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TNO report

2007-A-R0132/B

ASSESSMENT OF GLOBAL EMISSIONS FROM FUEL COMBUSTION IN THE FINAL DECADES OF THE 20TH CENTURY

Application of the Emission Inventory Model TEAM

Date	09 February 2007
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Under contract with	DG Research, RETRO Project
Project number	034.64145
Number of pages	41 (incl. appendices)
Number of appendices	

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1 Introduction

Most emission inventories estimate emissions for each pollutant using the equation

$$E_{Pollutant} = \sum_{activities} AR_{activity} \times EF_{activity,\, pollutant}$$

assuming a linear relation between the intensity of an activity $AR_{activity}$ ("Activity Rate") and the emission ($E_{pollutant}$) for each activity. The emission factor is the proportionality constant $EF_{activity,pollutant}$. Guidance documents for the preparation of national emission inventories (TFEIP 2004 and IPCC 1997) provide a source of emission factors that that is frequently applied in annual emission inventories submitted to international conventions and protocols. In this classical approach, compilation of a global emission inventory is typically the collection of (time series of) country level activity data and (country specific) emission factors. When such information is obtained from these national inventories, the resulting multinational inventories might contain inconsistencies, since different countries might have selected different methods from the guidance documents or might have applied country specific estimation methods. Moreover by the use of country specific emission factors knowledge on abatement in different countries gets hidden and hence cannot be used in further analyses. This severely limits the applicability of such inventories in policy assessments and scenario studies. The RAINS model solves this by using reduction efficiencies, rather than technology dependent emission factors when modelling abatement (Amann et al 1999).

To overcome the problems of inconsistencies, international inventories are also compiled, using independently derived emission factors for all countries. An example of this approach (Hameed and Dignon, 1988) uses regression analyses on reported emissions to establish such emission factors. Another example, the inventory developed by Van Aardenne et al (2001), assumes constant emission factors for long periods of times and large geographical areas. The latter can be seen as relatively rough approximations, since it only reflects the changing activity rates.

For some pollutants and some processes however, emissions will be greatly affected by the introduction of new technologies. An example of this is the introduction of catalysts in gasoline fuelled vehicles, decreasing the emission factors for NOx, CO and NMVOCs from passenger cars significantly. Both in retrospective and prospective time series ("projections") of emissions it is crucial to take the technological developments into account.

A different approach has been used in the EDGAR database for the global 1990 greenhouse gases and precursors emissions (Olivier et al, 1998, 1999) developed within the framework of the GEIA project. The EDGAR database develops emission factors by taking into account technological developments implicitly: for each inventory year a new set of emission factors is generated. This database has been further developed into a time series and is freely available on the Internet (EDGAR, 2005). The difficulty in this approach lays in the establishment and transparent management of country specific emission factors, especially when developments over time are concerned: the penetration of new technologies and better fuel qualities into the system is not explicitly modelled but requires the explicit development of time series of emission factors. To arrive at a more transparent treatment of technological developments, we developed an approach, based on the algorithm proposed by the Projections chapter of the EMEP/CORINAIR Guidebook (TFEIP 2004, see Figure 1).

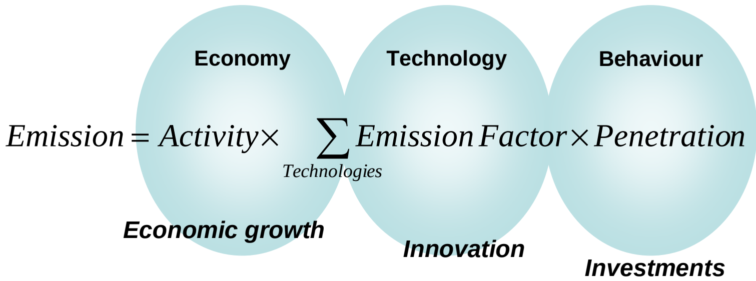

Figure 1 The three aspects of estimating emissions: economy, technology and behaviour(adapted from TFEIP, 2004, Projections chapter).

In our approach economic, technological and behavioural aspects are explicitly included in the basic approach of an emission estimate:

- The changes in structure and production in the economy is taken care of by the “Activity”. Activity data include apart from the economic sectors also activities like households and transport. Time series of activity data then model economic growth
- Technology is determining the Emission Factor: for a given technology each emission factor describes the relation between the intensity of the activity and the emissions.
- The selection of certain technologies for specific activities is modelled by “Penetration”. Its value indicates the percentage of the activity that uses a specific technology with associated emission factors. The change in penetration reflects the effects of investments in new or improved technologies and hence brings the behavioural aspect into the estimate.

We use this approach to estimate global emissions of CO_2, NO_x, CO, NMVOC and particulates (pm10) from fuel combustion, as defined in the IPCC 1996 Guidelines (IPCC, 1997) over the 40 year time span of 1960 to 2000. Using this estimate as a baseline, we also calculate the effects of different options that either have been chosen historically or that could have been chosen as alternative policies. The same model approach is used in a separate paper concentrating on establishing the uncertainties in the emissions of dioxins in central Europe (Pulles et al, 2005).

