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EMISSION DATABASE FOR GLOBAL ATMOSPHERIC RESEARCH (EDGAR): VERSION 2.0

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Abstract
To meet the urgent need of atmospheric chemistry and climate modellers a global emissions source database called EDGAR has been developed jointly by TNO and RIVM to estimate for 1990, on a regional and on a grid basis, annual emissions of greenhouse gases (CO_2, CH_4, N_2O, CO, NO_x, non-methane VOC, SO_x), of NH_3, and of ozone depleting compounds (halocarbons). The aim was to establish the global emissions from both anthropogenic and biogenic sources: a complete set of data required to estimate the total source strength of the various gases with an $1^o \times 1^o$ resolution (altitude resolution of 1 km), as agreed upon in the Global Emissions Inventory Activity (GEIA) of the International Atmospheric Chemistry Programme (IGAC). The data comprise demographic data, social and economic factors, land use distributions and emission factors (with due emphasis on the uncertainty). As understanding in this field is still changing, due attention is paid to flexibility regarding the disaggregation of sources, spatial and temporal resolution and species. The objective and methodology chosen for the construction of the database are presented, as well as the type and sources of data and the approach used for data collection. As an example, the construction of the N_2O inventory is discussed.

1. Introduction

Atmospheric chemistry and climate modellers require gridded global emissions data as input into their models. Within RIVM there is a need to monitor globally the climate affecting emissions and to gather the basic underlying data as input to the emissions calculation modules of RIVM's climate model IMAGE 2.0 (Integrated Model to Assess the Greenhouse Effect) as well as to support the validation of this model (Alcamo *et al.*, 1994). On a regional scale, emission data are required for tropospheric ozone modelling, e.g. as performed with the LOTOS model (Builtjes, 1992).

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 for the base year 1990 on a regional and on a grid basis the annual global emissions of the greenhouse gases CO_2, CH_4, N_2O, CO, NO_x (NO and NO_2), non-methane VOC and SO_x (SO_2 and SO_4), of NH_3, and of ozone depleting compounds (halocarbons) from both anthropogenic and biogenic sources. The finest spatial resolution of the data is $1^o \times 1^o$ (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), which is part of the International Geosphere-Biosphere Programme (IGBP). The temporal resolution is monthly for most natural sources, supplemented with information on the temporal variation of the other sources. The data comprise demographic data, social and economic factors, land use distributions and emission factors. As insights in this field are still changing, due attention is paid to flexibility regarding the disaggregation of sources, spatial and temporal resolution and species.

Based on the conclusions of a feasibility study performed by TNO (Baars *et al.*, 1991), RIVM and TNO have carried out a project to establish this global database. The work consists for one part of data selection, collection and processing, and for the other part of implementation of the database system (information analysis, system design, software development). Version 2.0 of the database system has been completed in January 1995. The database is located at RIVM and serves as an analysis tool, as an emissions generator for other atmosphere modelling groups, both within RIVM and TNO and externally, and acts as the database to provide the IMAGE model with the basic data to drive the model calculations on emissions. In this short paper we will, subsequently, discuss the functionality as requested by the future users, the approach used in data selection and collection, as an example the construction of the gridded N_2O inventory, and the structure of the database system. For a more detailed description we refer to Olivier *et al.* (1994).

2. User's requirements

EDGAR is designed to be used by modelling groups involved with atmospheric chemistry, for scenario studies and for 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 the feasibility study. The functionality proposed to fulfil the needs of potential users was discussed at a workshop held in 1992, in which participants from different atmospheric modelling groups were present. 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. Access of publicly available data will be by FTP (File Transfer Protocol) from RIVM's anonymous FTP site (internet address: info@rivm.nl; node address: 131.224.1.22), by WWW, or through e-mail.

3. Data selection and quality assurance

Data selection on activities has been done on the basis of internationally accepted statistical data, assembled by an international organization which has performed consistency checks of the data. With respect to emission factors, representativity and availability of data as well as compliance with GEIA, OECD and European emission database systems are important aspects taken into consideration. Although for outside users only emissions estimates for major source categories will be made available, a full data source description of the underlying data is available for all data included in EDGAR.

