landuse/ waste treatment	Agriculture	S	-	L	L	-	-	-	-	-		L	L	-	-	-	-	-
	Animals (excreta; ruminants)	S	-	M	M	-	-	-	-	-		M	M	-	-	-	-	-
	Biomas burning	L	S	M	L	M	L	M	L	-	L	L	L	L	L	L	L	-
	Landfills	L	-	M	-	-	-	-	-	-		L	-	-	-	-	-	-
	Agricultural waste burning	L	-	L	L	L	L	L	L	-		L	L	L	L	L	L	-
	Uncontrolled waste burning	L	-	-	-	-	-	-	L	-		-	-	-	-	-	V	-
Natural sources	Natural soils	M	-	L	-	-	-	-	-	-		L	-	-	-	-	-	-
	Grasslands	M	-	M	-	-	-	-	-	-		M	-	-	-	-	-	-
	Natural vegetation	M	-	M	-	-	-	-	L	-		M	-	-	-	-	L	-
	Oceans/wetlands	M	-	L	L	-	-	-	-	-		L	L	-	-	-	-	-
	Lightning	S	-	-	-	-	L	-	-	-	-	-	-	-	L	-	-	-
			CO2	CH4	N2O	CO	NOx	SO2	NMVOC	Hal. HCs	CO2	CH4	N2O	CO	NOx	SO2	NMVOC	Hal. HCs
All sources		-	-	-	-	-	-	-	-	-	S	M	L	M	M	M	L	S

Notes:
S = +- 10%
M = +- 50%
L = +-100%
V = >100%
- = Not Applicable

Sources: general: IPCC (IPCC [Houghton et al.], 1992 and 1994); SEI (Subak et al., 1992); EPA (Ahuja, 1990); World Bank (Ebert and Karmali, 1992); and own estimates.

for CO2: Marland and Rotty, 1984, and Von Hippel et al., 1993.

For fossil fuel use and industrial and agricultural production often reasonably accurate international statistics are available. This means that regional or global totals are often fairly precise. However, it is known that international statistics, on which EDGAR relies heavily, may show substantial differences in some cases with figures from national statistics of certain countries (Schipper *et al.*, 1992). Less commercial or non-commercial activities - from the viewpoint of traditional economics - such as biofuel use, waste burning and landfilling, are less well-known. The same applies to most natural sources, which are spatially so scatttered that often no accurate estimates of totals exist.

Emission factors show a substantial variation according to the type of process. An exception are factors strongly related to the physical or chemical characteristics of the process, e.g. fuel composition (CO_2, SO_2). For the EDGAR database we have, wherever possible, estimated average regional emission factors for aggregate source types.

For estimating uncertainty of emissions per grid cell, three aspects of the maps (related to processes used to distribute country emissions on a grid within a country) should receive attention (Olivier, 1994):

- the accuracy of the relative intensities (per country, if used to allocate national emissions);
- the choice of the theme of the map (this needs to be evaluated, since other themes may result in very different spatial distributions);
- the way in which border cells are treated in country-to-grid conversions.

Sometimes the accuracy of a thematic map itself can be assessed by comparing different versions of the map - i.e. with different reference years and origin of data - such as in the case of the population density map for which GEIA inventories currently use two maps (Logan/Harvard and NASA-GISS); these were constructed for different years, with other resolutions of basic data and with a somewhat different methodology to fill in missing sections (rural population).

The conclusion from this analysis and from the data in Table 7.1 is that the uncertainty estimates for emissions differ substantially according to the cross-section made in space, sources and compounds.

Summarizing, we can state the main goal was creation of a database containing the information necessary to: (1) calculate global emissions aggregated into world regions as well as on a per country basis, (2) calculate globally gridded emissions, focusing on the base year 1990 and also including historical emissions where both activity data and emission factors were readily available, and (3) provide an aggregated time-series of production and emissions of halocarbons. In conjunction with the uncertainty table and comparisons provided in this report, we conclude that a comprehensive database has been created, using consistent underlying activity and grid allocation data per source sector.

8. POLICY APPLICATIONS

8.1 Introduction

From the possibilities of EDGAR to make different cross-sections per source, region and year, we can draw conclusions on which and where the largest contributors of greenhouse gas emissions are, and which the fastest growing sources are. This can be done using the overview tables with regional and sectoral per compound which were presented in Chapter 6. As an alternative approach, we can also rank the 'Top 20' of largest regional sources to analyse the location and type of the dominant sources. To illustrate the information that can be drawn from such a ranking, in the section below this has been done for CO_2; of course for other compounds a similar list could be made.

By comparing activity intensities and emission factors regionally or in time, we can draw conclusions as to which emission sources can be controlled most efficiently. Control policies regarding emissions of greenhouse gases can approach this issue from two angles: either by focusing on compounds or on source categories. We note that EDGAR can identify in which sectors and regions a percentage-wise emission reduction has the largest effect on global total and regional emissions, but not whether or not these reductions are technically, economically or politically feasable.

In the following sections, we present, firstly, per compound the first results based on information extracted from EDGAR (e.g. as presented in Chapter 6) and, secondly, we point out key areas (sectors/regions) in which substantial emissions may be achieved. We conclude this chapter by summarizing the actual use of EDGAR data during the project and its potential future application for supporting policy development. We would like to stress again that no assessment is made of the feasibility of options for reducing emissions. These considerations must be included when developing emission control policies.

Table 8.1.1.a-c: The 25 largest regional anthropogenic sources of CO_2 emissions (all fractions > 1%), ranked by share and grouped per region and source, respectively

A. KEY REGIONS/SOURCES: ORDERED BY FRACTION

	Region	Source	% of global total	Cumulative	
1	USA	POWER GENERATION	6.0		
2	CIS	POWER GENERATION	4.4		
3	INDIA+	RESIDENTIAL BIOFUEL	4.2		
4	USA	ROAD	3.9	Top-5:	
5	CHINA+	INDUSTRY	3.8		22.2
6	CHINA+	RESIDENTIAL BIOFUEL	3.7		
7	W EUR.	POWER GENERATION	3.2		
8	AFRICA	RESIDENTIAL BIOFUEL	3.1		
9	CIS	INDUSTRY	3.0	Top-10:	
10	L AM.	DEFORESTATION	2.9		38.0
11	USA	INDUSTRY	2.3		
12	CHINA+	POWER GENERATION	2.3		
13	W EUR.	RESIDENTIAL	2.2		
14	W EUR.	ROAD	2.2	Top-15:	
15	CIS	RESIDENTIAL	2.2		49.2
16	USA	RESIDENTIAL	2.0		
17	AFRICA	DEFORESTATION	1.9		
18	W EUR.	INDUSTRY	1.9		
19	CHINA+	RESIDENTIAL	1.7	Top-20:	
20	E EUR.	POWER GENERATION	1.5		58.2
21	E ASIA	RESIDENTIAL BIOFUEL	1.5		
22	USA	INDUSTRY BIOFUEL	1.3		
23	INT. SHIP	INTERNATIONAL SHIP	1.2		
24	L AM.	RESIDENTIAL BIOFUEL	1.1	Top-25:	
25	JAPAN	POWER GENERATION	1.1		64.3
	Sum all fractions >1%:		64.3		

B. KEY REGIONS/SOURCES: GROUPED BY REGION

	Region	Source	% of global total	Sum per region	
1	USA	POWER GENERATION	6.0		
1	USA	ROAD	3.9		
1	USA	INDUSTRY	2.3		
1	USA	RESIDENTIAL	2.0		
1	USA	INDUSTRY BIOFUEL	1.3	USA	15.5
2	CHINA+	INDUSTRY	3.8		
2	CHINA+	RESIDENTIAL BIOFUEL	3.7		
2	CHINA+	POWER GENERATION	2.3		
2	CHINA+	RESIDENTIAL	1.7	CHINA+	11.5
3	CIS	POWER GENERATION	4.4		
3	CIS	INDUSTRY	3.0		
3	CIS	RESIDENTIAL	2.2	CIS	9.5
4	W EUR.	POWER GENERATION	3.2		
4	W EUR.	RESIDENTIAL	2.2		
4	W EUR.	ROAD	2.2		
4	W EUR.	INDUSTRY	1.9	W EUR.	9.5
5	AFRICA	RESIDENTIAL BIOFUEL	3.1		
5	AFRICA	DEFORESTATION	1.9	AFRICA	5.0
6	INDIA+	RESIDENTIAL BIOFUEL	4.2	INDIA+	4.2
7	L AM.	DEFORESTATION	2.9		
7	L AM.	RESIDENTIAL BIOFUEL	1.1	L AM.	4.0
8	E EUR.	POWER GENERATION	1.5	E EUR.	1.5
9	E ASIA	RESIDENTIAL BIOFUEL	1.5	E ASIA	1.5
10	INT. SHIP	INTERNATIONAL SHIP	1.2	INT. SHIP	1.2
11	JAPAN	POWER GENERATION	1.1	JAPAN	1.1
	Sum all fractions >1%:		64.3		64.3

C. KEY REGIONS/SOURCES: GROUPED BY SOURCE

	Source	Region	% of global total	Sum per source	
1	POWER GENERATION	USA	6.0		
1	POWER GENERATION	CIS	4.4		
1	POWER GENERATION	W EUR.	3.2		
1	POWER GENERATION	CHINA+	2.3		
1	POWER GENERATION	E EUR.	1.5		
1	POWER GENERATION	JAPAN	1.1	POWER GENERATION	18.3
2	RESIDENTIAL BIOFUEL	INDIA+	4.2		
2	RESIDENTIAL BIOFUEL	CHINA+	3.7		
2	RESIDENTIAL BIOFUEL	AFRICA	3.1		
2	RESIDENTIAL BIOFUEL	E ASIA	1.5		
2	RESIDENTIAL BIOFUEL	L AM.	1.1	RESIDENTIAL BIOFUE	13.5
3	INDUSTRY	CHINA+	3.8		
3	INDUSTRY	CIS	3.0		
3	INDUSTRY	USA	2.3		
3	INDUSTRY	W EUR.	1.9	INDUSTRY	11.0
4	RESIDENTIAL	W EUR.	2.2		
4	RESIDENTIAL	CIS	2.2		
4	RESIDENTIAL	USA	2.0		
4	RESIDENTIAL	CHINA+	1.7	RESIDENTIAL	8.1
5	ROAD	USA	3.9		
5	ROAD	W EUR.	2.2	ROAD	6.1
6	DEFORESTATION	L AM.	2.9		
6	DEFORESTATION	AFRICA	1.9	DEFORESTATION	4.8
7	INDUSTRY BIOFUEL	USA	1.3	INDUSTRY BIOFUEL	1.3
8	INTERNATIONAL SHIP	INT. SHIP	1.2	INT. SHIP	1.2
	Sum all fractions >1%:		64.3		64.3

8.2 Compound approach

8.2.1 Carbon dioxide (CO_2)

The results of the EDGAR calculations for CO_2 have been presented in the pie charts of Figure 6.1.1 and 6.1.2 and Table 6.1.1. When drawing conclusions from these figures we have to keep in mind that the emissions from biofuel use and large scale biomass burning are quite uncertain (see Chapter 7). Taking this into account, the figures presented in Section 6.1 indicate that the largest source categories are: large combustion plants (i.e. power generation and industrial combustion) (more than 1/3) and biofuel use (1/5). Together, they account for more than 50% of global CO_2 emissions. However, substantial differences between regions can be observed. In industrialized regions and in China large combustion plants account for 1/3 to 3/5 of total regional emissions. In addition, in industrialized regions land transport is also a substantial source, accounting for about 1/5, in contrast with most developing countries, where large-scale biomass burning and residential biofuel use dominate. Also, emissions caused by residential fuel use are rather high in regions with a moderate to cold climate, such as Canada, Western and Eastern Europe and the former USSR, but surprisingly also in the Middle East. China and Western Europe are the largest emitters regarding cement production. As far as individual contributions to the global total, power generation in the uSA is with 6% of all emissions by far the largest singular source of CO_2. Power generation in the former USSR, residential biofuel in the India and Chnia regions, road transport in the USA and the industry in the China region occupy the second to sixth place with shares of about 4% each. The third group consists of power generation in Western Europe, residential biofuel in Africa, industry in the former USSR and deforestation in Latin America, which all contribute about 3%.

Another approach to identify the largest sources is to rank the largest source/region combinations. In Table 8.1.1 the 25 combinations are listed with a share in anthropogenic emissions larger than 1%. They are presented in order of share, region and source sector, respectively. From this approach we can conclude that the sum of top 15 of the 209 combinations in Table 8.1.1.a already account for half of the global total CO_2 emissions. Alternatively, it clearly shows that amongst these largest regional sources next to power generation (in 6 regions), residential biofuel (in 5 regions) is the second largest regional source, even larger than industrial combustion. This, together other residential combustion, also causes China to outrun the former USSR and Western Europe in these Top 25 of largest regional sources. Again, we emphasize that these conclusions are based on our 'best estimates' of biofuel and large-scale biomass burning emissions, which have a rather large uncertainty (in both directions).

Analysis of historical trends, illustrated in Figures 6.1.4-6, shows that power generation and transport are the fastest growing sources worldwide, whereas coal combustion and cement production in China are regionally fast-growing sectors. From these observations the following key elements for achieving a reduction of CO_2 emissions can be deduced:

- reducing demand for electricity and mobility;
- increasing energy efficiency, in particular, of electrical services, power generation and transportation.

These measures are most effective in regions with a high consumption level (such as the USA, Western Europe and the former USSR), as well as in regions with high growth rates (e.g. China and India) where penetration of new efficient technology can be fast.

8.2.2 Methane (CH_4)

The results of the EDGAR calculations have been presented in the pie charts of Figure 6.2.1 and 6.2.2 and Table 6.2.1. It can be concluded from the figures that more than 50% of the global anthropogenic CH_4 emissions are caused by enteric fermentation (including animal wastes) and methanogenious processes from rice paddies. Reduction options are a change in type of livestock, a different food crop and a change in agricultural practice. However, this last option would imply drastic socio-economic changes. Also large-scale biomass burning and biofuel use, important emitting sources in most developing countries, are strongly related to socio-economic circumstances. Uncontrolled burning of agricultural residues could be reduced by applying strict regulations combined with a different agricultural practice.

In the industrialized countries, CH_4 emissions are largely caused by fossil-fuel production and landfills. Limited technological CH_4-reducing measures can be taken for underground mining and natural gas distribution, except in West Siberia, which is renown for the high natural gas losses that occur in the high pressure distribution network, where emission reducing measures would be highly effective. The considerable CH_4 contribution from landfills can be fairly well reduced by covering landfills and recovering CH_4 or by enhancing the burning of municipal waste. The latter option, however, would increase the emissions of other compounds.

8.2.3 Nitrous oxide (N_2O)

The results of the EDGAR calculations have been presented in the pie charts of Figure 6.3.1 and 6.3.2 and Table 6.3.1. Although there is a substantial uncertainty in the strength of some of these sources, it can be concluded from the figures that the largest potential for emission reduction of N_2O is in the agricultural and cattle breeding sectors. If agricultural practices could be optimized in this perspective, large emission reduction would be possible on a global scale. In addition, since a limited number of industrial-process sources also contribute substantially, fast reductions could be achieved in these sectors. Actually, manufacturers of adipic acid already cooperate in an emission-reduction programme. Limiting the biomass burning (deforestation, agricultural-waste burning in the field and savannah burning) would also reduce the N_2O emission, especially in Africa and Latin America.

8.2.4 Carbon monoxide (CO)

The results of the EDGAR calculations have been presented in the pie charts of Figure 6.4.1 and 6.4.2 and Table 6.4.1. From the figures it can be concluded that the category contributing the most to the CO world total, being large-scale biomass burning, largely takes place in developing countries; unfortunately this category is hard to control. The only way to reduce the CO emission from this source is to decrease the uncontrolled burning. This can be achieved by more controlled burning of the agricultural waste and limiting deforestation and savannah burning. On a large scale, this would imply major socio-economic changes.

The CO emission from road transport, important in industrialized countries, can be reduced by using motor vehicles with a better tuned-up and more efficient engine. Besides technological measures, more efficient energy management is desirable.

The emission from the third largest CO emitting source, biofuel use, can be reduced by improving the efficiency of the cooking stoves. This source is important in developing countries.

Emissions of CO by industrial and non-industrial combustion are only important in Europe and the former USSR. Several technological measures can be taken to reduce these emissions.

8.2.5 Nitrogen oxides (NO_x)

The results of the EDGAR calculations have been presented in the pie charts of Figure 6.5.1 and 6.5.2 and Table 6.5.1. As can be concluded from the figures, four dominant emission source categories exist on a global scale (in order of decreasing importance): road transport, large-scale biomass burning, electricity generation and industrial combustion.

For all these causes of emissions fairly effective options for NO_x emission reduction are available. For road transport, pertaining to NO_x emissions, of particular importance in industrialized countries, can be drastically reduced by equipping automobiles with a three-way exhaust catalyst. For both electricity generation and industrial combustion, several measures can be taken, such as the installation of 'Low NO_x units'. Besides these technological measures, energy reduction programmes for industrialized countries, in particular in the USA, is desirable with respect to the reduction of NO_x emissions. Uncontrolled burning of agricultural residues could be reduced by applying strict regulations combined with different agricultural practices.

8.2.6 Sulphur dioxide (SO_2)

The results of the EDGAR calculations have been presented in the pie charts of Figure 6.6.1 and 6.6.2 and Table 6.6.1. About 70% of the global SO_2 emission from fossil fuels stems from four regions: USA, OECD Europe, the former USSR and the China region. Globally, power generation and industry are the major emission sources, each with a share of about 1/3. This is due to the high consumption of coal in the power generation sector, in contrast with other sectors, where other fossil fuel types dominate. In Canada, USA and Eastern Europe the power generation sector contributes even 50 to 60% to total regional emissions. This will be caused either by the high consumption of coal and/or by high effective emission factors for coal combustion. In China coal consumption in the industrial and residential sectors is relatively high compared to other regions. This causes these sectors to have a large share in the regional emissions of about 50% and 15%, respectively. In the global total of industrial and residential SO_2 emissions, China's share is about 30% and 40%, respectively. In India and Japan land transport has a relatively large share of about 10 to 15% in the regional emissions.

Application of emission control technology, in particular in power generation and industry and in non-OECD regions, has a large potential for reducing sulphur emissions. In particular, coal used for power generation and in the iron and steel industry, and copper production (although in a number of regions these industries and utilities apply emission reduction technologies to some extent), are at present the sources of about 2/3 of global anthropogenic SO_2 emissions.

8.2.7 NMVOC and NMVOC compounds

The results of the EDGAR calculations have been presented in the pie charts of Figure 6.7.1 and 6.7.2 and Table 6.7.5. It can be concluded from the figures that there is not one dominating category for NMVOC emissions on a global scale. Each region has its own specific dominating source categories. Therefore each region needs to develop and apply its own policy (see Table 6.7.2).
For the regions Canada, Eastern and Western Europe, Japan, Oceania and the USA, road transport is the most important source category, contributing 32-48 % to the total regional NMVOC emission. The NMVOC emission can be reduced by applying a three-way catalyst in motor vehicle exhausts. For the regions of the Middle East and the former USSR, oil production is the most important source, with a contribution to the regional NMVOC total of 58 and 25%, respectively. The NMVOC emission can be reduced by taking technological measures. For the regions China, East Asia and India, biofuel use is the most important source, with contributions to the regional NMVOC total of 34, 30 and 44%, respectively. The NMVOC emission can be reduced by increasing the efficiency in use. For the regions of Africa and Latin America (uncontrolled) biomass burning is the most important source, with contributions to the regional NMVOC total of 47 and 39%, respectively. The NMVOC emission can be better reduced by changing attitudes than by taking technological measures.

