Recent trends in global greenhouse gas emissions: regional trends 1970–2000 and spatial distribution of key sources in 2000

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Abstract
In 2004, the Joint Research Centre (JRC) of the European Commission, the Netherlands Environmental Assessment Agency (MNP) and the Max Plank Institute for Chemistry (MPIC) started a project to create fast (bi-)annual updates of the EDGAR global emission inventory system, based on the more detailed previous version 3.2. Here, the key features of the Emission Database for Global Atmospheric Research, EDGAR 3 are first summarized, and then the compilation of recent global trends having a major influence on variables and the new ‘Fast Track’ approach to estimate recent emissions of greenhouse gases and air pollutants in 2000 at a country-specific level are described. Also provided is an overview of the approaches and data sources used for this EDGAR 3.2 Fast Track 2000 dataset, the different source sectors and the accuracies achieved, with a focus on anthropogenic sources of methane and nitrous oxide. Results of global emission trends for four air pollutants are also briefly addressed. Results for various sources and greenhouse gases at regional and national scales and on 1° × 1° degree grid have been made available on the EDGAR website.

Keywords: Greenhouse gas, air pollution, global, emissions, inventory, trend

1. Introduction
The Emission Database for Global Atmospheric Research (EDGAR), version 3, a set of global anthropogenic emission inventories of various trace gases, was developed by the National Institute for Public Health and Environment (RIVM) and the Netherlands Organisation for Applied Scientific Research (TNO) in collaboration with the Global Emission Inventory Activity (GEIA) of the International Geosphere-Biosphere Programme (IGBP). EDGAR provides emissions of direct greenhouse gases for the 1970–1995 period and for ozone...
precursors and SO$_2$ for the 1990–1995 period (Olivier et al. 2001, Olivier & Berdowski 2001). These datasets—supplemented with recent trend data—have been used for trend analysis of global emissions and atmospheric concentrations of trace gases and for analysis of regional distributions of present global emissions. The results of this work have been used in integrated assessments for RIVM’s and MNP’s annual national environmental balances and accompanying background reports (Environmental Data Compendium) (RIVM 2004, MNP 2005), for the Environmental Signals report of the European Environment Agency (EEA 2000) and for the EU project ‘POET’ (Precursors of Ozone and their Effects in the Troposphere; project EVK2-CT-1999-00011), and in the annual publication of the International Energy Agency (IEA) on trends in greenhouse gas emissions (IEA 2004). The EDGAR datasets are also included in the core datasets for global integrated environmental assessments made in the Global Environmental Outlooks (GEO) of the United Nations Environment Programme (UNEP 2005).

The rapid expansion of high-resolution spatially detailed satellite data, which is produced in almost real time, and from which total column concentrations of various atmospheric trace gases can be determined, further enhance the wishes of atmospheric modellers for more recent global emission inventories. Other policy-oriented users of the EDGAR data have also expressed interest in recent global trends, as only the Annex I countries to the Kyoto Protocol (the industrialised countries) provide their update of national emissions. This has led the new project team composed of Netherlands Environmental Assessment Agency (MNP [associated with RIVM]), the Joint Research Centre (JRC) of the European Commission in Ispra and the Max Planck Institute for Chemistry (MPIC) in Mainz to start a new ‘Fast Track’ approach for updating EDGAR 3, prior to and in parallel with the more detailed update to EDGAR 4, based on readily available data. Basically, the Fast Track approach uses international statistics for each EDGAR source category and constant “implied emission factors”, unless reported national emissions are available that show significant trends in the emission factors that are best not neglected. The latter comprise greenhouse gas emission trends reported by the Annex I countries to the Kyoto Protocol, however, in practice mostly limited to the OECD’90 countries (i.e. the member countries in 1990 of the Organisation for Economic Cooperation and Development).

The same dataset may be used for ozone precursors and SO$_2$, or the emission trends reported to the UN-ECE (Economic Commission for Europe), which are processed and sometimes adapted by the EMEP programme (Convention on Long-range Transboundary Air Pollution on the Financing of the Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe).

In this paper we will first provide an overview of the largest sources of anthropogenic greenhouse gas emissions; second, we will summarise the key features of the Emission Database for Global Atmospheric Research, EDGAR 3. Next, we will describe the compilation of recent global trends and their main influencing variables, focusing on sources of direct greenhouse gases, and the new ‘Fast Track’ approach to estimate recent emissions at country-specific level, consistent with the detailed estimates made for 1995 (EDGAR 32FT2000 dataset). Finally, our results for the global emission trends leading up to 2000 will be compared with other available datasets.

2. Anthropogenic sources of non-CO$_2$ greenhouse gases

For 2000 we estimated non-CO$_2$ greenhouse gas emissions to contribute about 18% to global total anthropogenic greenhouse gas emissions. Globally, the largest sources of anthropogenic greenhouse gas emissions are energy, contributing about 70%, mainly from carbon dioxide
(CO₂) from fuel combustion (63%), and agriculture, mainly methane (CH₄) and nitrous oxide (N₂O) both in equal amounts, contributing 15%. Smaller contributions come from CO₂ from biomass burning (8% of total emissions), mostly deforestation in developing countries, and CO₂ from cement production (2% of total emissions). All shares mentioned are based on EDGAR 32FT2000 data.