In order not to duplicate activities worldwide, RIVM and TNO are co-operating amongst others with activities in the framework of the Global Emissions Inventory Activity (GEIA), which is an activity of IGAC in which inventories are developed and exchanged between the participating international group. TNO and RIVM coordinate the GEIA inventories on anthropogenic VOC and on N_2O emissions. Besides these inventories/contributions from EDGAR to GEIA, results from early finished inventories by GEIA and other institutes are included in EDGAR. Inventories of NO_x from soils and of NH_3 are also performed within the GEIA framework.

Although 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) may also be included in the database, since an option will be provided to include and select alternative data sets (e.g. national sets) for emissions calculations. This facilitates comparison of data sets and creation of new global totals and maps by combining different sets.

To guarantee the quality of the data, besides full reference to and a careful selection of the data source, quality checks are performed on the result of the final data processing. Quality assurance will be implemented following fixed procedures on data processing (e.g. by detailed logging of all quality checks) (Van der Maas *et al.*, 1994). Although all sources are dealt with the research was focused on the major source categories. To the extent possible, compliance with developed GEIA inventories is pursued.

4. Source categories and related data

EDGAR consists of landuse-related processes, partially on a grid basis and partially on a country basis, energy related processes on a country basis, other industrial production and consumption processes, waste handling and other sources on a country basis. Major point sources are included or used as distribution parameters; allocation functions (thematic maps) are used to convert country emissions to gridded emissions.

Activity data are taken from statistical data available, e.g. from IEA (energy data), UN (industrial production and consumption), FAO (agricultural data). For biogenic 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 I).

Emission factors were evaluated separately. Existing inventories, e.g. of LOTOS, Corinair and NAPAP, are used to derive national or regional emission factors for surface sources. Emission factors for biogenic sources are often a function of the local climatic conditions, such as temperature, so here a more advanced approach is 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.

The allocation of emissions on a grid is dealt with in three ways. For major point sources, such as power plants and large basic materials producing industries, point source data are used to allocate part of national activities. If these are not present or not available - and also in case of a remaining part of national activities (while attributing the other part to point sources) - a distribution function will be used to allocate national emissions to the grid cells.

Finally part of the activity data were already collected at grid level. For estimating regional emissions we use the regional sub-division of the world as defined within the IMAGE 2.0 model as defaults (Alcamo *et al.*, 1994).

Table I
Major source categories used in EDGAR and dominant sources of trace gases.

Source category	CO_2	CH_4	N_2O	CO	NO_x	VOC	SO_x	HCs
Transportation	x		x	x	x	x		
Power generation	x				x		x	
Other combustion (industry, residentials)	x			x	x		x	
Fossil fuel production		x						
Gas distribution		x						
Solvent use						x		
Halocarbon use								x
Other industrial processes			x			x	x	
Waste disposal		x						
Agriculture		x	x					
Live stock (ruminants)		x						
Biomass burning	x	x	x	x	x	x		
Terrestrial ecosystems (soils)	x		x			x	x	
Oceans	x		x					
Other natural sources		x			x		x	

5. Example: construction of the N_2O inventory

The construction of the N_2O emissions inventory is a good example of how different types of emission sources have been combined to arrive at a spatially distributed inventory. The major source categories for N_2O are summarized in Table II and include fuel combustion and industrial processes, biomass burning, arable land, grasslands and animal excreta, and natural emissions from soils.

For *soils under natural vegetation* we used the results of Bouwman *et al.* (1993) and Kreileman and Bouwman (1994), because of the better agreement with atmospheric models and observations. For more details we refer to Bouwman *et al.*, 1995. For *grassland soils* the N_2O emission was estimated with the above described method for soils under natural vegetation, using Olson *et al.* (1983) to allocate grasslands (Bouwman *et al.*, 1995).

Table II
Major sources of N_2O, global strength (in Tg N_2O-N y^{-1}) and location type.