Thus, to reduce NMVOC emissions in a region, the most important categories should first be identified and then techniques to reduce those emissions should be evaluated.

8.2.8 Halocarbons and related compounds

The results of the EDGAR calculations have been presented in the pie charts of Figure 6.8.1 and 6.8.2 and Table 6.8.1. From the figures we can conclude, that the regional consumption and emission pattern is quite different for the different compounds. OECD Europe and the USA together contribute to global CFC-11 and CFC-12 emissions for more than 50%, followed by the former USSR and Japan with shares of the order of 10% each. This is also the case for emissions of CFC-113 and methyl chloroform, except that Japan now has a share of about 25%. For CFC-113 and CFC-114, however, this picture is quite different. In addition to OECD Europe and the USA, together again having a share of about 50%, now the China and Africa regions each have a share of about 10%. This difference in consumption patterns is likely to be a result of different applications (underlying the total consumption of halocarbons).

8.3 Sectoral approach

8.3.1 Fossil fuel use

Transportation is one of the more polluting categories of all fossil fuel combustion sectors, contributing substantially to the emissions of four compounds, viz. CO_2, CO, NO_x and NMVOC. Large combustion plants (power generation and industrial combustion) contribute substantially to the CO_2, NO_x and

SO_2 emissions. The production of fossil fuel contributes substantially to CH_4 and NMVOC emissions. In addition, gas distribution is a large source of CH_4 emissions.

The use of three-way catalysts in motor vehicle exhausts can substantially reduce the levels of NMVOC, CO, NO_x and CH_4 emitted, but will increase the CO_2 emission. All emissions from transport can be reduced by using better tuned-up and more efficient engines. The NO_x and SO_2 emissions from large combustion plants and the CH_4 and NMVOC emissions from fossil fuel production and gas distribution can be reduced by applying abatement techniques. Reduction of CO_2 emissions can only be achieved by increasing the efficiency and/or by decreasing the use of fossil fuels.

8.3.2 Biofuel use

Residential biofuel combustion, although the total amount is quite uncertain, contributes substantially to the emissions of CO_2, CO and NMVOC. All emissions from biofuels can be reduced by increasing the efficiency of the stoves used for cooking and heating, thereby also improving local air quality, both indoor and outdoor.

8.3.3 Industrial processes and solvent use

Solvent use contributes substantially to the NMVOC and halogenated hydrocarbon emissions. Halocarbon use contributes, as expected, to emissions of these compounds, whereas other industrial processes contribute substantially to global N_2O, NMVOC and SO_2 emissions. The contribution of solvent use to NMVOC and halocarbon emissions can be reduced by using products with a low or no solvent content. Changing to less reactive solvent compounds would also reduce the environmental impact.

The source category 'other industrial processes' contains a large variety of processes. Per region different processes dominate. In the India region, H_2SO_4 production accounts for about half of the regional industrial SO_2 emissions. Lead and steel are minor sources of industrial SO_2 emissions, although regionally important, as is the case for Japan. Analysis shows that copper production in Latin America, OECD Europe and the former USSR cause about 30% of the global total SO_2 emission from industrial sources. Different abatement techniques are available to reduce these emissions.

Regional shares in specific halocarbon emissions can differ substantially, which was shown in Section 6.8. This reflects a different regional application pattern, which in turn may also affect the future consumption levels of alternative halocarbons for CFCs (in particular HCFCs and HFCs), which are now phased out according to the Montreal Protocol.

8.3.4 Landuse and waste treatment

Biomass burning (agricultural waste burning in the field, deforestation and savannah burning) contributes to the emissions of CO_2, CH_4, N_2O, CO, NO_x and NMVOC. Agriculture and animals contribute to CH_4 and N_2O emissions, waste treatment (in particular landfills) to CH_4 and waste combustion also to NMVOC. Biomass burning is the dominant source of N_2O, CO, NO_x and NMVOC in Africa and

Latin America.

The emissions from this source category are hard to control, since almost all policy applications require a change in socio-economic factors. Emissions from waste treatment can be reduced technologically by changing from uncontrolled to controlled burning.

8.3.5 Natural sources

Natural soils contribute substantially to the emissions of CO_2, N_2O, NO_x, NMVOC and SO_2. Lightning contributes to the NO_x emission, oceans to the CO_2 and N_2O emissions, natural vegetation to the NMVOC emission and other natural sources to CH_4 and SO_2 (wetland, algae). These sources are considered to be uncontrollable.

8.4 Current and potential policy-related applications

Besides the gridded emissions inventories and regional emission data, now available for atmospheric modellers and for policy support studies (e.g. by ECN and Ecofys), respectively, the following achievements were made during the project:

1) concrete contributions to GEIA in the form of N_2O and NMVOC inventories;
2) demonstration of a comprehensively constructed set of emission inventories, internally consistent across compounds, sources, locations and years;
3) participation/coordination of GEIA working groups on N_2O, NMVOC and data management;
4) participation/leading expert groups on the emission calculation methodology of IPCC;
5) provision of IPCC with default emission factors and methodologies for CH_4 and N_2O sources;
6) provision of texts for the Draft IPCC Guidelines for National GHG Emission Inventories to be submitted within the Framework Convention of Climate Change (FCCC);
7) provision of process descriptions for the UN-ECE/EMEP handbook on emission inventories;
8) provision of information for validation studies of national GHG inventories submitted within the FCCC;
9) provision of regional and gridded data to evaluate the environmental impacts of global aircraft emissions in support of the Memorandum on Air Traffic and Air Pollution (LULU) of the Dutch government (referred to as Version 1.0 with data on 5^ox5^o);
10) provision of the IMAGE 2 model with a set of aggregated emission factors;
11) compilation of maps for a number of sources in support of other GEIA/IGAC research;
12) a database system capable of:
    - devising various cross-sections, thereby giving insights into which regions/sectors should be focused on in defining policies for optimal global emission reduction
    - extraction of aggregated emission factors for base years (e.g. for the IMAGE 2 model)
    - extraction of country-specific data
    - extraction of files for linkage with IMAGE emission scenario modules
    - application to (semi-)annual environmental assessments of global emission trends of green-

house gases, e.g. for the Dutch government or UNEP;

13) documentation in the form of:
    - a technical background document on design and implementation
    - a user manual provided by the on-line help system in all windows
    - description of contents of the database and methodology used for the setup
    - documentation file accompanying the public data files.

For a list of publications related to this project we refer the reader to Appendix 5.

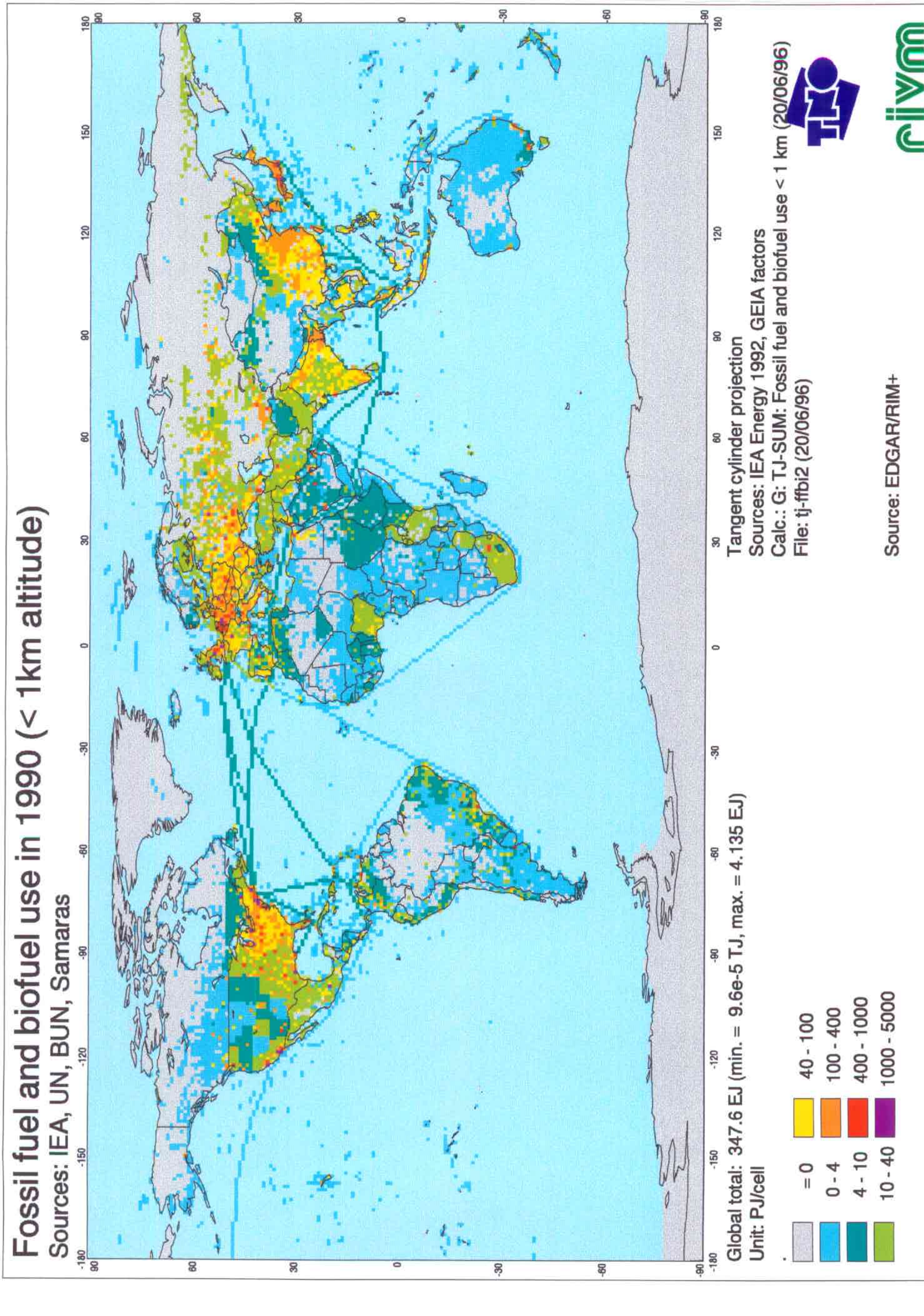
As a preliminary and intermediate Version 1.0 of EDGAR, functions were built to process and combine emissions of NO_x, CO and CH_4 on a 5°x5° grid from existing inventories. These were used to generate aircraft and surface source emissions for a study of the environmental impact of aircraft emissions (Olivier, 1995) and in a study of the atmospheric effects of global methane emissions (Beck *et al.*, 1995). Version 2.0 of EDGAR, which came into operation in November 1995, includes data sets covering all major anthropogenic sources and most natural sources, but does not yet include uncertainty estimates.

Although within the project it was not planned to include specific country inventories, national greenhouse-gas inventories, such as submitted to the Conference of Parties under the Framework Convention on Climate Change (FCCC), can also be included in the database. This is possible because an option is provided to include and select alternative data sets (e.g. national sets) for emissions calculations. Put another way: inclusion of multiple data sets is possible, since all data in the database are labelled with reference to their data source and are members of a larger so-called data set. This will facilitate comparison of data sets and creation of new global totals and maps by combining different sets. In the near future other anticipated applications are:

14) comparing and combining EDGAR and FCCC national inventory data as a means of:
    - validating national inventories;
    - evaluating recommended default emission factors;
    - providing the new estimate for global total emissions by adding the sum of national emission inventory data submitted under the FCCC, supplemented with EDGAR data for missing sources and non-reporting countries;
15) providing the IMAGE 2 model with updated emission factors;
16) providing default emission factors for IPCC Guidelines for national greenhouse gas inventories;
17) creating emission scenarios on grid, as an example for GEIA and as input for modellers.

The last item refers to calculation of future emissions on a 1°x1° grid that will be done by the User Support System of RIVM's global change model IMAGE 2. This will be realized by combining the regional emission scenario results of the model with the 1990 maps of the spatial distribution of many anthropogenic sources from EDGAR. The main goal of this project was to create a database with the information necessary to calculate globally gridded emissions in the base year 1990, and also historical emissions where both activity levels and emission factors were readily available When a need arises for estimating the spatial distribution of emissions of other compounds, not currently dealt with, this can be done easily, since all the underlying data are available. An illustration of these capabilities are given in Figure 8.4.1, where the distribution of global energy consumption is shown on the 1°x1° grid.

Figure 8.4.1: Global distribution of fossil fuel and biofuel use in 1990.



9. CONCLUSIONS

The main goal of this project was to create a database with the information necessary to calculate globally gridded emissions in the base year 1990, and also historical emissions where both activity levels and emission factors were readily available. This has been accomplished through the construction of a preliminary and intermediate Version 1.0 of EDGAR, with functions to process and combine emissions of NO_x, CO and CH_4 on a 5°x5° grid from existing inventories. These were used to generate aircraft and surface-source emissions for a study of the environmental impact of aircraft emissions and of the atmospheric effects of global methane emissions. Version 2.0 of EDGAR, which came into operation in November 1995, includes data sets covering all major anthropogenic sources and most natural sources of greenhouse gases for 1990, regionally as well as on a 1°x1° grid. For a number of sources historical emissions, e.g. of CO_2, can also be calculated. This version was validated by comparison of global results for main sources with other global estimates. It has limited functionality in calculating past and future emissions and does not include uncertainty estimates.

We have given a scientific description of the contents of the EDGAR Version 2.0 and presented some of the tabular and gridded results extracted from the database, including a first validation by comparison with IPCC estimates. Also, uncertainties connected to the data and to the resulting emissions tables and gridded maps were discussed. We showed the potential for policy applications by devising different cross-sections per source, region and year, from which we can infer the locations and types of the largest contributors of greenhouse gas emissions, which are the fastest growing sources. By comparing activity intensities and emission factors regionally or in time, conclusions can be drawn on which emission sources can be controlled most efficiently. We have pointed out key sectors and regions in which substantial emissions could be achieved.

The gridded emission inventories and regional emission data, are now available for atmospheric modellers and for policy support studies, respectively. As a spin-off during the project several contributions were made at the scientific level and for policy applications:

- to GEIA (e.g. in the form of N_2O and NMVOC inventories) and to IMAGE 2, by providing an interim set of aggregated emission factors;
- to IPCC (e.g. by participating in expert groups on emission calculation methodology and by providing default emission factors and methodologies for CH_4 and N_2O sources as well as texts for the Draft IPCC Guidelines for National GHG Emission Inventories);
- to the Dutch government, by providing regional and gridded data to evaluate the environmental impacts of global aircraft emissions (referred to as EDGAR Version 1.0 with data on a 5°x5° grid).

Summarizing we can state the main goal was creation of a database containing the information necessary to: 1) calculate global emissions aggregated into world regions and on a per country basis, 2) calculate globally gridded emissions, focusing on the base year 1990 and also including historical emissions where both activity data and emission factors were readily available, and 3) provide an aggregated time-series of production and emissions of halocarbons. In conjunction with the uncertainty table and comparisons provided in this report, we conclude that a comprehensive database has been created using consistent underlying activity and grid allocation data per source sector.

We conclude by recalling that EDGAR has an option of including national greenhouse-gas inventories, such as submitted to the Conference of Parties within the Framework Convention on Climate Change (FCCC), and comparing them with the original EDGAR data. For the near future there are plans for:

- comparing and combining EDGAR and FCCC national inventory data as a means of validating national inventories, evaluating recommended emission factors, and providing new global total emission estimates;
- providing the IMAGE 2 model with updated emission factors;
- creation of gridded emission scenarios using the User Support System of RIVM's IMAGE 2 model by combining the regional emission scenario results of the model with the 1990 gridded emission maps of many anthropogenic sources from EDGAR.

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APPENDIX 1: REGIONS

R.1 Definition of regions

Table R.1.1: EDGAR list of locations per region

ISO-N	ISO-A2	ISO-A3	NAME	LOGAN
Region A: CANADA				
124	CA	CAN	Canada	2800
Region B: USA				
840	US	USA	United States (USA)	17600
Region C: LATIN AMERICA				
660	AI	AIA	Anguilla	
28	AG	ATG	Antigua and Barbuda	
32	AR	ARG	Argentina	
533	AW	ABW	Aruba	
44	BS	BHS	Bahamas	1100
52	BB	BRB	Barbados	1400
84	BZ	BLZ	Belize	1600
68	BO	BOL	Bolivia	2000
74	BV	BVT	Bouvet Island	
76	BR	BRA	Brazil	2200
136	KY	CYM	Cayman Islands	20700
152	CL	CHL	Chile	3200
170	CO	COL	Colombia	3400
188	CR	CRI	Costa Rica	3800
192	CU	CUB	Cuba	3900
212	DM	DMA	Dominica	4400
214	DO	DOM	Dominican Republic	4500
218	EC	ECU	Ecuador	4600
222	SV	SLV	El Salvador	4800
238	FK	FLK	Falklands Islands (Malvinas)	5100
254	GF	GUF	French Guiana	5600
308	GD	GRD	Grenada	6600
312	GP	GLP	Guadeloupe	6700
320	GT	GTM	Guatemala	6800
328	GY	GUY	Guyana	7100
332	HT	HTI	Haiti	7200
340	HN	HND	Honduras	7300
388	JM	JAM	Jamaica	8500
474	MQ	MTQ	Martinique	10800
484	MX	MEX	Mexico	11100
500	MS	MSR	Montserrat	21600
532	AN	ANT	Netherlands Antilles	12000
558	NI	NIC	Nicaragua	12300
590	PA	PAN	Panama	13000
600	PY	PRY	Paraguay	13200
604	PE	PER	Peru	13300
630	PR	PRI	Puerto Rico	22300
659	KN	KNA	St Kitts & Nevis (St Christopher)	14100
662	LC	LCA	St Lucia	14200
670	VC	VCT	St Vincent & The Grenadines	14300
740	SR	SUR	Suriname	15800
780	TT	TTO	Trinidad and Tobago	16800
796	TC	TCA	Turks & Caicos Islands	
858	UY	URY	Uruguay	17800
862	VE	VEN	Venezuela	18100
850	VI	VIR	Virgin Islands (US)	23100