Globally, the largest man-made source of methane is agriculture (43%), mainly from enteric fermentation by animals (25%) and rice cultivation (12%), with smaller contributions from animal waste (3%) and savannah burning (3%). Other large sources are energy production and transmission (29%), mainly from coal production (11%) and gas production and transmission (11%), with a smaller contribution from oil production (3%), while waste handling presently contributes about 18%, of which 11% from wastewater and 7% from landfills.

For nitrous oxide the major global anthropogenic source is agriculture (84%), mainly from animal waste dropped on the soil by grazing animals (22%), crop production (13%), the use of synthetic fertilisers (12%), animal manure collected and used as fertilizer (11%), and animal waste in stables (5%). However, with a share of 19%, indirect N₂O emissions from agriculture also constitute a large source. These emissions arise from atmospheric deposition of nitrogen in ammonia (NH₃) and N₂O emitted from agricultural sources, as well as from leaching and run-off of nitrogen in soils. A smaller source is the manufacturing of nitric acid and adipic acid (4%), mostly in industrialized countries (mainly those of OECD’90).

With respect to the F-gases (fluorinated greenhouse gases), the largest current source is HFC-23 by-product emissions from HCFC-22 manufacture. The largest other HFC sources are HFC-134a applications (16%), notably from refrigeration and air-conditioners. However, total sources of other HFCs are at the moment about as large as the HFC-134a emissions (19%). By-product emissions of PFCs from primary aluminium production (CF₄ and C₂F₆) contribute 14%. The use of PFCs is mainly in the form of CF₄ and C₂F₆ used in semiconductor manufacture, while CaF₁₄ is predominantly used as a solvent. The largest source of SF₆ emissions is the manufacture and use of SF₆-containing switchgear (‘Gas Insulated Switchgear’, GIS) in the electricity distribution sector (15%). The other main use of SF₆ is as cover gas in magnesium die-casting and for semiconductor manufacture.

The figures from the EDGAR 32FT2000 dataset cited here may differ from global totals presented by others, but these are mostly within the estimated uncertainty ranges and agree with global budget studies (IPCC 2001).

3. EDGAR 3

EDGAR version 3 has been compiled using international statistics for 1970–1995 for individual countries and emission factors that are either country-specific (e.g. CH₄ from landfills) or regional (e.g. CH₄ from livestock) and sometimes global (e.g. CO₂, N₂O from fossil fuel combustion) and taken from the literature. For greenhouse gases the most used were default factors recommended by the Intergovernmental Panel on Climate Change (IPCC 1997, 2000). For some sources international statistics were not available to serve as activity data. Examples are biofuel use (except for Latin America, for which data from the Latin American Energy Organisation (OLADE) were used) and large-scale biomass burning (forest and savannah burning), waste disposal and wastewater (Olivier 2002, Olivier et al. 2002, Olivier et al. 2005). In cases of significant changes of these sources over time the emission factors were not set to a constant value but different values were used, for example, for 1970, 1990 and 1995. In addition, the emissions calculated for each country are spatially distributed to a 1 × 1 degree grid to provide the datasets needed as input for atmospheric
models. Regional EDGAR emissions are presented for 13 major world regions (Olivier & Berdowski 2001).

The emissions of the ozone precursors could not easily be calculated for the 1970–1990 period, since in many regions emission factors have changed over time due to environmental policies to control them. However, for users of long-term global historical emission datasets the EDGAR-HYDE datasets were developed for the 1890–1990 period, based on the EDGAR 2 datasets for 1990 (Van Aardenne et al. 2001). Figures 1 and 2 show the global trend since 1970 in methane emissions per source and per region, respectively, whereas Figures 3 and 4 show global trends in sources of nitrous oxide emissions and of HFCs, PFCs and SF₆ (so-called F-gases), which have been compiled for the 1970–1995 period from underlying data at country level. The total picture of global greenhouse gas emission trends is shown in Figure 5 per source category and in Figure 6 per world region.

4. Recent global trends
After completion of EDGAR 3, annual estimates for global total emissions of greenhouse gases for years after 1995 were, until recently, made by extrapolating global total activity data per major source category. This was done, for example, using the following data sources: (a) international statistics for fuel use (by sector from the International Energy Agency (IEA) or per main fuel type from British Petroleum (BP)); (b) cement production data from the U.S. Geological Survey (USGS); (c) key livestock data from the UN Food and Agriculture Organisation (FAO); and (d) F-gas sales data compiled by RAND. For CO₂ five source categories, were used, for CH₄, 16 sources, for N₂O, 18 sources and for F-gases, seven sources were used. These global activity trends from 1995 onwards were used to estimate the emissions in more recent years, but were corrected if the “implied emission factor” (i.e. the annual emissions divided by the activity data selected for the extrapolation) of the global 1990–1995 emissions showed a significant trend (Table I). In addition, some sources were
corrected for substantial changes known from national submissions to the UN Framework Convention on Climate Change (UNFCCC) (in Common Reporting Format files accompanying National Inventory Reports submitted to the UNFCCC and posted at the Climate Secretariat’s website (www.unfccc.int)). The most notable of these changes were a
A sharp decrease in N₂O from adipic acid production and the use of SF₆ in the electricity sector and for other purposes. The resulting trends, as shown in Figure 5, are published annually on the MNP website (MNP 2005).