Our approach is similar to methods applied in the black organic carbon inventory using the SPEW program as described by Bond et al (2004). Additionally to this study, we apply these principles to a forty years time series and use it to evaluate the contributions of different developments and policy alternatives. Our model differs from the one chosen in the RAINS model of IIASA (Amann et al 1999, Schöpp et all 1999) where the introduction of abatement technologies into the economy is modelled by multiplying the unabated emission estimates with a technology and pollutant dependent reduction factor. In TEAM the selection of technologies directly connects to the technology specific emission factors for all relevant pollutants and hence does not need to keep track of all pollutant specific abatement efficiencies.

2 The Emission Inventory Model TEAM

2.1 Emission Estimation and Database Structure

In our approach we explicitly model the time dependent introduction of alternative technologies into the emission inventory by applying the following equation:

$$E_{pollutant}(t) = \sum_{activities} \left(\sum_{technologies} \left(AR_{activity}(t) \times P_{activity,technology}(t) \times EF_{technology,\ pollutant} \right) \right)$$

$$\forall\ activities, \forall\ t : \sum_{technologies} P_{activity,technology}(t) = 100\%$$

with

$E_{pollutant}(t)$	The emission of a *pollutant* at a time interval *t*
$AR_{activity}(t)$	The activity rate for a certain *activity* at time interval *t*
$P_{activity,technology}(t)$	The penetration: the fraction (at time interval *t*) of the *activity* performed using a specific *technology*
$EF_{technology,\ pollutant}$	The emission factor, an attribute of the technology selected determining the linear relation between the activity rate and the resulting emission of a certain *pollutant,* using a specific *technology*

For each activity the rate is changing over time. In most inventories these data are organised in tables, providing an activity rate for each relevant activity for each time step (in most cases each year). The temporal resolution of the activity data determines also the temporal resolution of the inventory.

By introducing the penetration of technologies into the model, emission factors become independent of time. In this approach, the emission factors for the different pollutants[1] are a property of the technology and not of the activity. Emission factors also are independent of the location (= country). Time and location dependencies now is modelled by the time and location dependent penetration. The apparent, averaged or implied emission factors that are used in the classical approach are related to our emission factors as being the averaged value of all technologies applied for a certain activity in a certain country.

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[1] "Pollutant" in this paper includes also greenhouse gases. The IPCC Guidelines (IPCC, 1997) use the concept of "gas", since according to these guidelines, CO2 is not a pollutant. The EMEP/CORINAIR Guidebook (TFEIP, 2004) however uses "pollutant" since particulates are not a gas.

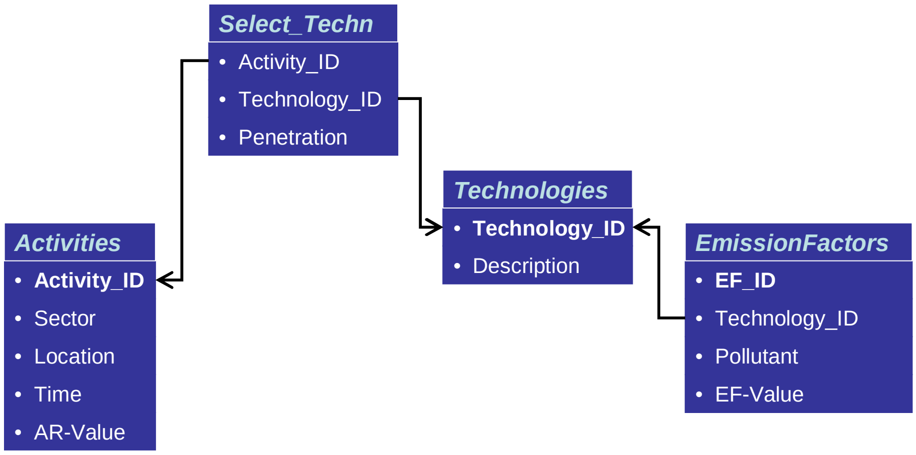


Figure 2 General scheme of the Emission Inventory Model applied in this study.

Compiling an emission inventory now exists of collecting activity data for the full time period under study similarly to the classical approach and building a database of technologies with associated emission factors. The TNO Emissions Assessment Model (TEAM) then is completed by the selection of one or more technologies for each relevant activity for every time step in the time series as indicated in Figure 2. The model makes the three main aspects or components described above explicitly available:

- The economic aspect, represented by a table of the activity rates ($AR_{activity}$) similar to the classical inventory approach; these activity rates are to be given for all relevant source activities, for each geographical unit and for every year in the inventory
- The technological aspect, represented by a table of all relevant technologies that can be used to perform the activity in any geographical unit of any year; each technology is accompanied by emission factors ($EF_{technology, pollutant}$) for each relevant pollutant in a linked table;
- The behavioural aspect, linking one or more technologies to each activity in every country and every year. This technology selection ($P_{activity,technology}$) could be a table, listing the penetration of each technology for every activity. It, however, can easily be replaced by a selection algorithm in for instance what-if studies.