Region D: AFRICA

12	DZ	DZA	Algeria	
24	AO	AGO	Angola	
204	BJ	BEN	Benin	1700
72	BW	BWA	Botswana	2100
86	IO	IOT	Britisch Indian Ocean Terr. (Chagos)	
854	BF	BFA	Burkina Faso	17700
108	BI	BDI	Burundi	2600
120	CM	CMR	Cameroon	2700
132	CV	CPV	Cape Verde	2900
140	CF	CAF	Central African Republic	3000
148	TD	TCD	Chad	3100
174	KM	COM	Comoros	3500
178	CG	COG	Congo	3600
384	CI	CIV	Cote d'Ivoire (Ivory Coast)	8400
262	DJ	DJI	Djibouti	4300
818	EG	EGY	Egypt	4700
226	GQ	GNQ	Equatorial Guinea	4900
230	ET	ETH	Ethiopia	5000
266	GA	GAB	Gabon	5800
270	GM	GMB	Gambia	5900
288	GH	GHA	Ghana	6200
324	GN	GIN	Guinea	6900
624	GW	GNB	Guinea-Bissau	7000
404	KE	KEN	Kenya	8900
426	LS	LSO	Lesotho	9600
430	LR	LBR	Liberia	9700
434	LY	LBY	Libyan Arab Jamahiriya	9800
450	MG	MDG	Madagascar	10200
454	MW	MWI	Malawi	10300
466	ML	MLI	Mali	10600
478	MR	MRT	Mauretania	10900
480	MU	MUS	Mauritius	11000
504	MA	MAR	Morocco	11400
508	MZ	MOZ	Mozambique	11500
516	NA	NAM	Namibia	11600
562	NE	NER	Niger	12400
566	NG	NGA	Nigeria	12500
638	RE	REU	Reunion	13800
646	RW	RWA	Rwanda	14000
678	ST	STP	Sao Tome & Principe	14500
686	SN	SEN	Senegal	14700
690	SC	SYC	Seychelles	14800
694	SL	SLE	Sierra Leone	14900
706	SO	SOM	Somalia	15200
710	ZA	ZAF	South Africa	15300
654	SH	SHN	St Helena	22400
736	SD	SDN	Sudan	15700
748	SZ	SWZ	Swaziland	15900
834	TZ	TZA	Tanzania, United Republic of	16400
768	TG	TGO	Togo	16600
788	TN	TUN	Tunesia	16900
800	UG	UGA	Uganda	17300
732	EH	ESH	Western Sahara	18400
180	ZR	ZAR	Zaire	18900
894	ZM	ZMB	Zambia	18300
716	ZW	ZWE	Zimbabwe	19000

Region E: OECD EUROPE

20 AD	AND	Andorra	
40 AT	AUT	Austria	1000
56 BE	BEL	Belgium	1500
208 DK	DNK	Denmark	4200
234 FO	FRO	Faeroe Islands (Foroyar)	5200
280 DE	DEU	Federal Republic of Germany	6100
246 FI	FIN	Finland	5400
250 FR	FRA	France	5500
278 DD	DDR	German Democratic Republic (former DDR)	6000
292 GI	GIB	Gibraltar	
300 GR	GRC	Greece	6400
304 GL	GRL	Greenland	6500
352 IS	ISL	Iceland	7600
372 IE	IRL	Ireland	8100
380 IT	ITA	Italy	8300
438 LI	LIE	Liechtenstein	9900
442 LU	LUX	Luxembourg	
470 MT	MLT	Malta	10700
492 MC	MCO	Monaco	
528 NL	NLD	Netherlands	11900
578 NO	NOR	Norway	12600
620 PT	PRT	Portugal	13600
674 SM	SMR	San Marino	
724 ES	ESP	Spain	15500
744 SJ	SJM	Svalbard and Jan Mayen Islands	
752 SE	SWE	Sweden	16000
756 CH	CHE	Switzerland	16100
826 GB	GBR	United Kingdom	17500
336 VA	VAT	Vatican City	

Region F: EASTERN EUROPE

8 AL	ALB	Albania	
100 BG	BGR	Bulgaria	2400
200 CS	CSK	Czechoslovakia (former)	4100
348 HU	HUN	Hungary	7500
616 PL	POL	Poland	13500
642 RO	ROM	Romania	13900
890 YU	YUG	Yugoslavia (former)	18800

Region G: CIS (FORMER USSR) (including Baltic states)

810 SU	SUN	USSR (former)	15400

Region H: MIDDLE EAST

4 AF	AFG	Afghanistan	
48 BH	BHR	Bahrain	1200
196 CY	CYP	Cyprus	4000
364 IR	IRN	Iran, Islamic Republic of	7900
368 IQ	IRQ	Iraq	8000
536 NT	NTZ	Iraq-Saudi Arabia Neutral Zone	
376 IL	ISR	Israel	8200
400 JO	JOR	Jordan	8700
414 KW	KWT	Kuwait	9300
422 LB	LBN	Lebanon	9500
512 OM	OMN	Oman	12700
634 QA	QAT	Qatar	13700
682 SA	SAU	Saudi Arabia	14600
760 SY	SYR	Syrian Arab Republic	16200
792 TR	TUR	Turkey	17000
784 AE	ARE	United Arab Emirates	17400
887 YE	YEM	Yemen	18700

Region I: INDIA REGION

50 BD	BGD	Bangladesh	1300
64 BT	BTN	Bhutan	1900
356 IN	IND	India	7700
462 MV	MDV	Maldives	
104 MM	MMR	Myanmar (former Burma)	2500
524 NP	NPL	Nepal	11800
586 PK	PAK	Pakistan	12800
144 LK	LKA	Sri Lanka	15600

Region J: CHINA REGION

156	CN	CHN	China	3300
344	HK	HKG	Hong Kong	7400
116	KH	KHM	Kampuchea (former Cambodia)	8800
408	KP	PRK	Korea, Democratic People's Republic of (	9100
418	LA	LAO	Lao Peoples Democratic Republic	9400
446	MO	MAC	Macau	21300
496	MN	MNG	Mongolia	11300
158	TW	TWN	Taiwan	16300
704	VN	VNM	Vietnam	18200

Region K: EAST ASIA

96	BN	BRN	Brunei	2300
360	ID	IDN	Indonesia	7800
410	KR	KOR	Korea, Republic of (South)	9200
458	MY	MYS	Malaysia	10400
598	PG	PNG	Papua New Guinea	13100
608	PH	PHL	Philippines	13400
702	SG	SGP	Singapore	15000
764	TH	THA	Thailand	16500
626	TP	TMP	Timor Timur (East Timor)	22800

Region L: OCEANIA

16	AS	ASM	American Samoa	
36	AU	AUS	Australia	900
162	CX	CXR	Christmas Island (Australia)	
166	CC	CCK	Cocos (Keeling) Islands	
184	CK	COK	Cook Islands	3700
242	FJ	FJI	Fiji	5300
258	PF	PYF	French Polynesia (Tuamotu & Marquesas)	5700
316	GU	GUM	Guam	12900
334	HM	HMD	Heard & McDonald Islands	
296	KI	KIR	Kiribati	9000
584	MH	MHL	Marshall Islands	
520	NR	NRU	Nauru	11700
540	NC	NCL	New Caledonia	12100
554	NZ	NZL	New Zealand	12200
570	NU	NIU	Niue	21700
574	NF	NFK	Norfolk Island	21800
580	MP	MNP	Northern Mariana Islands	
583	FM	FSM	Pacific Trust Territory (Micronesia)	
585	PW	PLW	Palau	22100
612	PN	PCN	Pitcairn Islands	
90	SB	SLB	Solomon Islands	15100
772	TK	TKL	Tokelau	22900
776	TO	TON	Tonga	16700
798	TV	TUV	Tuvalu	17200
548	VU	VUT	Vanuatu	17900
876	WF	WLF	Wallis & Futuna	23200
882	WS	WSM	Western Samoa	18500

Region M: JAPAN

392	JP	JPN	Japan	8600

Region X: SEA (OCEANS)

0	XX	XXX	Sea (oceans)	

Region Y: ANTARCTICA

10	AQ	ATA	Antarctica	

R.2 Definition of country to grid relation

To convert country emissions to a 1°x 1° grid using a gridded map as allocation function, we need a relation defining the correspondence between countries and the one degree grid. In EDGAR we comply with the current GEIA convention, which relates each 1°x 1° grid cell to one geographic entity (country, island or sea/oceans) (NASA-GISS, 1995). This 'political unit data set' includes 186 countries/geographic entities. It was constructed by (1) assigning each cell to the spatially dominant territorial unit (including see/oceans), (2) preserving as much as possible the total land area of each country, and (3) retaining small countries that would not be included on the basis of the former criteria.

However, a number of small entities occurring in international statistics used by EDGAR (e.g. of IEA, UN, FAO/AGROSTAT) appeared not included in this data set. In order not to make exclude data in processing the activity statistics and not to loose information when converting emissions on the one degree grid, we extended the original country-to-grid relation table with 21 minor entities. The Logan map of population density has been extended likewise. These added entities and their geographical and population data are listed in Appendix M.1.

APPENDIX 2: SOURCES

S.1 Detailed list of fossil fuel sources

Energy combustion and transformation

To have also the option of defining emission factors per main fuel type, the energy processes of EDGAR were defined in a hierarchical way, grouping sub-fuel types under main fuel types (see Table S.1.1). This option of defining factors at aggregated levels was also implemented for energy combustion and transformation sectors, while maintaining the IEA structure of main and detailed economic sectors as shown in Table S.1.2 for energy processes in Version 2.0. This hierarchy is connected to the fuel type hierarchy as shown in the heading of Table S.1.1: energy processes are structured in the following order: 1) main fuel type; 2) main (IEA) sector; 3) detailed fuel type; 4) detailed (IEA) sector.

At any (aggregate) level emission factor can be defined, in this structure e.g. for main fuel types per main sector. In EDGAR, energy processes can be recognized by their process codes, which all start with "E." followed by codes for fuel types and sectors separated with a dot. These codes are the same as the IEA codes (as shown in Tables S.1.1 and S.1.2).

Primary and secondary fuel production

Primary fuel production data is in general not stored as energy processes, since they do not refer to fuel combustion, but as activity levels in other main (or sub) processes. The same holds for production of secondary fuels, such as coke, oil products etc. Table S.1.3 shows how this data is classified in Version 2.0. In EDGAR, fuel production processes can be recognized by their process codes, which all start with "E.PRO." followed by the IEA code of the fuel type.

Table S.1.1: Fuel types used in Version 2.0

Code	Fossil fuels	Code	Main fuel type	MS 1) Code	Detailed fuel type	DS 2)
COA	**SOLID FUEL (COAL)**	HC	Hard coal	HDC	Hard coal	*
		BC	Lignite/brown coal	BRS	Brown coal and sub-bitum. coal	
				PEA	Peat	
		CP	Coal products	OCK	Coke-oven coke and lignite coke	
				GCK	Gas coke	
				PAT	Patent fuel	
				BKB	BKB	
TPR	**LIQUID FUELS (incl. crude etc.)**	CNF	Crude input	CRU	Crude oil	
				NGL	Natural gas liquids	
				RFD	Refinery feedstocks	
				NCR	Inputs other than crude or NGL	
				CNF	Crude/NGL/feedstocks/non-crude	
				ADD	Additives/blending components	
		TP1	Petroleum products: fuels	RGS	Refinery gas	
				LPG	Liquefied Petroleum Gas (LPG)	
				AVG	Aviation gasoline	
				MOG	Motor gasoline	
				JET	Jet fuel	
				OKE	Other kerosene	
				DIE	Gas/Diesel oil	
				HFO	Residual fuel oil	
				LIQ	Liquid fuel for electricity output	
		TP2	Petroleum products: non-energy	NAP	Naphtha	
				WSP	White spirit & SBP	
				LUB	Lubricants	
				BIT	Bitumen	
				PWX	Paraffin waxes	
				PCK	Petroleum coke	
				OPR	Other petroleum products	
GAS	**GASEOUS FUELS**			NGS	Natural gas	
				GGS	Gas works gas	
				OGS	Coke oven gas	
				BGS	Blast furnace gas	
				MGS	Manufactured gases for electr. output	
	Non-fossil fuels					
OST	**OTHER SOLID FUELS (NON-COAL)**	OS	Other fuels (waste, non-wood)	MWS	Municipal waste	
				IWS	Industrial waste	
				BLI	Black liquor	
		TR	Biomass (traditional, incl. wood,& crop waste)	WOD	Wood	
				WWS	Wood waste	
				VWS	Vegetal waste	
				CHA	Charcoal	
				OSF	Other solid fuels (non-specified)	
				BA	Bagasse	**
				DU	Dung	**
				ET	Ethanol	**

Note: Other secondary fuels in IEA statistics, not used for emission calculations in EDGAR:
- HEA Heat
- ELE Electricity
- NUC Nuclear electricity
- HYD Hydro electricity
- REN Other renewables: GEO Geothermal Electricity; SOL Solar/tidal power; WIN Wind

* Sub-types in the database, not used for fuel production and combustion emissions

Hard coal:
- CKC Coking coal
- BTC Anthracite and bituminous coal
- SBC Sub-bituminous coal (except Canada and Spain from 1977)

Brown/coal lignite:
- BRC Brown coal/lignite

** No IEA fuel type; added to IEA list.

1) Main IEA sector level in process tree (see Table S.2)
2) Detailed IEA sector level in process tree (see Table S.2)

Table S.1.2: Energy combustion and transformation sectors used as energy processes in Version 2.0

Code	Main IEA sector	Code	Detailed IEA sector	Code	Sub-sector (IEA/EDGAR)	
	Final consumption:					
IND	Total industry sector	IRO	Iron and steel			
		NFE	Non-ferrous metals			
		CHE	Chemical and petrochemical	EC	Energy for combustion	1) 2)
				NEC	Energy as Feedstock	1)
		PAP	Pulp, paper & printing			
		NME	Building materials			3)
		NBMP	Other industry (non-BMP)	TEQ	Transportation equipment	
				MAC	Machinery	
				MIN	Mining & quarrying	
				FOO	Food, beverages & tobacco	
				WOO	Wood & wood products	
				CON	Construction	
				TEX	Textiles & leather	
				INO	Non-specified industry	
OTH	Total other sectors	AGR	Agriculture			
		COM	Commercial & public services			
		RES	Residential			
		ONO	Non-specified other			
TRA	Total transport sector	ROA	Road			4)
		RAI	Rail			
		AIR	Domestic air transport			
		INT	International air transport			
		ILW	Inland shipping (waterways)			
		PIP	Pipeline transport			
		TRN	Non-specified transport			
NON	Non-energy use	NEI	Non-energy use Industry			5)
		NET	Non-energy useTransport			
		NEO	Non-nergy use all Others			
	Energy transformation:					
ENE	Total energy sector	EMI	Coal mines	6)		
		OGX	Oil and gas extraction			
		EPA	Patent fuel plants			
		ECK	Coke ovens			
		EGA	Gas works			
		EBK	BKB plants			
		ERE	Oil refineries			
		POW	Power plants			
		PUM	Pumped storage (electricity)			
		HYP	Pumped hydro production			
		ENU	Nuclear Industry			
		ENO	Non-specified energy sector			
TRF	Total transformation sector	PEL	Public electricity production	7)		
		AEL	Autoproducers of electricity			
		CHP	Public cogeneration (CHP)	8)		
		AHP	Autoproduced cogeneration (CHP)	8)		
		DHE	District heating (public)			
		TRE	Oil refineries ('CNF inputs')	9)		
		TGA	Gas works (inputs)	9)		
		TCK	Coke ovens (inputs)			
		BLA	Blast furnaces			
		TPA	Patent fuel plants			
		TBK	BKB plants			
		LIQ	Liquefaction plants			
		TNO	Non-specified transformation			
	International shipping:					
BUN	International marine bunkers					
	Fuel production			10)		
PROD	Production and trade	PRO	Indigenous production	11)		
		OSO	Other sources			
		IMP	Imports			
		EXP	Exports	11)		
		STO	Stock change			
		DOM	Domestic supply	11)		
		TFS	Transfers			
		RET	Returns to supply			
		STA	Statistical differences			
		TFC	Total final consumption (DUMMY)			

Notes:

1) Sub-sectors to distinguish energetic use (combustion) from non-energy use.
In sub-codes chemical industry is often abbreviated as CH instead of CHE
2) No IEA sector; sub-sector added in EDGAR for consistency
3) IEA name: Non-metallic minerals
4) Excluding international shipping, which is a separate IEA sector because of its transnational character.
5) Consumption sector relevant for CO2 calculations. Includes consumption of lubricants, waxes etc.
6) Own use (combustion) of the energy industries. Includes combustion in refineries.
7) Primary fuel input in fuel transformation industries, including electric power generation
8) Combined heat & power (CHP)
9) Inputs (crude etc.) only; fuel consumption for combustion is located under ENE.
10) Not used for emission calculations are the data for distribution losses (LOS)
11) This data is not used, except for:
EXP (Exports) for Oil loading of tankers; and
DOM (Domestic supply) for Gas transmission and industrial combustion of some other solid fuels.

Table S.1.3: Main sectors of primary and secondary fuel production

Code	Main sector IEA/EDGAR	Code	Sub-sector EDGAR (IEA)	Code	Sub-sub-sector IEA/EDGAR	Code	Most detailed level EDGAR
	Primary fuel production						
EMI	**Coal mines**	E.PRO.HDC	**Hard coal production**	E.PRO.CKC	Coking coal	E.PRO.CKC.SU	Surface mining (open pit)
						E.PRO.CKC.UG	Underground mining
				E.PRO.BTC	Anthracite and bituminous coal	E.PRO.BTC.SU	Surface mining (open pit)
						E.PRO.BTC.UG	Underground mining
				E.PRO.SBC	Sub-bituminous coal	E.PRO.SBC.SU	Surface mining (open pit)
						E.PRO.SBC.UG	Underground mining
		E.PRO.BRS	**Brown coal production**	E.PRO.BRC	Brown coal/lignite	E.PRO.BRC.SU	Surface mining (open pit)
						E.PRO.BRC.UG	Underground mining
				E.PRO.SBC2	Sub-bituminous coal in CAN and ESP	E.PRO.SBC2.SU	Surface mining (open pit)
						E.PRO.SBC2.UG	Underground mining
		E.PRO.PEA	**Peat production**				
OGX	Oil and gas extraction	CRUDE	**Oil production**	E.PRO.CRU	Crude oil		
				E.PRO.NGL	Natural gas liquids		
		E.PRO.NGS	**Gas production**				
	Secondary fuel production 1)						
ENE	Energy production (dummy)	E.PRO1	Production of biofuel	E.PRO.MWS..OSF	Municipal Solid Waste..Other solid fuels		
		E.PRO2	Production of other renewables	E.PRO.HYD..NUC	Hydro-electricity..Nuclear electricity		
		E.PRO3	***Production of oil products***	E.PRO.RGS..LIQ	Refinery gas..Liquid fuel for electricity		
E.PRO.GGS	***Gas works gas production***						
ET-OTHER	Other transformation sector	E.PRO.PAT	***Patent fuel production***				
		E.PRO.BKB	***BKB production***				
		E.PRO.BGS	***Blast furnace gas production***				
		E.PRO.OGS	***Coke oven gas production***				
IRON	Iron and Steel (+ cokes)	IRO					
		E.PRO.OCK	***Coke production (in TJ; not in kton)***				

Notes:

Primary fuel production processes are shown in bold.

Secondary fuels produced by refineries, coke ovens, blast furnaces, gas works etc. are shown in italic.

Inputs of refineries, coke ovens, gas works, blast furnaces etc. are located under the TRF sector of energy processes.

1) Used for net CO_2 calculations of the fuel transformation sectors.