In 2004 an attempt was made to differentiate these global trends into three world regions by making a separate estimation for Annex II (OECD’90) and Economies-In-Transition (EIT)
(former USSR and Eastern Europe) regions based on data reported to the UNFCCC by these countries for 1995 onwards. These data were extrapolated from 1995 to 2002 (IEA 2004) and from 2000 to 2003 (IEA 2005), respectively, then generally rounded to five percentage points (Table II). For the remaining non-Annex I region the trend was calculated from the global total trend estimated as described above and corrected for the Annex I trends. These regional trend data are used by the IEA to calculate the trend key sources as published in the IEA’s annual publication on emissions from greenhouse gases (IEA 2004, 2005).
5. Recent country-specific emission trends

The Annex I countries to the UNFCCC—i.e. industrialized countries comprised of OECD’90 countries and EIT countries—have to submit their update of national greenhouse gas emissions each year. However, in practice this refers to OECD’90 countries only, since many of the EIT countries are not yet able to meet their annual reporting requirements. For the ozone precursors CO, NMVOC and NOx and for SO2, both the UNFCCC submissions and the UN-ECE/EMEP datasets are available as data sources for estimating recent national trends with global coverage, as requested by modellers and policy makers. The emission trends reported to the UN-ECE are processed and sometimes adapted by the EMEP programme. In general, the reporting level of the UNFCCC and ECE source categories does not always match the EDGAR source categories. In these cases a similar reported category was used as indicator for the EDGAR source category.

For OECD countries (who did not report their emissions for these sources) the 1995–2000 trend index of the reported average OECD emission trend may be used as a proxy (see Table III). However, for some sources extrapolation with international statistics is not a good proxy for national emission trends. For example, extrapolation of the 1990–1995 emission trend for landfills generally provides a better estimate for recent emissions here. No annual statistics are available for the Land Use Change and Forestry sector (LUCF) either, that includes agricultural waste burning, and therefore these emissions are kept constant, unless specific trend information with global coverage is available. As an exception, the fossil fuel

| Region                  | CH4 1995–2002 | CH4 2000–2003 | N2O 1995–2002 | N2O 2000–2003 | F-gas 1995–2002 | F-gas 2000–2003 |
|-------------------------|---------------|---------------|---------------|---------------|----------------|-----------------|
| Annex II1               | –10%          | –5%           | –2%           | –2%           | –15%           | 5%              |
| Economies-in-transition1| –20%          | –10%          | 35%           | 15%           | 0%             | 0%              |
| Non-Annex I             | 10%           | –10%          | –10%          | 5%            | 150%           | 150%            |
| Global average          | 2%            | 4%            | 3%            | 4%            | 45%            | 27%             |

1For Annex II (mainly OECD’90 countries) and EIT, trends are based on emission data reported to the UNFCCC. Annex II and EIT countries taken collectively are called Annex I countries in the UNFCCC.
2For CO2 the global average trends are 14% for 1995–2002 and 6% for 2000–2003.

| Gas | Source category                                      | OECD’90 average 1995–2000 trend |
|-----|-----------------------------------------------------|---------------------------------|
| CH4 | Coal production                                     | 0.75                            |
|     | Oil production (processes)                          | 0.97                            |
|     | Gas production (UNFCCC venting and flaring)         | 0.82                            |
|     | Gas transmission                                    | 0.96                            |
|     | Landfills (including recovery)                      | 0.92                            |
|     | Wastewater treatment (including recovery)           | 1.02                            |
| N2O | Road transport                                      | 1.04                            |
|     | Adipic acid production                              | 0.25                            |
|     | Nitric acid production                              | 1.00                            |
|     | Wastewater treatment                                | 1.06                            |
combustion emissions have been calculated on the basis of the latest IEA energy statistics; while for large-scale biomass burning (a part of LUCF), the Van der Werf et al. (2003) datasets with gridded amounts of biomass burned for 1997–2002 were used.

6. Methodology and data sources used for year 2000 dataset

Since producing detailed updates is a laborious task, which is done only every five years or so, the new EDGAR consortium decided to initiate a new so-called ‘Fast Track’ action to estimate the most recent global emissions at country level, based on readily available data. The Fast Track 2000 dataset comprises, for the year 2000, global anthropogenic emissions of Kyoto Protocol greenhouse gases, CO$_2$, CH$_4$, N$_2$O, and F-gases (HFCs, PFCs and SF$_6$), and of the air pollutants, CO, NMVOC, NO$_x$ and SO$_2$. The emission data are presented as country/sector tables and as 1 x 1-degree grid files at the same level of detail as the EDGAR 3.2 emission data published on the internet.

Activity data for the Fast Track approach to estimate emissions for the year 2000, have been included following the EDGAR 3.2 method as described in Olivier and Berdowski (2001) and Olivier et al. (2002). The selection of emission factors was based on the assumption of unchanged control technologies compared to the year 1995, resulting in application of the emission factors for 1995 as included in version 3.2. However, to take emission reductions into account that have occurred due to control measures implemented since 1995, “implied” emission factors have been used for those countries for which information on emission reduction was available (mainly OECD’90 countries, referred to here as “OECD”). Implied emission factors are constructed by dividing annual emissions by activity data selected for the extrapolation. In general, these emission factors have been taken from the CRF emission data files that form part of the National Inventory Reports (NIR) to the UNFCCC (Van Aardenne et al. 2005).