Type	Sub-category	Houghton *et al.* (1992)	Pepper *et al.*	This study*	Location type
Terr. ecosystems	Soils (natural)	2.7-9.7	}6.1	4.3	land cover on grid[1]
	Grasslands	?	}	1.4	land cover on grid[1]
Agriculture	Arable lands[4]	0.1-3.0	2.0	1.8	arable land cover on grid[1]
	Animal excreta	-	-	1.0	animal density[2] on grid[3]
Biomass burning	Large scale burning	}	}0.6	0.1	from 5x5^{o} grid distribution[1]
	Agricultural waste	}0.2-1.0	}	0.1	arable land cover on grid[3]
	Post-burn effects	}	0.8	0.4	from 5x5^{o} grid distribution[1]
Combustion	Fossil fuels	0.3-0.9	0.4	0.3	population density on grid[3]
	Fuelwood	see biomass	ibid.	0.1	population density on grid[3]
Industrial processes	Adipic Acid	0.4-0.6	0.5	0.3	point sources
	Nitric Acid	0.1-0.3	0.2	0.3	point sources/population density[3]
Oceans		1.4-2.6	-	p.m.	
Total		**5.2-18.1**	**10.6**	**9.2**	

[1] Used as activity defined on grid.
[2] For chicken we used arable land cover on grid.
[3] Used as surrogate thematic map for distribution of country totals.
[4] Cultivated soils.
* Subject to latest revisions.

For *arable land* the estimates of the emissions from fertilized fields show a great uncertainty (Eichner, 1990; Bouwman, 1990). The method that gave the best correlation with atmospheric observations was included in EDGAR (Bouwman *et al.*, 1995). Recently, Khalil and Rasmussen (1992) identified *animal excreta* as a source of N_2O. Our estimate for nitrogen excretion for different animal categories is described in Bouwman *et al.* (1995). For *large scale biomass burning* during forest clearing, savanna burning and shifting cultivation, and for agricultural residue burning, we adopted the emission factors proposed by Crutzen and Andreae (1990). The amounts of biomass burned and the grid distribution are from Hao *et al.* (1990). For *agricultural waste burning* we use a total volume of 909 Tg C yr^{-1} (Andreae, 1991). Emission factors are from Crutzen and Andreae (1990). The estimated emission was distributed tentatively over the arable land area within grid cells. The so-called *post-burn effects* of human activity in tropical forests, which may change emission rates of biogenic trace gases, are decribed in (Bouwman *et al.*, 1995).
Studies and measurements of enhanced N_2O emissions following savanna burning are too scarce to make even a tentative estimate for this process.

Our emission estimate for *fossil fuel combustion* has been based on national energy data from IEA (1992) and emission factors from De Soete (1993) and (Olivier, 1993). The calculated country totals are distributed according to the gridded population densities of Logan (1993). For *fuelwood combustion*, we used a tentative estimate based on consumption data of FAO (1991) and IEA (1992) and an tentative emission factor (see De Vries *et al.*, 1994). Here too, we used the population density of Logan (1993) as allocation function for the national totals. *Adipic Acid (AA) production* data are primarily based on the production capacity and locations of plants given by Castellan *et al.* (1991). Emission factors are based on Reimer *et al.*, 1992. 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). Emission factors were selected from ranges described in Bouwman *et al.* (1995). In the absence of point source data, distribution of emissions was done using population density as a surrogate.

This example shows that the various sources of N_2O need to be treated differently. Our estimates per category compare rather well with global totals estimated by Pepper *et al.* (1992) (see Table II). It also clearly illustrates that by taking the process type of approach combined with activities defined either for areas (countries), points or grid cells, the estimation of emission factors as discussed above, and the use of selected thematic maps, we are able to construct an integrated gridded emissions inventory.

6. 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*, 1994). 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 corn, public transportation, painting of boats, the production of electricity etc.

Emissions, energy use and waste stream are calculated by multiplying the process level 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 (activity level) of process *i*
EF_{ix} = is the environmental load factor (here emission factor) of compound *x* for process *i* in a historical year.

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 is 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). EDGAR differs mainly from the other parts by the quantity of data to be processed, the emphasis on the location of activities (countries, regions, points or grid cells), and by the specific import/export and data analysis facilities.

7. Limitations

Version 2.0 of EDGAR, which is in operation from January 1995, includes a data set covering all major sources, but does not yet include fully assessed uncertainty estimates, and has a limited functionality in modelling and calculating past and future emissions. Also time profiles to distribute emissions over months are only partially included in version 2.0 of EDGAR. The main goal has been to create a database with the information necessary to calculate globally gridded emissions in the base year 1990. We envisage that later versions will be expanded with a linkage to the IMAGE model for scenario calculations on grid.

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