Codes refer to process codes in the database

S.2 Description of standard reported source categories

Table S.2.1: Codes and description of sectors per major source category

```
1.A. FUEL COMBUSTION PER SECTOR, INCLUDING FUEL PRODUCTION/TRANSMISSION:
--------------------------------------------------------------------------
Sectors for f:
A. Main sectors:
                    00 = ALL FUEL COMBUSTION, INCLUDING FUEL PRODUCTION/TRANSMISSION
                    10 = Industry (excluding coke ovens, refineries, etc.) *
                    20 = Power generation (public and auto; including cogeneration)
                    30 = Other transformation sector (refineries, coke ovens, gas works etc.)
                    40 = Residentials, Commercials and Other sector (RCO)
                    50 = Transport (including international shipping)
                    60 = Non-energy use and chemical feedstocks (for CO2)
                    70 = Coal production
                    80 = Oil production, transmission and handling
                    90 = Gas production and transmission

                    * For CO2 excluding chemical feedstocks (F11)

B. Standard reporting sectors:
                    10 = Industry (excluding coke ovens, refineries, etc.) *
                    20 = Power generation (public and auto; including cogeneration)
                    30 = Other transformation sector (refineries, coke ovens, gas works etc.)
                    40 = Residentials, Commercials and Other sector (RCO)
                    51 = Transport Road
                    54 = Transport Land Non-road (Rail+Inland water+Pipeline+Non-specified)
                    57 = Transport Air (Domestic+International) **
                    58 = Transport International shipping (marine bunkers)
                    60 = Non-energy use and chemical feedstocks (for CO2)
                    70 = Coal production ***
                    80 = Oil production, transmission and handling ****
                    90 = Gas production and transmission ***

                    *    For CO2 excluding chemical feedstocks (F11)
                    **   For air traffic on grid see separate list
                    ***  Not applicable for CO2
                    **** Not applicable for CO2 (for CO2 from flaring use F81)

                    A more detailed description is given in:
                    - IEA sector description notes in: Energy Statistics of OECD/non-OECD
                      countries, OECD/IEA, 1994)
                    - Sector description in: IPCC Guidelines for National Greenhouse Gas
                      Inventories, Vol. 1: Reporting instructions
                    - Files defining the process groups, using the IEA sector/fuel codes.

C. Detailed sectors:
           [not implemented on AFTP site; for information only]
                    11 = Industry: Iron & Steel (excluding coke ovens) *
                    12 = Industry: Non-ferro *
                    13 = Industry: Chemicals *  **
                    14 = Industry: Building materials *
                    15 = Industry: Pulp & Paper *
                    16 = Industry: Food & beverages *
                    17 = Industry: Other *
                    18 = Industry: BMP (Basic Materials Production) (sum of F11 to F15) *
                    19 = Industry: All, excluding chemical feedstocks **
                    21 = Power generation: public (excluding cogeneration)
                    22 = Power generation: autoproducers (excluding cogeneration)
                    23 = Power generation: total (excluding cogeneration)
                    24 = Power generation: public cogeneration
                    25 = Power generation: autoproduced cogeneration
                    26 = Power generation: total cogeneration
                    27 = Power generation: total public (incl. cogeneration)
                    28 = Power generation: total autoproduced (incl. cogeneration)
                    31 = OTS: Refineries
                    32 = OTS: Coke production
                    33 = OTS: Rest ****
                    35 = OTS (for CO2)
                    41 = RCO: Residentials
                    42 = RCO: Commercial and public services
                    43 = RCO: Other sector (including agriculture)
```

```
                 51 = Transport Road
                 52 = Transport Rail
                 53 = Transport Inland water
                 54 = Transport Land Non-road (Rail+Inland water+Pipeline+Non-specified)
                 55 = Transport Domestic Air
                 56 = Transport International Air
                 57 = Transport Air (Domestic+International)
                 58 = Transport International shipping (marine bunkers)
                 59 = Transport Non-specified (including pipelines)
                 61 = Non-energy use (for CO2)
                 62 = Chemical feedstock (for CO2)
                 65 = Other oil products (TP2) in all end-use sectors
                 66 = Other oil products (TP2) in industry
                 67 = Other oil products (TP2) in RCO+RRI+BUN
                 70 = Coal production ***
                 75 = Coal production+Coke production ***
                 81 = Oil production incl. transmission (excl. handling)
                 82 = Oil transmission (not included in Version 2.0) ***
                 83 = Oil handling (tankers) ***
                 85 = Oil prod., transm., handling, refining ***
                 91 = Gas production ***
                 92 = Gas transmission ***

                 *    Only for OECD countries, except for USA where coal consumption is
                      not split over industrial sub-sectors
                 **   For CO2 excluding chemical feedstocks (see F62)
                 ***  Not applicable for CO2
                 **** Including gas works and heat plants


1.B COMBUSTION PER FUEL TYPE AND SECTOR:
-------------------------------------
(ALTERNATIVE FOR ANALYSIS AND LINKAGE WITH IMAGE User Supprt System SCENARIO MODULES)

Sectors for c:   1 = Industry (excluding coke ovens, refineries) *
                 2 = Road transport
                 3 = Residentials
                 4 = Commercial and public services
                 5 = Other sector (agriculture, non-specified)
                 6 = Power generation (public and auto; including cogeneration)
                 7 = Other transformation sector (refineries, coke ovens, gas works etc.)
                 8 = Fossil fuel production and transmission

                 0 = Transport non-road land (RIO: rail, inland shipping, pipeline,
                     non-specified)
                 9 = Residentials, Commercials and Other sector (RCO)

                 * For CO2 including feedstocks and non-energy use

Fuel type for c:
                 g = gas (fossil fuel)
                 l = liquid (fossil fuel)
                 s = solid (fossil fuel)
                 t = traditional biofuels
                 m = modern biofuels

2. BIOFUEL COMBUSTION PER SECTOR:
--------------------------------
Standard reporting sectors for b:
                 10 = Industry (excluding coke ovens, refineries)
                 30 = Other transformation sector (refineries, coke ovens, gas works, etc.)
                 40 = RCO: Residentials *

                 * Only residential emissions; commercial and other sector have zero
                   biofuel combustion.

                 (other sectors have no biofuel combustion, thus no biofuel emissions)
```

```
3. INDUSTRIAL PROCESSES (non-combustion):
---------------------------------------
Standard reporting sectors for i:
                00 = ALL INDUSTRIAL PROCESSES
                10 = IRO: IRON&STEEL
                20 = NFE: NON-FERRO
                30 = CHE: CHEMICALS
                40 = NME: BUILDING MATERIALS (CEMENT)
                50 = PAP: PULP & PAPER (not included in Version 2.0)
                60 = FOO: FOOD, BEER & WINE (not included in Version 2.0)
                70 = SOL: SOLVENT USE
                80 = EVA: TRANSPORT EVAPORATION (not separately included in Version 2.0 *)

                90 = MIS-IND. MISCELLANEOUS (including halocarbons)

                * In Version 2.0 included as part of 'Road Transport' (F51)


Detailed sectors for i:
        [not implemented on AFTP site; for information only]
                11 = IRO-PELLET (not included in Version 2.0)
                12 = IRO-SINTER
                13 = IRO-PIG IRON
                14 = IRO-STEEL (OHF+BOF+EAF)
                16 = IRO-MILLS  (HOT/COLD)
                21 = NFE-COPPER (PRI+SEC)
                22 = NFE-LEAD (PRI+SEC)
                23 = NFE-ZINC (PRI+SEC)
                24 = NFE-ALUMINIUM (PRI+SEC)
                25 = NFE-OTHER
                31 = CHE-ADIPIC ACID (AA)
                32 = CHE-NITRIC ACID (NA)
                33 = CHE-AMMONIA (NH3)
                34 = CHE-SULPH. ACID (H2SO4)
                35 = CHE-N-FERTILISERS
                38 = CHE-BULK (MAJOR VOC EMITTORS):
                     Acetic acid
                     Acrylic polymers
                     Butadiene
                     Carbon black
                     Ethene (ethylene)
                     Formaldehyde (methanal)
                     Maleic anhydride
                     Polyethene LD + HD (total polyethylene)
                     Urea
                     Vinyl chloride

                39 = CHE-SPECIALTIES (SMALL VOC EMITTORS):
                     Acetaldehyde
                     Acetates
                     Acrylonitrile
                     Acetone
                     Benzene (benzol)
                     Butanol
                     Chlorine (Cl2)
                     Ethene oxide
                     Ethene glycol
                     Methanol
                     Phenol
                     Phthalic anhydride
                     Polypropene
                     Polystyrene
                     Propene
                     Poly Vinyl Chloride (PVC)
                     Rubber, total  (SBR + synthetic)
                     Styrene
                     Toluene
                     Xylenes
                41 = NME-CEMENT
                50 = PAP-PULP & PAPER (not included in Version 2.0)
                61 = FOO-BREAD (not included in Version 2.0)
                62 = FOO-BEER  (not included in Version 2.0)
                63 = FOO-WINE  (not included in Version 2.0)
                71 = SOL-CHEMICAL INDUSTRY
                72 = SOL-PAINT
                73 = SOL-CLEANING+INDUSTRIAL DEGREASING
                74 = SOL-GLUES/ADHESIVES+INK
                75 = SOL-LEATHER+VEGETAL OIL EXTRACTS
                76 = SOL-PESTICIDES
                77 = SOL-RUBBER & PLASTICS INDUSTRY
                78 = SOL-HOUSEHOLD PRODUCTS
                79 = SOL-OTHER SOLVENT USE
                80 = EVA-TRANSPART EVAPORATION (in Version 2.0 under fuel combustion)
                91 = MIS-CFC/HALOCARBONS (per compound)
                92 = MIS-INDUSTRY MISCELLANEOUS
```

```
4. LAND-USE AND WASTE TREATMENT:
-------------------------------
Standard reporting sectors for l:
                 00 = ALL LAND-USE AND WASTE TREATMENT
                 10 = AGRICULTURE ***
                 20 = ANIMALS (RUMINANT/WASTE)
                 30 = BIOMASS BURNING (LARGE) *  **
                 40 = WASTE TREATMENT **

                 *   For N2O including post-burn effects of deforestation
                 **  Base levels defined on grid (for L40 for agricultural waste burning
                     only)
                 *** For N2O excluding background emissions from grasslands

Detailed sectors for l:
        [not implemented on AFTP site; for information only]
                 11: AG-ARABLE LAND
                 12: AG-RICE CULTIVATION
                 21: AN-DAIRY CATTLE
                 22: AN-NON-DAIRY CATTLE
                 23: AN-GOATS
                 24: AN-CHICKEN
                 25: AN-PIGS
                 26: AN-SHEEP
                 27: AN-HORSES
                 28: AN-BUFFALOES
                 29: AN-CAMELS+CARIBOUS
                 31: BB-DEFORESTATION *
                 32: BB-SAVANNAH BURNING *
                 33: BB-POST-BURN EFFECTS (DEF.) (N2O) *
                 41: WH-AGRICULTURAL WASTE BURNING *
                 42: WH-UNCONTROLED WASTE BURNING (VOC)
                 43: WH-LANDFILLS (CH4)

                 * Base levels defined on grid


5. NATURAL SOURCES:
------------------
Standard reporting sectors for n:
                 10 = Natural soils (N2O; NOx) *  **
                 20 = Natural vegetation (NMVOC) ***
                 30 = Coastal/inland waters (not included in Version 2.0)
                 40 = Oceans (N2O) ****
                 50 = Lightning (NOx) (not included in Version 2.0)

                 *    For N2O including background emissions from grasslands
                 **   For NOx not yet implemented in V2.0
                 ***  Not yet implemented in V2.0
                 **** Includes negative emissions (sinks) in area where absorption
                      was assumed

6. AIR TRAFFIC:
--------------
Standard reporting sectors for a:
                 00 = Sum over all altitudes (0-19 km)
                 01 = Landing and Take-Off cycle (LTO; i.e. 0-1 km)
                 dc = Descend/Climb out (1-9 km)
                 cr = Cruise altitude (9-13 km)
                 hc = High Cruise (13-19 km)

Detailed sectors for a:
                 01 = Altitude band 00-01 km (= 'LTO cycle')
                 02 = Altitude band 01-02 km
                 ..
                 19 = Altitude band 18-19 km
```

S.3 Description of file format of gridded data

```
Description of filename codes: tsfyyccc.fff
                               ||||  |   |_ file format (e.g. 1x1, gei, wk1, prn, eps)
                               ||||  |_ compound (formula, 2 or 3 characters)
                               ||||_ year (last 2 digits)
                               |||_ sub-sector/fuel type
                               ||_ sector
                               |_ source type

File format:

        1x1 =   1x1 degree grid cells, with borders on whole degrees,
                using lower left corner coordinates as cell indicator
        gei =   GEIA format, using cell numbers to label grid cells
        wk1 =   table per sector and region for a compound in Lotus 123 format
        prn =   table per sector and region for a compound in ASCII format
        eps =   map in PostScript format

Format for grid files with extension "1x1":

        x,y,value

        with:   x = longitude (coordinate of lower left corner)
                y =latitude (coordinate lower left corner)
                value = real in format: n.nnnne+nn
        (comma used as separator; no spaces)

Unit:   kg element (C, N or S)/cell/a, except NMVOC: kg/cell/a and except in some
                                                                   summary tables

Compound:       co2 = CO2
                ch4 = CH4
                n2o = N2O
                co  = CO
                nox = NO2
                so2 = SO2
                nmv = NMVOC (total)
                vnn = NMVOC compound group no. nn (see separate list)
                nnn = last 3 (2) digits of CFC-11,12,113,114,115;
                                or Halon-1211,1301;
                                or HCFC-22,142b;
                xxx = other halogenated compounds (e.g. CTC, MCF, CH3Br as 3br)

Source type:    f = fuel combustion per sector, including fuel production/transmission
                c = combustion (per sector/fuel type) [Not implemented at FTP site]
                b = biofuel combustion per sector
                i = industrial processes (non-combustion) and solvent use
                l = landuse and waste treatment
                n = natural sources
                a = air traffic
                t = total (only for summary tables per compound)

N.B.
1. Grid files (*.1x1) are generally available at the site as compressed files (*.1x1.Z),
   in order to speed up data transfer and to save disc space. You will have to use the
   UNIX command 'uncompress' to get the original files, which may then expend in size by
   a factor of 2 or 3.
```

APPENDIX 3: DATA SETS

D.1 Data set for fossil fuel use

Construction of the data set

The IEA energy statistics 1971-1992 were used as activity data for fuel production and consumption (IEA/OECD, 1994). These statistics provide statistics for 24 OECD countries, 88 non-OECD countries and the sum of 3 remaining non-OECD country groups (see table D.1.1). To achieve a better spatial distribution the summed data of the latter 3 groups was disaggregated to individual country files using UN data to distribute regional production and consumption totals over these countries, thus creating 71 additional country files, which were given the ISO-N numerical code as country code (see Table D.1.2). In the database these can easily be recognized by the numerical IEA country code, which corresponds with the ISO-N numerical code of the country. Including these extensions, for the following EDGAR countries no separate energy data are available (see open fields of IEA code in country code table in Appendix R.1):
- Africa: Botswana, Equatorial Guinea, Lesotho, Namibia, Swaziland
- Latin America: Dominican Republic, Puerto Rico
- Asia: Yemen
- Europe: mini-states like Andorra
- Other: Greenland
- and many small island states/territories.

For road transport, Samaras (1993) provides information on fuel consumption for 43 countries, of which 37 are included in the (with UN data extended) IEA statistics but with no explicit data given for road transport and 6 countries are additional, i.e. not included in the extended IEA database. The original Samaras estimates for one year were extrapolated to the period 1971-1992 using GNP (or, if not available, population) as index (World Bank, 1993).

Total additional fuel consumption in 1990 is estimated to be 314.1 PJ, of which three countries contribute about 10% or more (PRI 21%, DOM 10%, CRI 9%) (see Table D.1.3). The total fuel consumption in road transport was in 1990 for the 43 countries 0.3% of global total consumption of liquid fuels. This is about 0.1% of global Total Primary Energy Supply. It is recognized that growth in transportation often is not proportional with GNP or population but often much stronger; however with lack of other info we used these as a indicator only. This means that before 1985 fuel consumption may be overestimated, whereas in 1990-1992 it may be somewhat underestimated.

For the 37 IEA/UN countries with no specific data for road transport, the time-series for road-gasoline and road-diesel consumption was used as estimate for this sub-sector. For the 6 countries, for which the extended IEA data set does not maintain any energy data we added the time-series as activity estimate for this particular source category.

For coal production additional assumptions were made on the division of hard coal and brown coal production in underground and surface (open pit) mining (see Table D.1.4).

Data processing

The IEA statistics data are given in natural units (e.g. in tons), in contrast with the IEA energy balance data, which are all specified in common energy units (toe-ton oil equivalent). However, in the energy balance data only main fuel types are distinguished such as solid, liquid and gaseous fuels. This was considered too aggregate for our needs, as for some key sectors the emission factors are specified per detailed fuel type, e.g. separately for gasoline and diesel consumption in transport. Therefore we decided to use the energy statistics data of IEA as our primary data set.

While processing the data into the database at the corresponding energy processes as base levels and derived energy demand factors for other processes, the units were converted into energy units (TJ) using the generic factors and country specific conversion tables supplied with the IEA energy statistics, so that all emission factors can be defined as kg/TJ (= g/GJ).

Table D.1.1: Countries in IEA Energy Balances and Statistics

OECD countries			**Non-OECD countries** *					
ISO-3	Name	IEA code	ISO-3	Name	IEA code	ISO-3	Name	IEA code
AUS	Australia	AUS	ALB	Albania	ALB	MLT	Malta	MAL
AUT	Austria	AUT	DZA	Algeria	ALG	MEX	Mexico	MEX
BEL	Belgium	BEL	AGO	Angola	ANG	MAR	Morocco	MOR
CAN	Canada	CAN	ARG	Argentina	ARG	MOZ	Mozambique	MOZ
DNK	Denmark	DNK	BHR	Bahrain	BAH	MMR	Myanmar	MYA
FIN	Finland	FIN	BGD	Bangladesh	BAN	NTZ	Neutral Zone	NZO
FRA	France	FRA	BEN	Benin	BEN	NPL	Nepal	NEP
DEU	Germany (western)	DEU	BOL	Bolivia	BOL	ANT	Netherlands Antilles	NET
GRC	Greece	GRE	BRA	Brazil	BRA	NGA	Nigeria	NIG
ISL	Iceland	ISL	BRN	Bruneï	BRU	PRK	North Korea	NKO
IRL	Ireland	IRE	BGR	Bulgaria	BUL	OMN	Oman	OMA
ITA	Italy	ITA	CMR	Cameroon	CAM	PAK	Pakistan	PAK
JPN	Japan	JPN	CHL	Chile	CHI	PAN	Panama	PAN
LUX	Luxembourg	LUX	CHN	China	CHN	PRY	Paraguay	PAR
NLD	Netherlands	NLD	COL	Colombia	COL	PER	Peru	PER
NZL	New Zealand	NZL	COG	Congo	CON	PHL	Philippines	PHI
NOR	Norway	NOR	CUB	Cuba	CUB	POL	Poland	POL
PRT	Portugal	POR	CYP	Cyprus	CYP	QAT	Qatar	QAT
ESP	Spain	ESP	CSK	Czechoslovakia	CSR	ROM	Romania	ROM
SWE	Sweden	SWE	ECU	Ecuador	ECU	SAU	Saudi Arabia	SAR
CHE	Switzerland	CHE	DDR	Eastern Germany	EGE	SEN	Senegal	SEN
TUR	Turkey	TUR	EGY	Egypt	EGY	SGP	Singapore	SIN
GBR	United Kingdom	GBR	ETH	Ethiopia	ETH	ZAF	South Africa	SAF
USA	United States	USA	GAB	Gabon	GAB	KOR	South Korea	SKO
			GHA	Ghana	GHA	LKA	Sri Lanka	SRI
			GIB	Gibraltar	GIB	SDN	Sudan	SUD
			GTM	Guatemala	GUA	SYR	Syria	SYR
			HKG	Hong Kong	HON	TWN	Taiwan	TAI
			HUN	Hungary	HUN	TZA	Tanzania	TAN
			IND	India	IND	THA	Thailand	THA
			IDN	Indonesia	INS	TTO	Trinidad	TRI
			IRN	Iran	IRA	TUN	Tunisia	TUN
			IRQ	Iraq	IRQ	ARE	United Arab Emirates	UAE
			ISR	Israel	ISR	URY	Uruguay	URU
			CIV	Ivory Coast	IVO	SUN	former USSR	USS
			JAM	Jamaica	JAM	VEN	Venezuela	VEN
			JOR	Jordan	JOR	VNM	Viet Nam	VIE
			KEN	Kenya	KEN	YEM	Yemen	YEM
			KWT	Kuwait	KUW	YUG	Yugoslavia	YUG
			LBN	Lebanon	LEB	ZAR	Zaire	ZAI
			LBY	Libya	LIB	ZMB	Zambia	ZAM
			MYS	Malaysia	MAY	ZWE	Zimbabwe	ZIM

* In addition totals are given for 'Other Africa', 'Other America' and 'Other Asia'.