The gridded emissions all use the same grid maps for the within-country distributions as in EDGAR 3.2, except for large-scale biomass burning, for which the GFED (Global Fire Emissions Database) data were used (see Section 6.4). Monthly emissions and effective emission heights are also provided as auxiliary datasets for the latter.

In general, this estimation procedure is expected to produce reasonably accurate results, with an accuracy similar to the uncertainty reported (estimated) for the 1995 emission dataset. However, an exception has to be made for sources where unexpected rapid changes may occur, for example, due to the introduction of new control policies or when the national source category refers to only one or a few point sources. In the latter case, changes in the operations by the manufacturer can result in apparent discontinuities in the emissions (e.g. expansion of production capacity or the closing down of a production plant or changing to another manufacturing process). In those cases EDGAR estimates may be different from national inventories compiled by the countries themselves.

6.1. Fossil fuels and biofuels

Activity data for fossil fuel production and use are taken from IEA statistics for OECD and non-OECD (IEA/OECD 2003a,b) countries. For countries included in the IEA data for the three aggregated ‘other’ regions (Other Latin America, Other Africa and Other Asia), the totals have been split into country data using population density figures from FAO (2005a). For other countries, for which no data is presented in the IEA statistics (mostly very small islands), the EDGAR 3.2 1990–1995 trend has been extrapolated to the year 2000. Data on hard coal and brown coal production have been split into surface and underground mining as
included in EDGAR 3.2. Discontinuities with the EDGAR 3.2 data may be found due to (i) updated IEA energy statistics, in particular for former USSR countries and specific developing countries and (ii) distribution of country data included in the ‘other regions’ of IEA using population statistics instead of data from UN statistics applied in EDGAR 3.2. Emission factors for 2000 have, in general, been taken from the EDGAR 3.2 data for 1995, except in OECD countries for which control measures have been included using so-called implied emission factors. This refers, in particular, to non-CO₂ combustion emissions from road transport, industrial combustion and power generation (see Table IV).

Exceptions to the above-mentioned activity data and emission factors are gas flaring emissions, methane emissions from fossil fuel production and international shipping emissions. Gas flaring emissions were calculated by combining the EDGAR 3.2 values for 1995 with the 1995–2000 CO₂ trends from the Carbon Dioxide Information Analysis Center (CDIAC) (Marland et al. 2003). Constant 1995 emissions have been applied for some countries for which CDIAC did not report CO₂ flaring emissions in 2000 and for which it seems unrealistic that gas flaring did not occur (e.g. Nigeria, Norway and China). Country-specific trends reported to the UNFCCC have been used to calculate methane emissions from fossil fuel production and distribution.

For biofuel combustion in the residential/commercial sector, the same trend estimation procedure was used as for EDGAR 3.2 to maintain consistency with the 1995 emissions data: the total population trend was used for industrialised countries, while for developing countries the weighted trends of rural and urban population were used (see Olivier et al. 2001). However, data from IEA statistics for OECD non-OECD countries were used for biofuel use in industry and power generation for the year 2000 (IEA/OECD 2003b). Due to lack of data, constant 1995 values were applied to charcoal production and biofuel use in road transport. Under the assumption of unchanged control technologies in the production and use of biofuels, emission factors have been assumed to remain constant from 1995 to 2000.

Table IV. Sectors for which implied emission factors have been calculated on the basis of reported emissions to the UNFCCC.

| Source category                          | CH₄ | N₂O | CO | NMVOC | NOₓ | SO₂ |
|------------------------------------------|-----|-----|----|-------|-----|-----|
| Industrial combustion                    | –   | –   | x  | x     | x   | x   |
| Power generation                         | –   | –   | x  | x     | x   | x   |
| Other energy conversion                  | –   | –   | x  | x     | x   | x   |
| Road transport                           | –   | x   | x  | x     | x   | x   |
| Non-road land transport                  | –   | –   | x  | x     | x   | x   |
| Coal production                          | x   |     |    |       |     |     |
| Oil production (processes)               | x   |     |    |       |     |     |
| Oil production (flaring)                 | x   | –   | x  | x     | x   | x   |
| Gas production                           | x   |     |    |       |     |     |
| Gas transmission                         | x   |     |    |       |     |     |
| Adipic acid and nitric acid production   |     |     |    | x     |     |     |
| Landfills (incl. recovery)               | x   |     |    |       |     |     |
| Wastewater treatment (incl. recovery)    | x   | x   | –  | –     | –   | –   |

Note: Columns marked with x indicate that the emissions for that compound have been constructed using an implied emission factor for the specific sector. Columns marked with – indicate that the EDGAR 3.2 emission factor for 1995 has been applied. Blank boxes are not applicable to these compounds.
6.2. Industrial processes, solvents and other product use