Table D.1.2: Split of IEA data for 'Other Africa', 'Other America' and 'Other Asia' regions according to UN data

Fuel consumption:

Other Africa: 27		Other America: 25		Other Asia: 18	
ISO-A3	ISO-N1	ISO-A3	ISO-N1	ISO-A3	ISO-N1
BWA	***072***	ATG	028	AFG	004
BFA	854	BHS	044	ASM	016
BDI	108	BRB	052	BTN	064
CPV	132	BLZ	084	KHM	116
CAF	140	BMU	060	***CXR***	***162***
TCD	148	VGB	092	LAO	418
COM	174	CYM	136	MAC	446
GNQ	226	CRI	188	MDV	462
DJI	262	DMA	212	MNG	496
GMB	270	DOM	214	NRU	520
GIN	324	SLV	222	***PLW***	***585***
GNB	624	FLK	238	***COK***	***184***
LSO	***426***	GUF	254	SLB	090
LBR	430	GRD	308	FJI	242
MDG	450	GLP	312	PYF	258
MWI	454	GUY	328	GUM	316
MLI	466	HTI	332	NCL	540
MRT	478	HND	340	PNG	598
MUS	480	MTQ	474	***TMP***	***626***
NAM	***516***	***MSR***	***500***	TON	776
NER	562	NIC	558	VIR	580
REU	638	KNA	659	WSM	882
RWA	646	LCA	662		
SHN	***654***	SPM	666		
STP	678	VCT	670		
SYC	690	SUR	740		
SLE	694	***TCA***	***796***		
SOM	706				
ESH	732				
SWZ	***748***				
TGO	768				
UGA	800				

Fuel production:

Other Africa		Other America		Other Asia	
ISO-A3	ISO-N1	ISO-A3	ISO-N1	ISO-A3	ISO-N1
NER	562 1)	BRB	052 3)	MNG	496 5)
RWA	646 2)	SUR	740 4)	AFG	004 6)

1) All solids
2) All gas
3) Part of liquids; all gas
4) Part of liquids
5) All brown coal (lignite); part of hard coal
6) Part of hard coal; all gas

Note: In BOLD/ITALIC: countries not included in UN statistics or with total consumption = 0

Source: UN, 1992 Table 3: Consumption total
Table 6, 8, 28: Total Production per fuel type

Table D.1.3: Additional data for fuel consumption in road transport from Samaras

Country		Indicator applied (GNP or POP	1990 estimate Gasoline (TJ)	Diesel (TJ)	Total (TJ)	Fr. of added total (%)
BHS		GNP	1230.5	1194.5	2425.0	0.8
BWA	*	GNP	2321.8	1129.7	3451.5	1.1
BFA		GNP	2360.5	1136.6	3497.2	1.1
BDI		GNP	2208.9	2602.6	4811.5	1.5
CPV		GNP	107.1	187.6	294.7	0.1
CAF		GNP	1634.0	1045.1	2679.1	0.9
TCD		GNP	72.3	1610.0	1682.3	0.5
COM		GNP	135.5	279.4	415.0	0.1
CRI		GNP	11495.1	17418.6	28913.7	9.2
DJI		POP	392.1	272.7	664.8	0.2
DOM		GNP	22078.3	8822.1	30900.4	9.8
SLV	*	GNP	8606.0	3611.4	12217.3	3.9
FJI		GNP	1934.3	2345.8	4280.1	1.4
GUF		POP	2476.3	737.9	3214.2	1.0
GMB		GNP	1289.1	91.0	1380.1	0.4
GLP		POP	5173.2	7775.4	12948.6	4.1
GNB		GNP	1322.5	628.1	1950.6	0.6
GUY		GNP	2432.2	1901.8	4333.9	1.4
HTI		POP	2478.4	2486.7	4965.1	1.6
HND		GNP	5576.0	4343.1	9919.1	3.2
LAO		POP	1281.9	2493.9	3775.8	1.2
LSO	*	GNP	1101.6	1025.8	2127.4	0.7
LBR		POP	2132.7	552.4	2685.1	0.9
MDG		GNP	2604.8	2974.7	5579.5	1.8
MWI		GNP	2012.2	2721.0	4733.3	1.5
MLI		GNP	2629.3	1405.1	4034.4	1.3
MTQ		POP	4706.5	382.9	5089.4	1.6
MRT	*	GNP	380.4	934.8	1315.2	0.4
MUS		GNP	2410.7	1810.9	4221.5	1.3
NCL		POP	3126.2	363.7	3489.9	1.1
NIC		GNP	4894.2	12372.6	17266.8	5.5
NER		GNP	999.9	3985.1	4985.0	1.6
PNG		GNP	3484.6	2873.0	6357.6	2.0
PRI	*	GNP	44149.6	24413.5	68563.0	21.8
REU		POP	5254.5	6289.2	11543.7	3.7
RWA		GNP	1549.2	746.8	2296.0	0.7
SYC		GNP	122.3	178.4	300.7	0.1
SLE		GNP	6474.0	1835.4	8309.4	2.6
SOM		POP	2893.5	4769.1	7662.6	2.4
SUR		GNP	2983.4	1970.7	4954.1	1.6
SWZ	*	GNP	1946.2	2241.6	4187.8	1.3
TGO		GNP	964.5	37.2	1001.7	0.3
UGA		POP	4214.0	490.1	4704.1	1.5
Sum (PJ)			**177.6**	**136.5**	**314.1**	**100.0**

Note:

		Total added as percentage of global total:
Global TPES:	344 EJ	0.1
o.w. liquids:	123 EJ	0.3

* Countries with no IEA/UN data at all.

Sources: Samaras (1993)
World Bank (1993)

Table D.1.4: Fractions of surface and underground mining for hard coal and brown coal production per country used in the Coal Mine Production 1990 Map (V.1)

ISO code	HDC-Surface	HDC-Undergr.	BRC-Surface	BRC-Undergr.	Remark
AFG		1.000			No P/U data
ALB			0.783	0.217	
ARG		1.000			
AUS	0.640	0.360	1.000		
AUT			0.375	0.625	
BEL		1.000			
BRA	0.266	0.734			
BUL			1.000		
BWA		1.000			
CAN	0.892	0.108	1.000		
CHL		1.000	1.000		
CHN	0.082	0.918			
COL	0.900	0.100			
CSK		1.000	1.000		
DDR			1.000		
DEU		1.000	1.000		
DZA		1.000			
ESP	0.396	0.604	0.930	0.070	
FRA	0.076	0.924	0.250	0.750	
GBR	0.161	0.839			
GRC			1.000		
HUN	0.252	0.748			Acc. to IEA all coals are hard coal
IDN	0.928	0.072	1.000		
IND	0.353	0.647	1.000		
IRL		1.000			
IRN		1.000			
ITA		1.000	1.000		
JPN		1.000			
KOR		1.000			
MAR		1.000			
MEX	0.153	0.847			
MMR		1.000	1.000		
MNG	0.481	0.519	0.900	0.100	
MOZ		1.000			
MYS	0.636	0.364			
NGA		1.000			
NOR		1.000			
NZL	0.750	0.250	1.000		No data on lignite; assume Surface
PAK	1.000				
PER	1.000				
PHL	0.506	0.494			
POL		1.000	1.000		
PRK	1.000		1.000		
PRT			1.000		
ROM	0.500	0.500	1.000		
SUN	0.338	0.662	0.820	0.180	
SWE		1.000			No data on P/U
THA			1.000		
TUR		1.000	0.758	0.242	
TWN		1.000			
TZA		1.000			
USA	0.537	0.463	1.000		
VEN	1.000				
VTM	1.000				
YUG			0.904	0.096	
ZAF	0.363	0.637			
ZAR	0.333	0.667			
ZMB	1.000				
ZWE	0.667	0.333			

Sources: Mining Journal, 1994; Flegan, 1994 (CIS); Doyle, 1987 (China); supplemented with other IEA-CR and BoM reports.
Based on Coal Mine Production 1990 map - VERSION 1.0 (created by RIVM, 1995)

D.2 Calculated aggregated emission factors for fossil fuel combustion

Table D.2.1: Calculated globally and regionally aggregated emission factors for fossil fuel combustion in 1990 (rounded; in g/GJ, full molecular mass)

			Global average	OECD					Former Centr. Pl. Europe		Other non-OECD regions					
Compound	Fuel type	Main sector		USA	CANADA	W EUROPE	JAPAN	OCEANIA	CIS	E EUROPE	LATIN AM.	AFRICA	MIDDLE EAST	INDIA REGION	CHINA REGION	EAST ASIA
EF-CH4	solid	INDUSTRY	**10**	10	10	10	10	10	10	10	10	10	10	10	10	10
EF-CH4	solid	POWER GENERATION	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1
EF-CH4	solid	TOTAL OTHER SECTOR	**300**	300	300	300	300	300	300	300	300	300	300	300	300	300
EF-CH4	solid	NON-ROAD SURFACE TRANSPORT	**10**			10		10	10	10	10	10	10	10	10	
EF-CH4	liquid	INDUSTRY	**2**	2	2	2	2	2	2	2	2	2	2	2	2	2
EF-CH4	liquid	POWER GENERATION	**3**	3	3	3	3	3	3	3	3	3	3	3	3	3
EF-CH4	liquid	TOTAL OTHER SECTOR	**10**	10	5	5	5	10	20	5	10	5	5	5	5	5
EF-CH4	gasoline	ROAD TRANSPORT	**20**	15	15	23	20	25	20	30	20	20	20	70	20	50
EF-CH4	diesel	ROAD TRANSPORT	**5**	5	5	5	5	5	5	5	5	5	5	5	5	5
EF-CH4	lpg	ROAD TRANSPORT	**20**	20	20	20	20	20			20					20
EF-CH4	liquid	NON-ROAD SURFACE TRANSPORT	**5**	5	5	5	5	5	5	5	5	5	5	5	5	5
EF-CH4	gas	INDUSTRY	**5**	5	5	5	5	5	5	5	5	5	5	5	5	5
EF-CH4	gas	POWER GENERATION	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1
EF-CH4	gas	TOTAL OTHER SECTOR														
EF-CH4	gas	NON-ROAD SURFACE TRANSPORT														
EF-CO	solid	INDUSTRY	**130**	40	150	70	150	150	150	70	150	150	130	150	150	150
EF-CO	solid	POWER GENERATION	**15**	15	15	15	20	20	20	20	20	20	10	20	20	20
EF-CO	solid	TOTAL OTHER SECTOR	**4700**	5000	5700	3000	2800	4800	5000	3800	5600	4900	6000	4500	5000	5000
EF-CO	solid	NON-ROAD SURFACE TRANSPORT	**150**			100		150	150	100	150	150	100	150	150	
EF-CO	liquid	INDUSTRY	**10**	20	10	10	10	10	10	10	10	10	10	10	10	10
EF-CO	liquid	POWER GENERATION	**15**	20	10	10	10	10	20	10	10	10	10	10	10	10
EF-CO	liquid	TOTAL OTHER SECTOR	**30**	20	30	30	40	170	20	20	20	40	30	60	30	40
EF-CO	gasoline	ROAD TRANSPORT	**6200**	4700	4700	6300	2900	5300	9800	10700	8400	8200	8500	11100	8500	9400
EF-CO	diesel	ROAD TRANSPORT	**900**	600	600	600	1100	900	1300	900	1200	1000	1100	1000	1100	1300
EF-CO	lpg	ROAD TRANSPORT	**2500**	2400	2400	2800	2400	2400			2400					2400
EF-CO	liquid	NON-ROAD SURFACE TRANSPORT	**800**	600	500	600	800	700	700	800	1100	1000	1100	900	900	1100
EF-CO	gas	INDUSTRY	**30**	40	20	40	20	20	20	20	20	20	20	20	20	20
EF-CO	gas	POWER GENERATION	**20**	20	20	10	20	20	20	10	20	20	20	20	20	20
EF-CO	gas	TOTAL OTHER SECTOR				550				70						
EF-CO	gas	NON-ROAD SURFACE TRANSPORT														
EF-NOx	solid	INDUSTRY	**230**	280	190	150	160	250	270	160	180	240	180	250	240	200
EF-NOx	solid	POWER GENERATION	**310**	350	310	200	100	340	330	140	370	390	300	380	390	360
EF-NOx	solid	TOTAL OTHER SECTOR	**80**	80	80	80	90	80	80	60	80	80	70	80	80	80
EF-NOx	solid	NON-ROAD SURFACE TRANSPORT	**270**			190		270	270	180	270	270	180	270	270	
EF-NOx	liquid	INDUSTRY	**60**	60	60	70	40	70	60	100	60	70	50	60	50	60
EF-NOx	liquid	POWER GENERATION	**200**	170	240	230	120	100	260	190	230	180	150	200	220	220
EF-NOx	liquid	TOTAL OTHER SECTOR	**50**	50	50	50	50	50	50	50	50	50	50	50	50	50
EF-NOx	gasoline	ROAD TRANSPORT	**600**	700	700	700	200	700	500	500	500	700	500	300	500	400
EF-NOx	diesel	ROAD TRANSPORT	**800**	700	700	700	800	700	900	1000	900	1000	900	900	900	900
EF-NOx	lpg	ROAD TRANSPORT	**900**	900	900	900	900	900			900					900
EF-NOx	liquid	NON-ROAD SURFACE TRANSPORT	**700**	600	600	700	700	600	600	1000	900	900	900	900	700	800
EF-NOx	gas	INDUSTRY	**160**	270	110	150	110	110	110	130	110	110	110	110	110	110
EF-NOx	gas	POWER GENERATION	**160**	200	150	150	150	150	150	190	150	150	150	150	150	150
EF-NOx	gas	TOTAL OTHER SECTOR	**60**	50	50	80	50	50	50	60	50	50	50	50	50	50
EF-NOx	gas	NON-ROAD SURFACE TRANSPORT														

Table D.2.1: Calculated globally and regionally aggregated emission factors for fossil fuel combustion in 1990 (rounded; in g/GJ, full molecular mass) (c'ted)

			Global average	OECD					Former Centr. Pl. Europe		Other non-OECD regions					
Compound	Fuel type	Main sector		USA	CANADA	W EUROPE	JAPAN	OCEANIA	CIS	E EUROPE	LATIN AM.	AFRICA	MIDDLE EAST	INDIA REGION	CHINA REGION	EAST ASIA
EF-SO2	solid	INDUSTRY	**800**	800	700	700	300	500	800	800	700	700	1200	500	1000	800
EF-SO2	solid	POWER GENERATION	**900**	800	1400	900	500	500	900	1500	800	700	1500	600	1000	1000
EF-SO2	solid	TOTAL OTHER SECTOR	**900**	700	1100	900	500	800	800	900	1000	600	1400	600	1000	700
EF-SO2	solid	NON-ROAD SURFACE TRANSPORT	**900**			700		400	800	800	600	700	1100	500	1000	
EF-SO2	liquid	INDUSTRY	**410**	160	380	340	80	210	630	660	650	690	700	740	540	530
EF-SO2	liquid	POWER GENERATION	**900**	500	1100	1000	50	400	1200	1500	1100	900	700	1000	1000	1100
EF-SO2	liquid	TOTAL OTHER SECTOR	**180**	220	160	150	100	130	140	380	200	150	280	180	190	200
EF-SO2	gasoline	ROAD TRANSPORT	**50**	50	50	50	50	50	50	50	50	50	50	50	50	50
EF-SO2	diesel	ROAD TRANSPORT	**170**	140	140	140	200	140	140	140	140	140	140	540	250	140
EF-SO2	lpg	ROAD TRANSPORT	**20**	20	20	20	20	20			20					20
EF-SO2	liquid	NON-ROAD SURFACE TRANSPORT	**160**	130	110	130	220	150	80	130	130	140	140	520	200	130
EF-SO2	gas	INDUSTRY	**20**	25	5	80	30	5		5	5	10	5		40	
EF-SO2	gas	POWER GENERATION		10		60	5			10	1				30	
EF-SO2	gas	TOTAL OTHER SECTOR														
EF-SO2	gas	NON-ROAD SURFACE TRANSPORT				140										
EF-NMVOC	solid	INDUSTRY	**20**	5	20	10	20	20	20	10	20	20	20	20	20	20
EF-NMVOC	solid	POWER GENERATION	**2**	2	1	2	2	1	1	3	2	2	1	2	2	2
EF-NMVOC	solid	TOTAL OTHER SECTOR	**180**	200	200	80	80	170	200	130	200	200	190	170	200	200
EF-NMVOC	solid	NON-ROAD SURFACE TRANSPORT	**20**			14		20	20	13	20	20	13	20	20	
EF-NMVOC	liquid	INDUSTRY	**2**	4	2	2	1	2	2	2	2	2	2	2	2	2
EF-NMVOC	liquid	POWER GENERATION	**3**	5	3	3	2	2	3	5	3	3	2	3	3	3
EF-NMVOC	liquid	TOTAL OTHER SECTOR	**3**	3	3	3	3	3	3	2	3	3	3	3	3	3
EF-NMVOC	gasoline	ROAD TRANSPORT	**1000**	600	1000	1300	1400	1100	1100	1700	1300	1300	1300	4300	1200	3000
EF-NMVOC	diesel	ROAD TRANSPORT	**170**	180	110	140	150	130	220	190	190	200	190	160	210	190
EF-NMVOC	lpg	ROAD TRANSPORT	**380**	370	370	400	370	370			370					370
EF-NMVOC	liquid	NON-ROAD SURFACE TRANSPORT	**140**	160	80	120	110	100	110	180	170	190	180	150	160	170
EF-NMVOC	gas	INDUSTRY		10		5				5						
EF-NMVOC	gas	POWER GENERATION				5				5						
EF-NMVOC	gas	TOTAL OTHER SECTOR				35				10						
EF-NMVOC	gas	NON-ROAD SURFACE TRANSPORT														

Notes:

INDUSTRY	EXCLUDING THE ENERGY 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

solid \
liquid main fossil fuel types as defined in Table S.1 of Appendix 2.
gas /

For CO2 and N2O 3 sector independent emission factors were used, one per main fossil fuel type (with a few exceptions):

EF-CO2 (kg CO2/GJ)	solid	93.5	except for gas, LPG and ethane used as chemical feedstock (see Table 5.1.2).
	liquid	70.62	except for int. shipping (72.05) and non-energy use of naphtha, bitumen, lubricants, and of gas, LPG and ethane used as chemical feedstock (see Table 5.1.2).
	gas	56.1	
EF-N2O (g N2O/GJ)	solid	1.4	
	liquid	0.6	except for gasoline use in ROAD TRANSPORT in USA, CANADA, W EUROPE, JAPAN, OCEANIA due to the use of catalysts (see Table 5.1.3).
	gas	0.1	

D.3 Data set for biofuel consumption

As biofuels, in particular traditional biofuels, are often not commercially traded, it is very hard to obtain reliable national statistical data on consumption. This even holds for industrialized countries where non-foissil fuel consumption is not or only partially monitored by statistical agencies. Besides estimates of total national consumption, other information is also very difficult - if not impossible - to obtain: consumption per fuel type, definition of fuel types used, average fuel composition (moisture content, carbon content), distribution between urban and rural fractions, time period to which the data refer, and burning characteristics. If available, data often refer to several years ago. Although in developing countries biofuels are predominantly used in the rural residential sector for cooking purposes, we note that the service sector and small-scale industries, such as bread and brick manufacturing, can be substantial users (Hall, 1991).

In urbanized areas the compactness and portability of residential fuels are important fuel properties influencing the fuel mix. The marked differences in fuel quality introduce a shift from fuelwood to charcoal, and from biofuels to fossil fuels such as kerosene and LPG, and further to electricity (Jones, 1991). These two shifts, however, have an opposite effect on the per capita consumption of biofuel: the shift from fuelwood to charcoal introduces a *multiplier* of 6 to 12 because of production losses, whereas the shift towards fossil fuels obviously results in a cutback of biofuel use. The overall effect on the average per capita consumption of biofuel depends critically on the development of urban income and income distribution. Scurlock and Hall (1990), assuming that at present the shift away from traditional fuels in urban areas is not offset by the inherent energy losses of increased charcoal use, use for developing countries an average per capita consumption of biofuel of 1.0 ton/yr fuelwood equivalent for rural areas and 0.5 ton/yr for urban areas. However, they note that locally per capita consumption can be in the range of 0.5 to 2.9 ton/yr. Observed trends in development of biofuel use are not conclusive: some studies report a substantial decrease of biofuel use (such as Sathaye and Tyler, 1991, on selected Asian cities), whereas others note indications of increases over the last decade (such as Raskin and Lazarus, 1991, on Southern Africa).

Construction of the data set

For the construction of the EDGAR data set for biofuel use we have analyzed various references or biofuel use in individual countries. For present biofuel use in developing countries we decided to use either per country estimates compiled by the *Biomass User's Network* (BUN) (Hall *et al.*, 1994) or by OLADE (OLADE, 1993). For Latin American countries OLADE date were used when the BUN estimate was not based on a country specific reference. For the 23 OECD countries, Eastern European countries and the former USSR we used IEA statistics, extended with an amount for fuelwood consumption in case the BUN estimate for a country exceeded the IEA total figure (see Table D.3.5 for details). In the latter case total fuelwood consumption has been divided between the industry and the residential sector based on a ratio of 9:1 of total biofuel use in these sectors (WRI, 1986), except for the USA where we used a 28%-72% split (INEL/LANL/ORNL/SNL/SERI, 1990). The same procedure was applied for 26 Latin American countries, for which OLADE statistics were used, with increased fuelwood use in the residential sector in case BUN reported a higher estimate based of a country specific reference.

Next, we made assumptions how to divide the total biofuel consumption per country over various biofuels listed in Table D.3.1. We checked a number of country studies and defined groups of countries which we assumed to have a similar fuel split as the country/countries for which the case studies provided specific estimates of the fuel split. In Table D.3.2 the subdivisions for specific countries are listed. For the remaining African and Middle East countries a division was made in countries with and without cattle, thus defining two profiles: one with dung use and another without dung use.

For Latin American countries included in the OLADE statistics on biofuel use we used the OLADE figures for charcoal and sugar cane fuel consumption. Subsequently, the fuelwood consumption was calculated by subtracting the OLADE figures for charcoal and sugar cane fuel from the BUN figure for total biomass use. For Latin American countries not included in the OLADE statistics of biofuel use, a similar distinction was made as for African/Middle east countries: in countries having bagasse production (contributing 1% to the biofuel use and fuelwood the other 99%), and in countries having no bagasse production (fuelwood contributing 100%). Table D.3.4 summarizes the groups of countries for which a common profile was selected.

Information on the common profiles is presented in Table D.3.4.

Finally, we made an estimate how much of each biofuel was allocated to which sector: residentials, commercials, industry, power generation, transport, etc. Here we used a straightforward approach, assuming that IEA data, which in general refer to different types of waste mentioned in Table D.3.1, be used in industry if not explicitly allocated to one of the main IEA sectors. Traditional biofuel consumption, excluding wood waste, has been divided between the residential and the industrial sector. Modern biofuels - that is: ethanol - were allocated according to the country specific information.

Table D.3.1: Biofuels distinguished in EDGAR and their EDGAR/IEA code

Fuel type	IEA code
Total other solid fuels	OSF [1)]
o.w. WASTE (NON-WOOD):	
- Industrial waste	IWS
- Municipal waste	MWS
- Black liquor	BLI
o.w. TRADITIONAL BIOFUEL:	
- Wood	WOD
- Wood waste	WWS
- Charcoal	CHA
- Vegetal waste	VWS
- Dung	DU [2)]
- Bagasse	BA [2)]
- Other solid fuels (non-specified)	NSF [3)]
o.w. MODERN BIOFUEL:	
- Ethanol	ET [2)]

[1)] Unspecified total in IEA statistics.
[2)] No IEA fuel type.
[3)] This category may also refer to non-wood waste.

Table D.3.2: Country specific fuel-subdivision of total biofuel consumption (in %)

ISO3	WOD	WWS	CHA	VWS	BA	DU	ET	BLI	Reference
PHL	84.8		0.8	9.8	4.0			0.5	Serna, 1989
ZAF	75.3					24.7			Scholes *et al.*, 1994
SOM	52.3		47.7						Robinson and Smith, 1983
SEN	64.0			10.5	25.5				UNEP/OECD/IPCC/GEF,1994
MUS	20.2				79.8				Baguant *et al.*, 1992
SDN	65.9		22.5	9.9		1.7			Haskoning/ECN/NEA, 1992
BGD	10.6	5.1	[1]	67.8		16.5			GOB, 1987; Eusuf *et al.*, 1991
BRA	42.5		15.5				42.0		Geller and Zylberstajn, 1991
IDN	98.3		1.7						BPPT/KFA Jülich, 1988
IND	59.0		0.5	14.6		25.9			Barnard and Kristoferson, 1985
KEN	74.7		13.1	10.5		1.7	0.1		Senelwa and Hall, 1993
CHN	43.9			53.7		2.4			Zhu Yaji *et al.*, 1990
TZA	96.0		4.0						UNDP/WB-ESAP, 1984b
PAK	62.6			16.5		21.0			Leach, 1993
EGY				88.5		11.5			El Halwagi *et al.*, 1984
TUR	60.0			40.0					Veldt, pers. comm., 1995
ETH	43.1		1.3	22.8	0.6	32.2			UNDP/WB-ESAP, 1984
VNM	69.7 [2]		1.2 [2]	29.1 [3]					FAO, 1992
LAO	100.0		[1]						GOL, 1990

[1] Included in fuelwood.
[2] Subdivision fuelwood/charcoal based on India (IND).
[3] Includes bagasse.

Table D.3.3: Fuel-subdivision of biofuel consumption used for other countries

Region/country (ISO3 code)	Profile used
Africa/Middle East:	
COM, CPV, GNQ, GAB, LBR, REU, SHN, STP, SYC, ZAR	AFR1
NAM, BFA, BWA, BEN, CAF, CIV, GMB, GHA, GIN, MDG, NGA, TGO, ZWE, CMR, COG, GNB, SLE, UGA, AGO, BDI, MWI, MOZ, RWA, ZMB	AFR2
ARE, BHR, DJI, DZA, ESH, IRQ, JOR, KWT, LBY, MAR, MLI, MRT, NER, OMN, QAT, SAU, TCD, TUN, YEM	EGY
CYP, IRN, LBN, SYR, Gaza Strip, West Bank	TUR
Asia:	
AFG	PAK
HKG, KOR, MAC, MNG, PRK	CHN
BTN, NPL, IOT, MDV, LKA	IND
BRN, TMP, MYS, SGP, COK, FJI, PYF, GUM, KIR, NRU, NCL, NIU, PNG, ASM, WSM, SLB, TON, TUV, VUT, WLF, LAO, FSM	IDN
KHM, THA, MMR	VNM
Latin America:	
ARG, BAR, BOL, BRA, CHI, COL, COS, CUB, ECU, ELS, GRE, GUA, GUY, HAI, HON, JAM, MEX, NIC, PAN, PAR, PER, DOM, SUR, TRI, URU, VEN	OLADE, 1993 [1]
AIA, ATG, BLZ, GLP, MTQ, PRI, KNA, LCA, VCT, VGB, VIR	LAT1
ABW, BHS, BMU, CYM, DMA, MSR, ANT, TCA, FLK, GUF	LAT2

[1] For countries included in the OLADE statistics on biofuel use, for charcoal and sugar cane fuel, the OLADE figures are used; next, the fuelwood use was calculated by subtracting the OLADE figures for charcoal and sugar cane fuel from the BUN figure for total biomass use.

Table D.3.4: Fuel-subdivision of biofuel consumption: profiles for specific groups of countries

Region	WOD	WWS	CHA	VWS	BA	DU	ET	BLI
AFR1 [1)]	80.8		9.3	9.8	0.1			
AFR2 [2)]	71.0		8.2	8.6	0.1	12.1		
LAT1 [3)]	99.0				1.0			
LAT2 [4)]	100.0							

[1)] Profile AFR #1 is for African countries without cattle: Zaire, Gabon, Eq. Guinea, Reunion, Comoros, Seychelles, Cape Verde, Saint Helena, Sao Tome & Principe and Liberia.

[2)] Profile AFR #2 is for all other countries in African and the Middle East, which do not have a country specific profile.

[3)] Profile LAT #1 is for Latin American countries not mentioned in OLADE data, having bagasse production: Anguilla, Antigua and Barbuda, Belize, Guadeloupe, Martinique, Puerto Rico, St. Kitts and Nevis, St. Lucia, St. Vincent/Grenadines, British Virgin Islands and US Virgin Islands.

[4)] Profile LAT #2 is for Latin American countries not mentioned in OLADE data, which do not have bagasse production: Aruba, Bahamas, Bermuda, Cayman Islands, Dominica, Montserrat, Netherlands Antilles, Turks and Caicos Islands, Falkland Islands, French Guiana.

Table D.3.5: Fuelwood consumption in OECD countries in 1990 (in PJ)

Country	Residential	Industrial	Total	Perc. of OECD total
Australia	0	0	0	0.0
Austria	10	90	100	2.1
Belgium	2	15	17	0.4
Canada	47	419	466	9.8
DDR (former)	1	5	6	0.1
Denmark	7	60	67	1.4
Finland	11	102	113	2.4
France	32	284	316	6.7
Germany (former BRD)	2	20	22	0.5
Greece	4	38	42	0.9
Iceland	0	0	0	0.0
Ireland	5	41	46	1.0
Israel	0	0	0	0.0
Italy	12	110	122	2.6
Japan	1	5	6	0.1
Luxembourg	0	0	0	0.0
Netherlands	2	15	17	0.4
New Zealand	0	0	0	0.0
Norway	0	0	0	0.0
Portugal	3	31	34	0.7
Spain	4	36	40	0.8
Sweden	0	0	0	0.0
Switserland	1	8	9	0.2
Turkey	243	27	270	5.7
United Kingdom	4	39	43	0.9
USA	840	2160	3000	63.3
Total	**1231**	**3505**	**4736**	**100.0**

D.4 Data set for solvent use

The per country solvent use has been estimated using data on consumption, application and production of nine specific applications and an estimate for the use in the other categories. These nine specific applications which got most attention are: cleaning, glues and adhesives, graphic arts (ink), industrial degreasing, leather, paint, pesticides, rubber and plastics industry, and vegetal oil extraction; as other sources we considered other solvent use, including chemical industry and household use. Per application per country or region as much data as possible are collected. In general, for industrialized countries much data was found, whereas for other countries less data was available. When no country data were available, estimates were made based on regional data.

In case even no regional data are available, 'default' data have been generated which were based on socio-economic groupings. Per application we calculated per socio-economic group the average per capita use by applying the known per capita use of other countries belonging to the same socio-economic group. The definition of socio-economic groups is based on several social and economic parameters of a country, each with a weight factor, using the formula:

$$A^{0.25}*(1-B/100)^{0.25}*(C/100)^{0.25}*(D/100)^{0.1}*E^{0.4}*F^{0.1}*(G/100)^{0.05}$$

with:

A =	life expectancy divided by the highest life expectancy
B =	net birth rate per 1000 inhabitants
C =	percentage working in the industry
D =	percentage working in the services
E =	per capita GDP divided by the highest per capita GDP
F =	per capita electricity use divided by the highest per capita electricity use
G =	literacy rate

Most parameters have a range between 0 and 1. In general, if the parameter range is larger it has a more important role in the group identification of the country. Per capita GDP, for example, with values between 0.1 and 1.0 has the largest range. According to the outcome of the formula above, each country has been classified in one of four groups, as shown in Table D.4.1. Group 1 consists of most OECD countries, supplemented by a few others. In Group 2 we see, among others, other OECD countries, Eastern European countries, and the former USSR.

Table D.4.1: Socio-economic grouping of the world used in estimating per capita use of solvents

Group	Value range	Countries in group
Group 1	> 0.35	CHE, NOR, LUX, SWE, JPN, CAN, FIN, DEU, USA, NRU, LIE, ISL, AUT, DNK, FLK, BEL, NLD, FRA, KWT, DDR, AUS, SMR, ITA, BMU, GBR, MCO, CSK, ARE, QAT
Group 2	0.175-0.35	HKG, SGP, NZL, BRN, GUM, SUN, ABW, AND, ESP, BGR, POL, IRL, ISL, CYM, YUG, ANT PRI, ROM, VIR, GRL, BHR, BHS, CYP, LBY, TWN, MLT, NCL, SAU, MAC, GRC, OMN, VGB, PYF, PRT, KOR, BRB, HUN, TTO, VEN, ATG
Group 3	0.09-0.175	ARG, ASM, REU, URY, ZAF, SUR, GLP, KNA, GAB, SYC, CUB, BRA, MTQ, GUF, MYS, CHL, MEX, DZA, IRQ, CRI, MUS, JAM, PRK, TUR, JOR, The Gaza Strip/West Bank, COL, MNG, TUN, THA, ECU, PAN, PER, BLZ, ALB, LCA, SYR, IRN, DMA, GRD, VCT, BWA, PRY, FJI
Group 4	< 0.09	All 78 other countries, among which are CHN, IND, IDN, PAK, BGD, NGA

Note: For explanation of the ISO-Alpha 3 codes see Table R.1 in Appendix 1.

APPENDIX 4: MAPS

M.1 Construction/modification of population map

The global population distribution map plays a pivotal role in the construction of grid-based emission inventories for anthropogenic sources, as it acts as default or surrogate to distribute country emissions when no source specific map is available or when it can reasonably be assumed that the intensity of source activities is strongly correlated with population density. We greatfully acknowledge dr. J. Logan of Harvard University for providing the global population distribution map she constructed for other inventories, for instance the GEIA inventories on SO_2 and NO_x (Logan, 1993).

Map construction

When using statistical data on energy and industrial production in preparing the emission inventories, we noted that the population map does not include a number of small territorial entities, mostly islands, for which statistical data was available. For this reason, as mentioned earlier in Appendix R.2, 21 more minor territorial entities are included in EDGAR Version 2.0 than in the current GEIA standard. This is also reflected in the population maps currently used for GEIA inventories. Therefore, the Logan map of population density has been slightly extended by converting 21 ocean cells to island cells, while preserving the original definition of cells already defined as 'land'. These added entities and their geographical and population data are listed in the table below. This extended map is presented in Figure M.1.1.

With respect to the political unit table constructed using the country-to-grid-cell conversion table of NASA-GISS (1995), which was based on Lerner *et al.* (1988), the following minor entities: Andorra, Gibraltar, Monaco, Montserrat and Vatican City, were not included as separate entities occupying one complete cell, because this would destroy the population distribution in the respective cell and of its neighbours. For more details we refer to the Table M.1.1 below and its notes.

Table M.1.1: Entities included in EDGAR Version 2.0, but not in the Logan/GISS list

Entities in EDGAR, but not in Logan/GISS list

Additional code (own EDGAR extension of basic list)	Population (x1000)	Note	X	Y
***20100* American Samoa**	39.000		-171	-15
20200 Andorra	52.000	2)	1	42
***20300* Aruba**	62.500		-71	12
***20400* Bouvet Island**	??		3	-55
***20500* Britisch Indian Ocean Terr. (Chagos)**	2.900		72	-6
20600 British Virgin Islands	13.000	3)	-65	18
***20700* Cayman Islands**	27.000		-82	19
***20800* Christmas Island (Australia)**	2.000		105	-11
***20900* Cocos (Keeling) Islands**	0.600		96	-12
21000 Gibraltar	30.700	2)	-5.21	36.1
***21100* Heard & McDonald Islands**	NPP (= 0)		73	-53
21200 Iraq-Saudi Arabia Neutral Zone	??		??	
***21300* Macau**	479.000	4)	-1	45
***21400* Marshall Islands**	40.600		167	8
21500 Monaco	29.900	2)	7.25	43.4
21600 Montserrat	13.000	2)	64	17
***21700* Niue**	2.200		-170	-20
***21800* Norfolk Island**	2.000		167	-30
***21900* Northern Mariana Islands**	20.600		146	17
***22000* Pacific Trust Territory (Micronesia)**	109.000	1)	152	7
***22100* Palau**	14.100		134	7
***22200* Pitcairn Islands**	0.059		-130	-25
***22300* Puerto Rico**	3599.000	5)	-68	18
			-67	18
			-66	18
***22400* St Helena**	5.600		-16	-6
***22500* St-Pierre & Miquelon**	6.400		-57	46
***22600* Svalbard and Jan Mayen Islands**	3.900		see list SJM	7)
***22700* Tahiti and Moorea**	115.800		-149	-17
22800 Timor Timur (East Timor)	??	6)	9	125
			9	126
***22900* Tokelau**	1.700		-173	-9
23000 Vatican City	0.800	2)	12.27	41.5
***23100* Virgin Islands (US)**	113.000	3)	-65	18
***23200* Wallis & Futuna**	15.400		-177	-14
Sum of 21 underlined entities:	**580.459**			
(The largest being Pacific Trust Territory, Tahiti and Moorea, US Virgin Islands, all over 100,000 pop.)				

bold = modified
not-bold: see note **
underlined = currently located as 'Sea'; not in Logan population map; added to EDGAR map

Notes: Population data from Times Atlas of the World. 9th Comprehensive Ed.