Production data on iron and steel (by technology) have been taken from the International Iron and Steel Institute (IISI) (2004). Production data of the non-ferrous industry are based on USGS (2004), while the fractional contribution of different processes from EDGAR 3.2 was applied to PFCs from primary aluminium production. Industrial production data for the chemical industry are taken from the UN commodity statistics (UN 2004). Constant 1995 values were assumed for the countries where no UN data were available. An exception was made for N₂O emissions from adipic acid and nitric acid manufacture from OECD countries, which were extrapolated from 1995 using the country-specific 1995–2000 trends reported to the UNFCCC. The following data sources have been used for the other industrial source categories: cement (USGS 2004), paper and pulp (FAO 2005b), food (FAO 2005b or constant values for countries with no data in FAO). For NMVOC from solvents, the trend in total population was used (FAO 2005b). Emission factors have been assumed to remain constant from 1995 to 2000, except for country-specific trends of N₂O emissions from adipic acid manufacture in OECD countries that showed an average technology-driven emission decrease of about 75%.

For the largest sources of HFC, PFC and SF₆ emissions, country-specific or OECD-average trends reported to the UNFCCC were used for OECD countries, while reported global total emissions, production or consumption trends were used as a proxy for non-OECD countries. HFC-23 by-product emissions from HCFC-22 manufacturing from OECD countries were extrapolated from 1995 using the country-specific 1995–2000 trend reported to the UNFCCC. The global total HCFC-22 production trend reported by AFEAS (Alternative Fluorocarbons Environmental Acceptability Study) (2005) of 0% was used for non-OECD countries. Emissions from HFC-134a use were dealt with in the same way, using a 1995–2000 trend factor of 2.7 for non-reporting OECD countries. The global total HFC-134a emission trend reported by AFEAS was used for non-OECD countries. The same procedure was followed for emissions from other HFC use from OECD countries. PFC by-product emissions from aluminium production from OECD countries were extrapolated from 1995 using the country-specific 1995–2000 emission trend reported to the UNFCCC. For non-OECD countries the 1995 emissions were extrapolated using the 1995–2000 trend, country-specific primary aluminium production reported by USGS. PFC emissions from semiconductor manufacturing and from PFC use as solvent from OECD countries were extrapolated from 1995 using the country-specific 1995–2000 trend reported to the UNFCCC; for all other countries the reported OECD total trend was used. PFC emissions from all other sources were assumed to remain constant. SF₆ emissions from semiconductor manufacture and from use in magnesium production from OECD countries were extrapolated from 1995 using the country-specific 1995–2000 trend reported to the UNFCCC. The global total consumption trend reported by RAND was used for non-OECD countries (Smythe 2004), except for magnesium production where the UNFCCC emission trend for OECD countries was used as a proxy.

6.3. Agriculture

The International Fertiliser Industry Association (IFA) nitrogen fertiliser consumption trend (FAO 2005b) and the amount of animal waste from fertiliser scaled with the livestock numbers from FAO (2005a) were used to calculate N₂O emissions from fertiliser application. CH₄ emissions from rice cultivation and from ruminants are based on total harvest area trends and total cattle trend data, respectively, taken from FAO (2005b). Nitrous oxide
emissions from confined animal waste have also been scaled to total cattle trend data (FAO 2005b). N\textsubscript{2}O emissions from crop production and crop residues were scaled using selected FAO crop data (FAO 2005a). Indirect N\textsubscript{2}O emissions from atmospheric deposition and from leaching and run-off were scaled to the trend in the sum of N\textsubscript{2}O emissions from fertiliser application, confined animal waste and crop residues. Emissions from agricultural waste burning are discussed under large-scale biomass burning. All emission factors have been assumed to remain constant from 1995 to 2000.

6.4. Large-scale biomass burning

Large-scale biomass burning emissions were taken from the Global Fire Emissions Database (GFED Van der Werf et al. 2003), except for agricultural waste burning, which was scaled to trends in the production of selected FAO crops (EDGAR 3.2 method). The ecosystem database of Olson et al. (1983) was aggregated into five classes: shrub/bush, forest, agriculture and other (e.g. urban regions/deserts). GFED 1.0 data in agricultural regions were attributed to savannah and grassland fires. Middle and high latitude grassland fires form a new EDGAR source category that was not reported before. There is an insignificant overlap with EDGAR category agricultural waste burning, which is presented separately with constant 1995 emissions. The indirect post-burn emissions of N\textsubscript{2}O from tropical forest fires have been extrapolated using the calculated 1995–2000 trend in direct N\textsubscript{2}O emissions from that source category. Given the structural difference in both activity data and emission factors of the GFED based emission dataset and EDGAR 3.2 biomass burning emissions, four variants of large-scale biomass burning have been included in the dataset. These are the variants using actual year 2000 data and using multi-year (1997–2002) averaged data as activity data, both combined either the same emission factors as in EDGAR 3.2 and with the emission factors compiled by Andreae and Merlet (2001). For the last set of emission factors an update by Andreae (2004, pers. commun.) was used for the NO\textsubscript{x} emission factors. The use of these for sets allows for comparison with EDGAR 3.2 estimates for earlier years and for assessing the most recent emission estimates for 2000. For more details please refer to Van Aardenne et al. (2005). To still maintain maximum consistency with the EDGAR 3.2 data, we used the GFED with multi-year (1997–2002) averaged activity data and EDGAR 3.2 emission factors (BB-AVG-EF32 dataset) in the standard reporting of regional and per country emissions for 2000.