1) Coordinates of Chunk island
2) Included in EDGAR as entity, but not in c2g conversion table (would damage larger country distributions).
3) US Virgin Islands are largest; British Virgin Islands have much less people; therefore include US VI, not UK VI.
4) In Logan/GISS located as France (5500)
5) In Logan/GISS located as USA (17652)
6) Included in EDGAR as entity, but not in c2g conversion table (not on WORLD 90 coverage).
7) Population put in cel (15,78)

SJM list: 15-17, 77; 13-18, 78; 21, 78; 11-18, 79; 21-25, 79 (now located as Norway (12600))
NPP: Not permanently populated

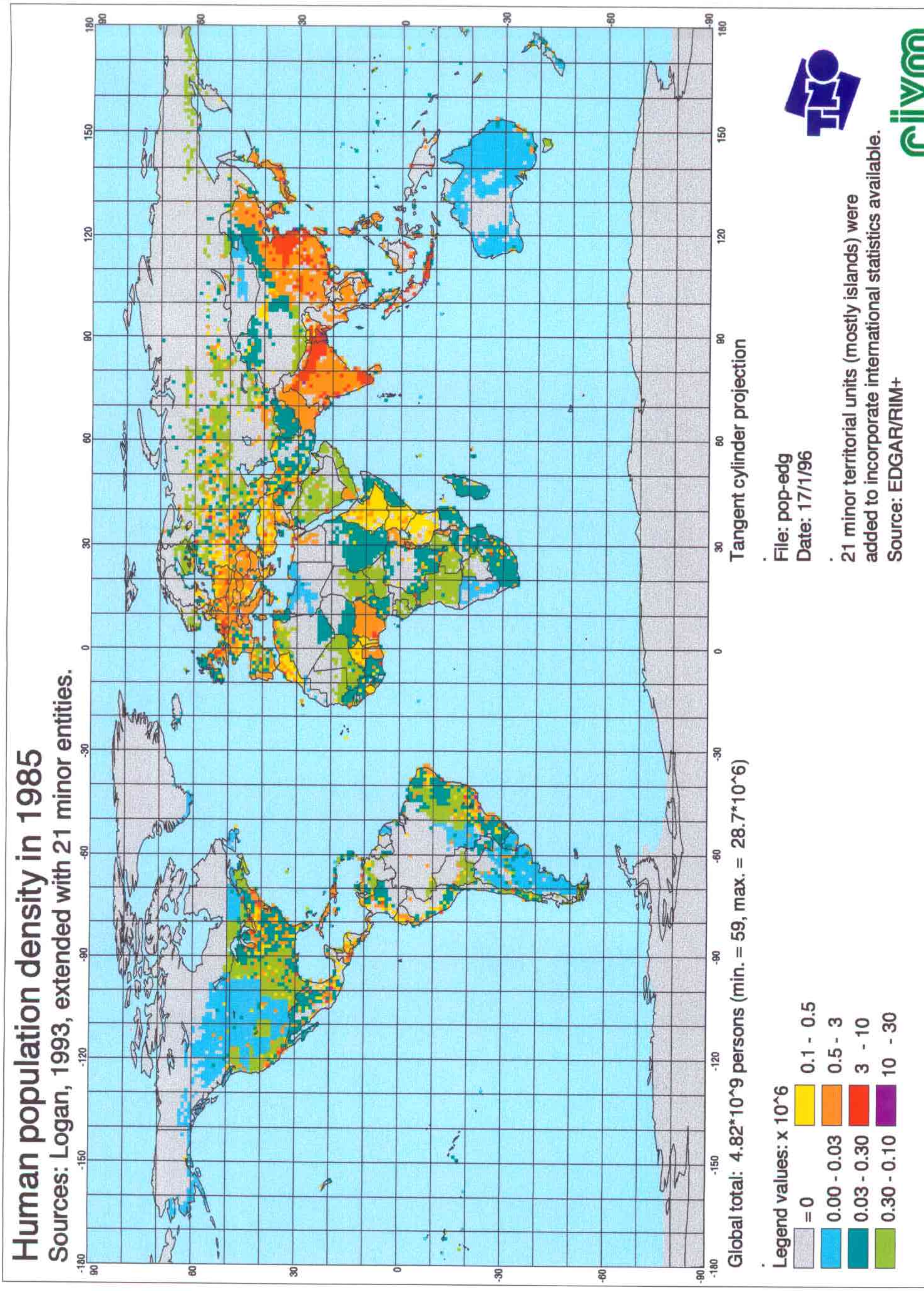
Entities in Logan/GISS, but not in EDGAR

Logan/GISS code and name	Population (persons)	Note	X	Y
25500 KERGUELEN	75	1)	1b)	
18600 YEMEN DEM		2)		

Notes:

1) Not in EDGAR (69, -50); pop. 75 people
1b) *In original file the grid cell for Kerguelen was erroneously (-69,-50)*
2) Joined with Yemen AR (18700)

Figure M.1.1: Logan population density map for 1985, extended with 21 minor entities.



M.2 Construction of coal production maps

The map of global distribution of coal production in 1990 has been composed of four sub-maps: one for hard and one for brown coal, both separated into surface mining (open pit) and underground mining, to be able to apply different methane emission factors for each of these cases. According to IEA (1994) there are 60 countries with production of hard and/or brown coal (lignite) in 1990. An inventory of Mining Journal (1992) reports coal production by almost the same group of countries, except that they added Botswana, Swaziland and Malawi to their list, but at the other hand they do not include Peru, Ireland and Sweden. Version 1.0 of our coal production map is based on reported production in 1990 by the IEA and includes about 2100 mines in 60 countries, of which 588 are located in the former USSR, 389 in the USA, 180 in China, 149 in India and 110 in Australia.

Map construction

First, for each country the following coal mine data was collected, preferably for 1990: coal type, amount and type of production, and the location of the mine. Production was reported in tonnes, either saleable, or clean or Run-Of-Mine (ROM), i.e. untreated. Although the definition of reported coal production varied between mines, per country the classification was often - but always - the same. Principal sources were: Mining Journal (1992), which provided data for all major producing countries, except for the former USSR and China for which Flegon (1994) and Doyle (1987) were used, respectively. Additional sources were Doyle (1990) [for Malaysia, Mongolia, North Korea, Taiwan and Vietnam], Daniel (1991) [for Mozambique, Tanzania and Zaire], and BoM (1989b, 1991, 1992) [for Afghanistan, Algeria, Ireland, Mongolia, Myanmar, Pakistan, Peru, Sweden and Tanzania]. We note that for China and India a substantial part of the reported mines could not be located on the map. The coal mine databook of the Mining Journal Ltd was selected as primary source, since it contains information on both production and locations, as well as on the type of coal and of the mining operation (surface or underground). A drawback is that it does not refer to 1990 for all countries. Another omission is that the calorific value of the coal is not specified per mine. Thereby it was not possible to convert all production quantities to a common energy unit. Walker (1993) was used for a visual check of the coordinates found for the locations per country.

Next, points in grid cells which are - according to the GEIA political unit map or 'country-to-grid cell relation' - defined as ocean or as related to another country than the point source is in, were moved to an adjacent cell, which is related to the country to which the point source belongs.

Subsequently, per country the total amount of hard and brown coal production (in TJ) was divided into a fraction produced by surface mining and another fraction produced by underground mining. We compared our fractions of surface mining, calculated from the located mine data described above, with figures reported by Thakur *et al.* (1994). This was done for the top-10 producing countries, representing more than 85% of global total production. For all countries the differences were small, except for India and China where the difference were more than 50%. Therefore, we used the surface and underground fractions calculated from the mines included in the coal map to make the split of total production data, except for India where we used the fractions as reported by Thakur *et al.* (1994). Since surface mining in China represents only a minor fraction, we did not substituted our map based calculations here.

Finally, per country the 1990 figures for hard and brown coal production, surface and underground mined, were allocated to each to each located mine within that country according to its reported production in physical units (tonnes).

Concluding remarks

Regarding the quality of the final result we note that for China and India the quality of distribution may be relatively low since the coordinates of about half of the reported mines could not be tracked down in gazetteers. In addition, in China a large part of coal is produced in small mines, of which no location have been reported at all. Also, in some other Asian countries the data found in other references were not always comparable, probably because of the use of different names of mines and locations. Nevertheless, a comparison with coalfields indicated in Walker (1993) and a coal map provided by Matthews (pers. comm., 1995) showed a good coverage and distribution, also within China and India. Further research may lead to improved distribution patterns. Taking these remarks for granted, we believe that the overall quality of our composite map, in particular the high density areas, is sufficient for use to generate the spatial distribution of methane emissions from coal production.

In Table M.2.1 the emission factors are listed used for calculating methane emissions from coal mining.

Table M.2.1: Emission factors for methane from coal production in 1990

Hard coal:				Brown coal:			
Underground		Surface		Underground		Surface	
World	835	World	77	World	24	World	24
USA	815	USA	75	AFG	39	AFG	39
CSK	785	AUS	60	ROM	39	BRA	39
DEU	675	GBR	15	VNM	39	COL	39
HUN	585			AUS	0.26	CSK	39
POL	585			THA	0.26	NOR	39
ROM	585					PHL	39
SUN	585					PRT	39
GBR	455					ROM	39
AUS	335					VNM	39
AFG	325					AUS	0.26
CHN	325					DDR	0.26
IDN	325					DZA	0.26
IND	325					ESP	0.26
KOR	325					GBR	0.26
MMR	325					IRN	0.26
MNG	325					PRK	0.26
MYS	325					SUN	0.26
PHL	325						
TWN	325						
ZAF	270						

Note: For ISO3 country codes we refer to Appendix R.1.

M.3 Construction of maps for oil and gas production, oil handling and oil refining

Crude oil production map

The global distribution of crude oil production is primarily based upon the *World Wide Crude Oil Production Survey* of OGJ (1995). for the USSR, data on the location and magnitude of the crude oil production facilities have been derived for the greater part from maps on oil and gas fields published by IPE (1990, 1994). For the USA, the activity levels on grid have been taken mainly from EPA (1993). The total amount of crude oil production for each country reported by IEA (1994) has been allocated to each oil field within that country according to its reported production. The crude oil production map comprises approximately 3000 point sources, including offshore production platforms.

Natural gas production map

The global distribution (location and magnitude) of the gas production facilities has been compiled from maps on oil and gas fields published by IPE (1990, 1994). For the former USSR we used local production figures from Sagers and Shabad (1990). The national - for large countries local - production of natural gas has been divided over the countries or counties point sources according the estimated production. For some countries, where natural gas is mainly produced as associated gas, point sources from the oil production map have been used. The natural gas production map comprises about 600 point sources, including offshore production.

Tanker loading map

For countries with a significant oil export through marine tankers, a global survey on tanker terminals (i.e. single point moorings) from IPE (1989) has been used. The throughput per point has been estimated by taking the sum of the production of the accompanying oil fields. Subsequently, the total amount of crude oil export for each country as reported by IEA (1994) has been allocated to the loading points within that country according to their reported throughput. The tanker loading map contains about 300 point sources.

Petroleum refining map

The global distribution of oil refineries is compiled from data provided by OGJ (1995). For the former USSR and the Eastern European countries, locations and capacities for refineries have been taken from Veldt (1994) and TNO-MW (1990), respectively. The total amount of crude for each country reported by IEA (1994) has been allocated to each refinery within that country according to its capacity. The petroleum refining map includes approximately 700 point sources.

M.4 Construction of the map of global N_2O emissions from adipic acid production

The map of global distribution of N_2O emissions from production of adipic acid (AA) contains 22 point sources in 17 countries and refers to an estimated annual production capacity around 1993 of about 2.6 kton and a global average abatement rate of 53%.

Map construction

The map is based on the production capacity and location of 17 plants reported by Castellan *et al.* (1991), supplemented with estimates for production in Brazil, China and South Korea provided by McCulloch (1993) and own estimates for the former USSR and Eastern Europe. For the latter two we assumed a production capacity of 250 ton each, which is in line with estimates made by Thiemens and Trogler (1991). To allocate Eastern European production on the grid, we made the additional assumption that Poland is the likely producer within Eastern Europe. The DuPont plant in Singapore, which was due to be in operation from 1993, has been included in the map in order to be able to include this point in grid-based emission projections for 1993 onwards. Lacking further information, for Brazil, China, South Korea, Poland and the former USSR we used the country capital as the location of the adipic acid plant.

Subsequently, points in grid cells which are - according to the GEIA political unit map or 'country-to-grid cell relation' - defined as ocean or as related to another country than the point source is in, were moved to an adjacent cell, which is related to the country to which the point source belongs.

The total production capacity, thus calculated, adds up to about 2.5 kton of adipic acid per year in 1993. The actual global production may be some 20-25% lower than the capacity (Castellan *et al.*, 1991; McCulloch, 1993). Our estimate is close to Thiemens and Trogler (1991), who reported an estimated global production for 1989 of 2.2 kton.

To incorporate information available on different abatement rates, we corrected the gross emissions for these reduction rates. The emission factor for unabated emissions is 300 g N_2O per kg of adipic acid. When abated by incineration, N_2O emissions may be reduced by 98%, as in the case of the DuPont plant in Victoria (Texas, USA) accounting for about 15% of the world's production capacity (Reimer *et al.*, 1993). The global average abatement may be about 32%, while the average for all DuPont plants - in total about 30% of the world's production capacity - may be 53% (Reimer *et al.*, 1993). As a result, we have adopted 4 g N_2O-N per kg AA (98% abatement) for the DuPont Victoria plant and 191 g N_2O-N per kg AA in the other DuPont plants. For all other producers we used an emission rate of 147 g N_2O-N per kg AA produced, corresponding to 23% abatement.

Concluding remark

In order to estimate the current or future grid-based emissions of N_2O from AA production using this map, one should correct for the fraction of production capacity which is actually utilized and possible additional abatement which may be added in the future. For five countries/regions for which the exact location of the plant is not known, we preferred to use the country capital as a surrogate instead of distributing country emissions over all populated grid cells, which does not increase the spatial quality neither in case there is presumably only one point source.

M.5 Construction of non-ferro metal production maps

Seven maps have been compiled for global distribution of production non-ferro metals: for copper, lead and zinc, both for primary and secondary production, and for primary aluminium production. All maps are based on reported production capacity, not actual production. The copper maps contain 124 primary smelters in 44 countries and 47 secondary plants in 27 countries, which add up to 11.1 and 2.3 Mton capacity in 1990, respectively. For the map of primary lead production 75 point sources are used in 38 countries. The map of secondary lead production contains 175 points in 52 countries. For 1990 the total production capacities of these plants is about 3.5 and 2.8 Mton, respectively. For the map of primary zinc production we used 81 point sources in 38 countries. The map of secondary zinc production contains 52 points in 20 countries. The total production capacities of these plants is about 7.7 and 0.6 Mton in 1990, respectively. Finally, the map of primary aluminium production contains 153 point sources in 43 countries, adding to a total capacity of 22.3 Mton per year for years around 1990.

Map construction

For all maps we used the countries for which UN (1993/1995) provides national production figures of the selected commodities for 1990 as a primary reference in developing the non-ferro metal production maps. Whenever possible, we included only plants active in 1990 in our compilation.

The copper maps are based on information provided by the International Copper Study Group (ICSG, pers. comm., 1995). To get a optimum match for 1990, we omitted primary smelters and secondary productions plants from our list which were reported to be out of production in 1990 or due to be on steam after 1990.

For the maps of lead and zinc production we used data reported by the International Lead and Zinc Study Group (ILZSG, 1994a,b,c). Here we also excluded plants from the list which were not in operation in 1990. In addition, we added countries for which the UN (1993) reports production, but which do not occur in the ILZSG reports. For the map of primary lead production 14 locations in 7 countries were added based on BoM (1989, 1991, 1992) or on secondary production locations in those countries. To compile the map of secondary lead production we added 10 point sources in 5 countries, taken from BoM (1989, 1991, 1992) or from primary production locations. The map of primary zinc production was extended with 4 locations in 4 countries based on BoM data or on secondary production locations of zinc or lead, whereas 4 points in 2 countries taken from primary zinc production locations were added to the map of secondary zinc production.

Version 1 of primary aluminium production map was compiled from data reported by BoM (1989a,b, 1991, 1992). We acknowledge that other data sources may provide a more complete picture, however these became available only after completion of the Version 2.0 of EDGAR.

As a last step, points in grid cells which are - according to the GEIA political unit map or 'country-to-grid cell relation' - defined as ocean or as related to another country than the point source is in, were moved to an adjacent cell, which is related to the country to which the point source belongs.

Concluding remarks

Since the maps are compiled from reported production capacities not from actual production, in reality the spatial distribution of actual emissions within a country, which is based on actual production levels, may be somewhat different. However, taking into account the uncertainties involved in estimating actual emissions at the country level, this uncertainty may well be smaller or of comparable size as a per plant emission estimate.

M.6 Construction of main international shipping route map

In order to be able to allocate the emissions from fuel consumption of international marine bunkers, which associates with the sector 'international shipping', we needed to compile a grid-based map for this source. Version 1 of this map has been simply compiled as a group of low resolution polygons derived from the visual presentation of the routes as labelled as 'main shipping routes' in the Times' Atlas of the World (1992), and extended with a few others which are described below in more detail. In addition, all grid cells of the map got one out of three different intensity levels (1, 4 or 16). The complete map consists of almost 1000 grid cells, of which about 450 cells were classified as having an intensity of 25, 490 cells with intensity level 100 and 58 cells with a level 400.

Map construction

The map of international shipping activities has been based on shipping routes presented on maps in the Times' Atlas of the World (1992) and on a preliminary estimate of SO_2 emissions from international shipping presented in a paper submitted to the International Maritime Organization, which was based on international trade between countries, a polygon analysis of international shipping routes between main ports, and per country estimates of the sulphur content of bunker fuels loaded (IMO, 1992). The latter paper also provides emission intensities expressed as kg S/mile/year for each polygon section. Assuming that the sulphur content does not vary much between countries, these emission intensities are also a measure of fuel consumption per mile.

A comparison between these references shows the following major differences in main routes: the Times' Atlas presents Japan-USA, Brazil-Argentina, Morocco-Brazil, Spain-Egypt as main routes, which the IMO paper does not consider to be important. On the other hand, the IMO estimate of main routes include Denmark-Finland (= Baltic Sea), Netherlands-Venezuela, Spain-USA, and to a lesser extent Oman-Sri Lanka and Indonesia-Australia, which are not among the Times' Atlas main routes. Regarding the intensity of the shipping routes, the Times' Atlas only distinguishes 'main' and 'other' shipping routes, whereas the emission intensity estimates in IMO paper (expressed as kg S/mile/yr) differ substantially:

* Highest: North Sea, Baltic Sea and the coast of France and Portugal
* High: Red Sea, Persian Gulf and Arabian Sea
* Low: Pacific, except Indonesia-Japan (= USA-Japan and USA-Panama)
South Atlantic (= Venezuela-Brazil-Argentina and the African coast)
Australia
* Middle: rest of the shipping routes considered.

Since the IMO paper only presents very preliminary results, Version 1.0 of the international shipping map has been compiled mainly from the shipping routes as labelled as 'main shipping routes' in the Times' Atlas of the World (1992), extended with the following connections labelled as 'other shipping routes' as suggested by the IMO paper (IMO, 1992), also to get a better interregional coverage:

- Baltic Sea
- UK-Venezuela ('London-Maracaibo')
- Spain-USA ('Gibraltar-New York')
- Oman-Sri Lanka ('Masqat-Colombo')
- Indonesia-Australia ('Singapore-Sydney').

Based on the preliminary figures presented in the IMO paper we decided not to use a sophisticated approach for the intensity distribution, but rather use one of three intensity levels for each discrete line: high, moderate and low, corresponding to 400, 100 and 25 units/cell/yr, respectively. This gives the following result:

* High: North Sea, Baltic Sea, coast of France and Portugal (North Atlantic)
* Low: USA-Japan, USA-Panama (Pacific, except Indonesia-Japan),
Venezuela-Brazil-Argentina, Morocco-Brazil, African coast (South Atlantic),
South Africa-Oman (East African coast)
Indonesia-Australia (North of Australia)
* Moderate: All other main shipping routes.

The total map comprises about 1000 cells, the 58 cells of high intensity taken a share of almost 30%, the 490 cells classified as moderate intensive contain about 60% and the remaining 450 low intensive cells have a share of about 10% in global total bunker fuel consumption.

The actual cells of each route were determined by dividing the selected routes on the map visually into polygons consisting of almost straight lines segments. Then, of these segments the cross section with the $1^{o}x1^{o}$ grid cells was calculated, using straight line segments on a map using a tangent cylinder projection.

Concluding remarks

Although we have only included what we believe to be the main shipping routes and an indication of their relative intensity, we believe that the International Shipping Map Version 1.0 gives a fair fist approximation of the spatial distribution of international shipping activities. Of course, the map may be improved by fitting in regional shipping inventories as the become available, such as expected for the North Atlantic from the EMEP programme or the North Pacific near the Asian coasts e.g. from the RAINS ASIA programme. Nevertheless, this map is a major improvement compared to the alternative of a uniform distribution over all ocean cells.

M.7 Construction of air traffic maps

The global air traffic maps consist of four comprehensive sets of maps on 1°x1° for 19 altitude bands of 1 km, thus ranging from 0 to 19 km altitude above the earth's surface, for emissions for NO_x, CO and VOC and for fuel consumption in 1990 by all aircraft. The VOC map actually refers to all emitted unburned hydrocarbons, which we assumed to be NMVOC, thus neglecting methane and other non-VOC substances. The maps were provided by NASA (1993), which is kindly acknowledged for providing these separate sets of the 3D distribution of emissions and fuel consumption by all aircraft in 1990. This set of maps has also been adopted by GEIA as Version 1.0 of the GEIA inventory of aircraft emissions on 1°x1°. Another comprehensive global inventory of aircraft activities, which was recently compiled by the ECAC/ANCAT group in support of the AERONOX project of the European Union (ECAC/ANCAT, 1994), was not yet available at 1°x1° resolution. Also, they did not yet include the three compounds availably in the NASA inventory. Therefore, and also because to comply with GEIA inventories, we used the NASA maps for 3D aircraft emissions in EDGAR Version 2.0.

The maps were compiled by Boeing and McDonnell Douglas in support of the *Atmospheric Effects of Stratospheric Aircraft/High-Speed Research Programme* (AESA/HSRP). They include all air traffic, civil as well as military, including general aviation, and were created from a detailed inventory of aircraft movements, aircraft type and flight phase specific emission factors (Wuebbles *et al.*, 1992, 1993).

Map construction

Since the global total fuel consumption included in the NASA inventory includes 78.4% of total registered jet fuel consumption in 1990 as compared statistics of IEA (1994), we calibrated all four sets to 1990 total fuel consumption in IEA (1994) of 170.7 Mton (3.79 EJ). This implies a multiplication by a factor of 1.2753. However, we note that other statistics may give somewhat different figures for the global total, such as UN (1992), which reports a global total of 156.2 Mton (i.e. 9% less than the IEA value).

The fuel consumption maps are used to estimate the global 3D distribution of all emissions except NO_x, CO and NMVOC, for which we used the specific (but fuel-calibrated) NASA maps. Methane emissions appear to be negligible in all flight conditions, except for the Landing and Take-Off (LTO) cycle, where according to Olivier (1995) the methane emissions account for about 10% of total VOC emissions. For this reason and referring to the inherent uncertainty of the total VOC emission factors for this sector, we did not correct the VOC maps for the methane fraction but used them directly as distribution of NMVOC emissions from air traffic. Except for methane, where only emissions in the LTO cycle were assumed, for other compounds such as CO_2, N_2O and SO_2, we applied a global average emission factor to the fuel consumption maps.

Concluding remarks

To provide the user a visual impression of the distribution of emissions below 1 km, which are essentially emissions in the LTO cycles around airports, we show in Fig. M.7.1 the global distribution of fuel consumption by all air traffic in the 0-1 km altitude band, part of which is actually emitted at the airport during taxiing or idle operations. Depending on the model application, the related emissions of this band may be added to the other surface source emissions. In addition, we show in Fig. M.7.2 the global distribution of NOx emissions at cruising altitudes. To show the flight intensity distribution over different altitudes and to show the influence of altitude on the fleet average emission factor, we present in Table M.7.1 the fuel consumption, emissions and aggregated emission factors contained in the original NASA inventory.

Figure M.7.1: Fuel consumption of aircraft in LTO cycle in 1990 (0-1 km altitude).

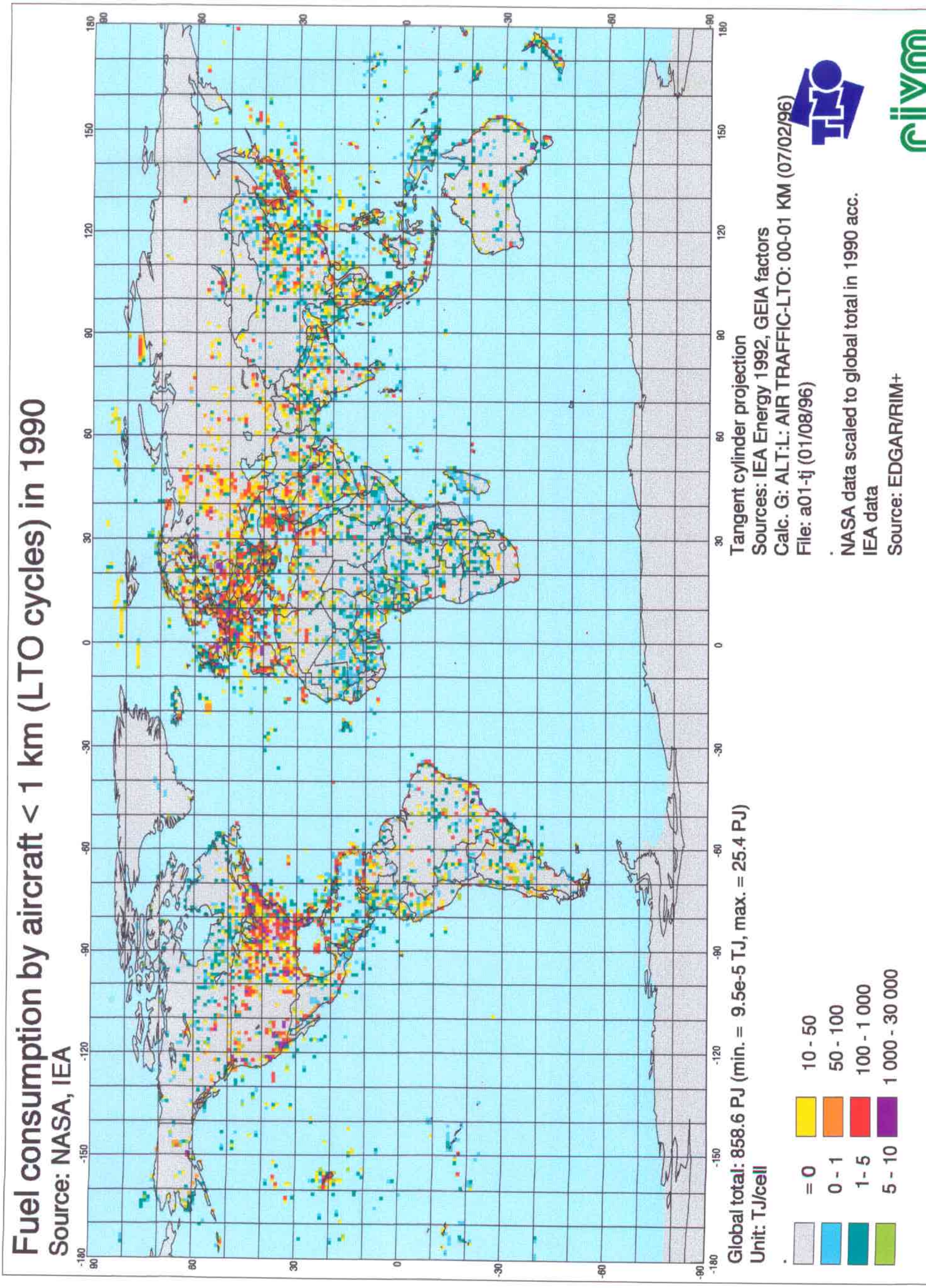


Table M.7.1: Fuel consumption, emissions and aggregated emission factors contained in the original NASA HSRP air traffic inventory for 1990

Table 1: HSRP base year data on aircraft activities (1990).

Altitude (in km) up to..	Fuel consumption (10^9 kg)	(PJ/yr)	Emissions NOx (10^30 molec.	(Tg/yr)	VOC (10^30 molec.	(Tg/yr)	CO (10^30 molec.	(Tg/yr)	Emission factors NOx (g/kg)	VOC (g/kg)	CO (g/kg)	Altitude (in km) up to..
<1 = LTO	*15.1*	*673.2*	*2387.6*	*0.182*	*1766.6*	*0.047*	*4111.7*	*0.191*	*12.1*	*3.1*	*12.7*	*<1 = LTO*
1-2	4.9	217.8	760.6	0.058	319.1	0.008	1018.9	0.047	11.9	1.7	9.7	1-2
3	3.9	174.7	696.9	0.053	307.2	0.008	699.5	0.033	13.6	2.1	8.3	3
4	4.2	187.4	818.1	0.062	292.3	0.008	653.6	0.030	14.9	1.8	7.2	4
5	3.6	161.7	666.6	0.051	290.8	0.008	624.2	0.029	14.0	2.1	8.0	5
6	3.4	152.3	623.1	0.048	304.7	0.008	638.2	0.030	13.9	2.4	8.7	6
7	4.4	196.7	640.7	0.049	317.1	0.008	1028.4	0.048	11.1	1.9	10.8	7
8	4.9	218.8	678.7	0.052	426.2	0.011	1177.9	0.055	10.6	2.3	11.2	8
9	4.4	194.8	636.3	0.049	551.2	0.015	1050.7	0.049	11.1	3.4	11.2	9
*10 *	*10.2*	*453.4*	*1350.7*	*0.103*	*855.7*	*0.023*	*2187.2*	*0.102*	*10.1*	*2.2*	*10.0*	*10 *
11 cruise	*39.5*	*1760.7*	*4865.7*	*0.372*	*2845.2*	*0.076*	*5210.3*	*0.242*	*9.4*	*1.9*	*6.1*	*11* cruise
12 /	*30.6*	*1362.4*	*4527.5*	*0.346*	*2815.0*	*0.075*	*3815.0*	*0.177*	*11.3*	*2.4*	*5.8*	*12*
13	3.2	141.9	328.5	0.025	1175.1	0.031	1290.5	0.060	7.9	9.8	18.9	13 /
14	1.0	45.1	128.0	0.010	459.2	0.012	322.7	0.015	9.7	12.1	14.8	14
15	0.2	10.2	16.4	0.001	381.0	0.010	227.0	0.011	5.5	44.3	46.2	15
16	0.2	8.5	20.6	0.002	97.4	0.003	76.6	0.004	8.2	13.6	18.7	16
17	0.038	1.7	3.0	0.000	10.9	0.000	54.9	0.003	6.1	7.7	68.0	17
18	0.050	2.2	3.9	0.000	15.4	0.000	77.4	0.004	6.0	8.2	72.3	18
19	0.014	0.6	1.1	0.000	4.6	0.000	23.1	0.001	5.9	8.5	74.9	19
Total:	**133.75**	**5964.3**	**19154.0**	**1.46**	**13234.7**	**0.35**	**24287.8**	**1.13**	**10.94**	**2.63**	**8.44**	**Total**
Global total/average <13 km:	132.22	5896.0	18981.0	1.45	12266.2	0.33	23506.1	1.09	10.97	2.46	8.27	< 13 km
> 13 km:	1.53	68.3	173.0	0.01	968.5	0.03	781.7	0.04	8.63	16.80	23.73	> 13 km

source: NASA, HSRP (1993); analyzed by EDGAR/RIM+ (RIVM, 1993)

Table 2: Summary table of HSRP fuel consumption 1990 by altitude ranges.

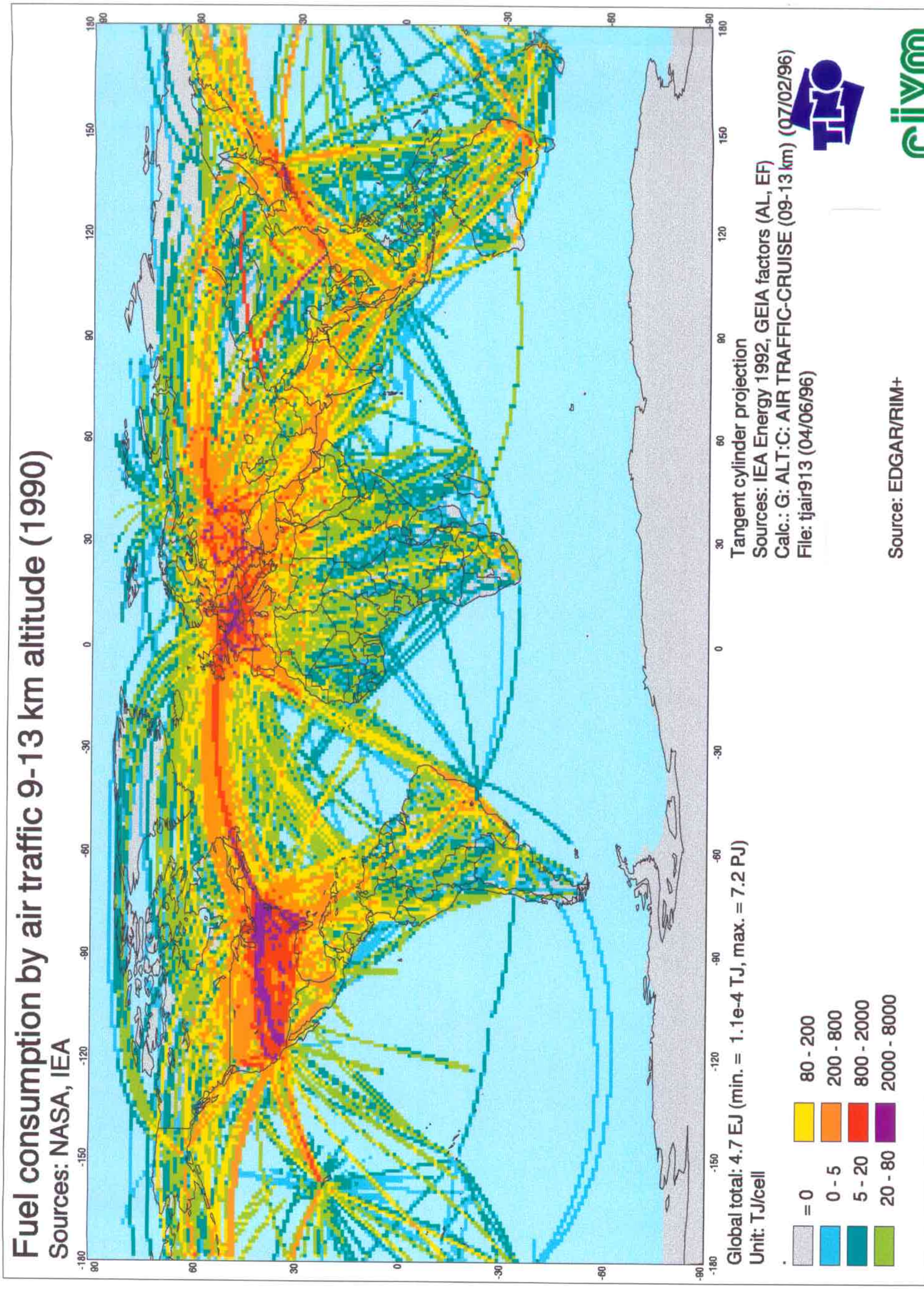
Flight mode/altitude	kg	PJ	%	% of NOx	Tg NOx	% of VOC	Tg VOC	% of CO	Tg CO	EF NOx	EF VOC	EF CO	Flight mode/altitude
sum of LTO (< 1):	15.1	673.2	11.3	12.5	0.18	13.3	0.05	16.9	0.19	12.08	3.11	12.66	sum of LTO (< 1)
sum of climb_approach:	33.7	1504.4	25.2	28.8	0.42	21.2	0.07	28.4	0.32	12.50	2.21	9.50	sum of climb_approach
sum of cruise (9-13):	83.4	3718.4	62.3	57.8	0.85	58.1	0.20	51.5	0.58	10.14	2.45	6.97	sum of cruise (8-13)
sum of SST (?):	1.5	68.3	1.1	0.9	0.01	7.3	0.03	3.2	0.04	8.63	16.80	23.73	sum of SST (?)
Total:	**133.8**	**5964.3**	**100.0**	**100.0**	**1.46**	**100.0**	**0.35**	**100.0**	**1.13**	**10.94**	**2.63**	**8.44**	**Total**

source: NASA, HSRP (1993); analyzed by EDGAR/RIM+ (RIVM, 1993)

N.B. 1 6247 cells for LTO activities (< 1km)
26225 cells (= maximum) in 11-12 km band

N.B. 2 1 lb = 0.4536 kg
1 mol = 6.022*10^23
1 mol NO2 = 46 g
1 mol CO = 28 g
1 mol VOC = 16 g (all VOC expressed as CH4)

Figure M.7.2: Fuel consumption by air traffic during cruise in 1990 (9-13 km altitude).



APPENDIX 5: PUBLICATIONS RELATED TO THE PROJECT

Benkovitz, C.M., Berdowski, J.J.M. & C. Veldt (1994) **The GEIA global gridded inventory of anthropogenic VOCs.** In: *Proceedings of The Emission Inventory; Applications and Improvement. AWMA-EPA Special Conference, Raleigh NC (USA), November 1-3, 1994.*

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