6.5. Waste handling

Landfill emissions (net CH\textsubscript{4}) from OECD countries and a few EIT countries were extrapolated from 1995 onwards using the country-specific 1995–2000 trends reported to the UNFCCC. For non-OECD countries, where methane recovery is assumed to be insignificant, the 1990–1995 emission trend was extrapolated, since annual landfill emissions are less sensitive to recent changes in activity data, being the sum of emissions from waste deposited several years ago. Wastewater treatment and disposal emissions of net CH\textsubscript{4} were extrapolated using the 1995–2000 trend in total national population, except for wastewater treatment by OECD countries for which country-specific 1995–2000 trends reported to the UNFCCC or the reported OECD total trend were used. N\textsubscript{2}O from wastewater treatment from OECD countries and a few EIT countries was extrapolated using the country-specific 1995–2000 trend reported to the UNFCCC. For non-OECD countries the 1995 emissions were extrapolated using the 1995–2000 trend in total national population. N\textsubscript{2}O from wastewater disposal was extrapolated using the 1995–2000
trend in total national population. Finally, emissions from uncontrolled waste incineration were kept constant.

7. Results and comparison with other global trend estimates

7.1. Comparison with previous aggregated global trend estimates: greenhouse gases

Until recently, annual estimates for recent years after 1995 of global total emissions of greenhouse gases were made by RIVM/MNP by extrapolation per major source category (Table V). Global activity trends were used to estimate the source’s emissions in more recent years; however, non-CO₂ emissions were corrected if the “implied emission factor” of the global 1990–1995 emissions show a significant trend or if substantial changes are known from national submissions to the UN Climate Secretariat (UNFCCC). Here the “implied emission factor” refers to the annual sectoral emissions divided by the activity data selected as volume indicator. These more aggregate global total source trends are published annually on the RIVM/MNP website as part of the Environmental Data Compendium, in Dutch abbreviated to MNC (RIVM 2004, MNP 2005), and in Part 3 of the annual IEA publication, “CO₂ from fuel combustion” (Olivier 2004, Olivier et al. 2005).

A comparison of methods in Table V shows that the MNC method, using only half the number of sources compared to the FT method, analyses global trends at a much more aggregated source level than the Fast Track method. More important, the MNC method does not show any regional or country-specific details, so does not capture the more delicate differences in volume trends by countries with higher and countries with lower emission factors. For compounds such as methane and nitrous oxide these differences result in strikingly different 1995–2000 trends, for both 5 percentage points different as shown in Table VI: for CH₄ this is now about 6% versus 1% and for N₂O 4% versus 1%. This illustrates that apparently the much more aggregated MNC method sometimes does not capture key determining trends. Although the FT method uses another method to estimate large-scale biomass burning emissions (which shows in the comparison made in Table VI), an analysis of total emissions excluding these sources does not alter the main conclusions (the differences with the MNC trend are then for both about 4 percentage points); see the Appendix for more details). The difference in the CO₂ emission trend is due to the use of another type of data source for large-scale biomass burning instead of just assuming that these emissions remained constant. Table VI shows that the global total anthropogenic emission trend for CO₂ in the FT method is also about 4% higher than in the MNC method. For the total of F-gas emissions, the differences are small, but for individual sources, which depend

| Type          | Gas   | No. sources in 32FT2000 method | No. sources in MNC method |
|---------------|-------|-------------------------------|--------------------------|
| Greenhouse gas| CO₂   | 15                            | 5                        |
|               | CH₄   | 30                            | 16                       |
|               | N₂O   | 34                            | 18                       |
|               | F-gases | 34 (9 + 10 + 14)                | 7 (3 + 2 + 2)             |
| Precursors    | CO    | 24                            | –                        |
|               | NMVOC | 28                            | –                        |
|               | NOₓ   | 24                            | –                        |
|               | SO₂   | 25                            | –                        |

Table V. Number of source categories used in the MNC method for global total trend estimates and in the FT method.
on market changes such as the phase out of (H)CFC use, the differences were found to be much larger (see Table A.3 in the Appendix).

The MNC method is still useful for the most recent years for which detailed statistics and emissions are not yet complete, thus when the much more refined FT method is not yet applicable (for extending in 2005, the emission trend from 2000 to 2003, for example). However, future updates of the aggregated global emission trend estimates using the MNC method will be calibrated to the more detailed global total estimate per source category, as determined for particular years by the Fast Track method. Furthermore, the resulting trend is considered less accurate than assumed previously.

7.2. Comparison with other global trend estimates: air pollutants

Very few global inventories with national details have been made that include all anthropogenic emission sources. In Table VII the EDGAR 32FT2000 estimates of CO and NO\textsubscript{x} are shown and compared with the only other global datasets for 2000 with country details. Although partial in their source coverage, the only public datasets available to date are RETRO emissions for CO and NO\textsubscript{x} from fuel use and industrial processes (RETRO 2005). This table shows a difference in global 1995–2000 emission trends of a factor of two (when expressed as percentage): for CO the FT method gives a −3% trend versus −6% in RETRO; for NO\textsubscript{x} we calculated a +4% trend versus +2% in RETRO. However, interestingly enough, for CO the RETRO trend for the previous 1990–1995 period also differs markedly from the EDGAR 3.2 estimate for that period. Further analysis of the differences between the datasets should show whether differences are due to either basic emission factors or assumed regional or country-specific technology mixes. We recall that for non-OECD/non-ECE countries no changes in the (implied) emission factors have been assumed in the Fast Track approach.

8. Data availability

The emission datasets are made publicly available through the internet, accompanied by documentation on methodology, data sources and any caveats identified over time. The emissions can be downloaded, by region, country or on a 1 × 1 degree grid (see Figure 7 for an example), from the EDGAR website at http://www.mnp.nl/edgar [alternative address: http://edgar.jrc.it] or from the GEIA/ACCENT Emissions data portal accessible through http://www.accent-network.org.
Table VII. Global total 2000 emission trends of CO and NO\textsubscript{x} using the FT method\textsuperscript{2} compared with other studies.

| Gas   | Method | 1990\textsuperscript{1} | 1995\textsuperscript{1} | 2000 | Diff $00/95$ (Tg) | Diff $00/95$ (%) | Diff $95/90$ (%)\textsuperscript{1} |
|-------|--------|--------------------------|--------------------------|------|------------------|----------------|-----------------|
| CO    | FT     | 846                      | 861                      | 1077 | 216              | 25%            | 2%              |
|       | FT min\textsuperscript{3} | 531                      | 537                      | 519  | −17              | −3%            | −1%             |
|       | RETRO\textsuperscript{4}   | 534                      | 506                      | 477  | −29              | −6%            | −5%             |
| NO\textsubscript{x} | FT | 109.7                    | 111.3                    | 126.6| 15               | 14%            | 2%              |
|       | FT min\textsuperscript{3} | 96.1                     | 97.2                     | 101.4| 4.2              | 4.3%           | 1.1%            |
|       | RETRO\textsuperscript{4}   | 88.1                     | 88.8                     | 90.5 | 1.7              | 1.9%           | 0.8%            |
| NMVOC | FT     | 153                      | 160                      | 186  | 27               | 17%            | 4%              |
|       | FT min\textsuperscript{3} | 133                      | 137                      | 135  | −2               | −2%            | 3%              |
| SO\textsubscript{2}    | FT     | 154                      | 142                      | 150  | 8                | 6%             | −8%             |
|       | FT min\textsuperscript{3} | 152                      | 139                      | 145  | 6                | 5%             | −8%             |

\textsuperscript{1}EDGAR 3.2 data.
\textsuperscript{2}FT BB dataset: BB-AVG-EF32.
\textsuperscript{3}Excluding fuel production, large-scale biomass burning and waste handling.
\textsuperscript{4}RETRO sectors: pow + res + inc + tra + ships (i.e. excluding fuel production, agriculture, biomass burning, waste handling); data from the GEIA/ACCENT Emissions web portal.

Figure 7. Spatial distribution of anthropogenic methane emissions in 2000 (Source: EDGAR 32FF2000).

9. Conclusions

The Fast Track method used to estimate recent five-year emission trends can be concluded to be a major improvement compared with the MNC method used for greenhouse gases and compared to non-existent—at least until very recently—global high-resolution datasets for air...
pollutants. For greenhouse gases this method uses twice the number of sources as the MNC method and, also, actual country-specific trends rather than global trends in the years prior to the year of extrapolation. The FT method provides more accurate and more detailed trend estimates (see listed below) than the global MNC method:

- more accurate trends: not only at country level but also at regional and global level;
- available for more source categories, also on grid;
- also available for precursor emissions.

Further analysis, such as comparison with the EDGAR 4 data for 1995 and 2000 currently under development, may provide quantitative indications of the trend accuracy of the FT method. It can, however, already be concluded that the accuracy of the MNC method for emission trend estimation of periods of five years or more may be limited, particularly when it comprises major sources where the emission intensities are highly regionally stratified. As for the 2000 emissions for air pollutants, global trends of anthropogenic emissions have changed significantly in five years’ time (e.g. +15% to +25%). However, the present assumptions used for non-OECD countries, implying that emission factors have not changed, could be improved to provide a more accurate estimate of the source trends. Finally we note that, although it was discussed above, we observed the following when compiling the FT2000 datasets:

- Official national datasets are often available for OECD countries only and are not always consistent in country intercomparisons.
- Global emission trends are in the first place determined by such international statistics as driving variables, but trends in basic emission factors and/or technology mixes are crucial for determining total trends. This is because the main driving variables are transport and power generation for which, in many countries, the emission factors change significantly over time, in particular for air pollutants such as CO, NOx and NMVOC.
- Some other caveats were identified in the dataset (see online documentation for the latest version).

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Appendix: Comparison of 32FT2000 and MNC methods for CH4, N2O and F-gases

Although there are some differences due to different data sources and assumptions made for large-scale biomass burning, the main conclusion is that a more detailed calculation for a few key sources was largely responsible for the observed differences in the global total trend estimate: coal and gas production for CH4 (Table A.1) and nitric acid and
adipic acid production and animal waste dropped on soils for N₂O (Table A.2). For total F-gases the differences are very small, and also for individual sources the differences found are mostly between +10% and −10%, except for emissions from other SF₆ uses (Table A.3).

**Table A.1. Methane emissions per source category in 2000 (Tg CH₄) (FT dataset: BB-AVG-EF32).**

| Source                                      | 2000-FT | 2000-MNC | Diff. | Key diff. | Explanation               |
|---------------------------------------------|---------|----------|-------|-----------|---------------------------|
| Biofuel use                                 | 14.9    | 15.7     | −0.8  | 6         | More detailed calculation |
| Fossil fuel combustion                      | 3.4     | 4.2      | −0.8  | 7         | New activity dataset      |
| Coal production                             | 33.9    | 28.6     | 5.3   | 1         | More detailed calculation |
| Oil production/processing                   | 10.5    | 10.0     | 0.5   | 4         | More detailed calculation |
| Gas production/transmission                 | 49.4    | 46.2     | 3.2   |           |                           |
| Industrial processes                        | 0.9     | 0.8      | 0.1   |           |                           |
| Rice cultivation                            | 39.3    | 39.9     | −0.5  |           |                           |
| Animals (enteric fermentation)              | 80.0    | 79.5     | 0.5   |           |                           |
| Animal waste                                | 8.5     | 8.6      | −0.1  |           |                           |
| Agricultural waste burning                  | 0.8     | 0.7      | 0.1   |           |                           |
| Savannah burning                            | 9.3     | 6.0      | 3.3   | 3         | Diff data source/assump.  |
| Deforestation                               | 9.7     | 4.5      | 5.2   | 2         | Diff data source/assump.  |
| Vegetation fires                            | 1.0     | 1.9      | −0.9  | 5         | Diff data source/assump.  |
| Landfills                                   | 23.1    | 23.3     | −0.2  |           |                           |
| Wastewater (disposal/treatment)             | 34.8    | 35.5     | −0.6  |           |                           |
| Waste incineration                          | 0.2     | 0.2      | 0.0   |           |                           |
| **Total**                                   | **319.8**| **305.7**| **14.1**|           |                           |

**Table A.2. Nitrous oxide emissions per source category in 2000 (Tg N₂O) (FT dataset: BB-AVG-EF32).**

| Source                                      | 2000-FT | 2000-MNC | Diff. | Key diff. | Explanation               |
|---------------------------------------------|---------|----------|-------|-----------|---------------------------|
| Biofuel use                                 | 0.2     | 0.2      | −0.01 |           |                           |
| Fossil fuel combustion                      | 0.3     | 0.3      | −0.01 |           |                           |
| Oil production                              | 0.0     | 0.0      | 0.00  |           |                           |
| Nitric acid production                      | 0.4     | 0.2      | 0.18  | 1         | More detailed calculation |
| Adipic acid production                      | 0.1     | 0.1      | 0.03  |           |                           |
| Use of N₂O                                 | 0.0     | 0.0      | 0.00  |           |                           |
| Synthetic fertiliser use                    | 2.8     | 1.5      | 0.07  |           |                           |
| Animal waste as fertiliser see synt. fert. |         | 1.2      |       |           |                           |
| Animal waste (stables)                      | 0.6     | 0.6      | 0.00  |           |                           |
| Agricultural waste burning                  | 0.0     | 0.0      | 0.00  |           |                           |
| Savannah burning                            | 0.1     | 0.1      | 0.06  |           | Diff data source/assump.  |
| Deforestation                               | 0.1     | 0.0      | 0.05  |           | Diff data source/assump.  |
| Post-burn deforestation                     | 0.6     | 0.3      | 0.34  | 2         | Diff data source/assump.  |
| Vegetation fires (temperate)                | 0.0     | 0.0      | −0.01 |           |                           |
| Crop production                             | 1.6     | 1.6      | −0.07 |           |                           |
| Animal waste (on grasslands)                | 2.7     | 2.8      | −0.12 | 3         | More detailed calculation |
| Atmos. dep./Leaching & Run-Off              | 2.3     | 2.4      | −0.05 |           |                           |
| Wastewater (disposal/treatment)             | 0.3     | 0.3      | −0.02 |           |                           |
| Waste incineration                          | 0.0     | 0.0      | 0.00  |           |                           |
| **Total**                                   | **12.0**| **11.6** | **0.5**|           |                           |
Table A.3. Fluorinated emissions per source category in 2000 (Tg CO₂-eq.) (Source: EDGAR 32FT2000).

| Source                                    | 2000-FT | 2000-MNC | Diff. | Key diff. | Explanation                      |
|-------------------------------------------|---------|----------|-------|-----------|----------------------------------|
| PFC from aluminium production             | 69      | 79       | −10   | 2         | More detailed calculation        |
| PFC use                                   | 39      | 36       | 4     |           |                                  |
| HFC-23 from HCFC-22 manufacture           | 77      | 85       | −8    |           |                                  |
| HFC-134a use                              | 78      | 85       | −7    |           |                                  |
| HFC other uses                            | 91      | 84       | 7     |           |                                  |
| SF₆ for electricity                       | 70      | 77       | −7    |           | Diff data source/assumpt.        |
| SF₆ other uses                            | 54      | 26       | 28    | 1         | New activity dataset             |
| **Total**                                 | **479** | **472**  | **7** |           |                                  |

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