By connecting to emission factors for different pollutants indirectly by selecting specific technologies for each activity, our model avoids one of the reasons for mistakes and errors as identified by Winniwarter and Schimak (2005). Emissions estimated in this approach are automatically consistent for all pollutants.

For this study we compiled a global emission inventory for energy related emissions for the time period 1960 (OECD countries) or 1970 (non-OECD countries) to 2000 using this inventory model. The next sections present details on the data sources and assumptions used to do so.

2.2 Activity Data

Both in the Climate Convention (UNFCCC, 1992, http://unfccc.int) and in the Convention on Long Range Transboundary Air Pollution (CLRTAP, 1979, http://www.unece.org/env/lrtap/) countries are requested to annually report the emissions of certain gases and pollutants into the atmosphere in a transparent and comparable way. To this end, both conventions have adopted an activity definition scheme that organises all relevant activities into a hierarchical structure. This source category structure for the combustion of fuels is given in Table 1. Fuel combustion data have been taken form the IEA energy statistics datasets for respectively the OECD (1960 - 2000) and non-OECD countries (1971 - 2000). The table also presents the link established with the IEA data set. In several cases the IEA database groups countries into regions (“Other Africa”, “Other Asia”, etc.). In these cases the energy data are split over the countries within each region, using relative population sizes. Where new countries in the IEA dataset are established or existing ones disappear (former Soviet Union, former Yugoslavia), energy use data were only used for the years that such countries existed. Since here we only deal with countries aggregated as OECD members or non-OECD members, total emissions in these countries show a reasonable time series consistency. For some fuels and some sectors however energy consumption for the year 1991 shows unexpected deviations that might be caused by the transitions in statistical systems in these countries.

Table 1 Source categories in the fuel combustion sectors (from IPCC, 1997) and link to the IEA energy data set (IEA, 2003).

IPCC code	Sector name	IEA flow code	IEA flow name
1.A	fuel combustion activities (sectoral approach)		
1.A.1	energy industries		
1.A.1.a	public electricity and heat production	PUBELEC	Public Electricity Plant
		PUBCHP	Public CHP Plant
		PUBHEAT	Public Heat Plant
1.A.1.b	petroleum refining		
1.A.1.c	manufacture of solid fuels and other energy industries		
1.A.2	manufacturing industries and construction		
1.A.2.a	iron and steel	IRONSTL	Iron and Steel [ISIC Group 271 and Class 2731] The use of Coke Oven Coke and Lignite Coke is not included as “fuel” in this source category, but as “feedstock”.
1.A.2.b	non-ferrous metals	NONFERR	Non-Ferrous Metals [ISIC Group 272 and Class 2732]
1.A.2.c	chemicals	CHEMICAL - NECHEM	Chemical and Petrochemical [ISIC Division 24] To calculate the fuel combusted the IEA Flow NECHEM (Memo: Feed stocks Use in Petrochemical Industry) must be subtracted from the flow CHEMICAL
1.A.2.d	pulp, paper and print	PAPERPRO	Paper, Pulp and Printing [ISIC Divisions 21 and 22]
1.A.2.e	food processing,	FOODPRO	Food and Tobacco [ISIC Divisions 15 and 16]

IPCC code	Sector name	IEA flow code	IEA flow name
	beverages and tobacco		
1.A.2.f	other (please specify in a covering note)	NONMET	Non-Metallic Minerals: Includes products such as glass ceramic, cement, etc. [ISIC Division 26]
		TRANSEQ	Transport Equipment [ISIC Divisions 34 and 35]
		MACHINE	Machinery: Fabricated metal products, machinery and equipment other than transport equipment [ISIC Divisions 28, 29, 30, 31 and 32].
		MINING	Mining and Quarrying: [ISIC Divisions 13 and 14]
		WOODPRO	Wood and wood products (other than pulp and paper) [ISIC Division 20]
		CONSTRUC	Construction: [ISIC Division 45]
		TEXTILES	Textile and Leather : [ISIC Divisions 17, 18 and 19]
		INONSPEC	Non-specified Industry: Any manufacturing industry not included above. Includes ISIC Divisions 25, 33, 36 and 37.
1.A.3	transport		
1.A.3.a	Domestic Air Transport	DOMESAIR	Deliveries of aviation fuels to all domestic air transport, commercial, private, agricultural, military, etc. It also includes use for purposes other than flying, e.g. bench testing of engines, but not airline use of fuel for road transport. For many countries this also incorrectly includes fuel used by domestically owned carriers for outbound international traffic.
1.A.3.b	Road	ROAD	All fuels used in road vehicles (including military) as well as agricultural and industrial highway use. Excludes motor gasoline used in stationary engines, and diesel oil for use in tractors that are not for highway use.
1.A.3.c	Rail	RAIL	All quantities used in rail traffic, including industrial railways.
1.A.3.d	Internal Navigation	INLWATER	(including small craft and coastal vessels not purchasing their bunker requirements under international marine bunker contracts). Fuel used for ocean, coastal and inland fishing should be included in agriculture.
1.A.3.e	Non-specified Transport	TRNONSPE	
1.A.4	other sectors		
1.A.4.a	Commercial and Public Services	COMMPUB	All activities coming into ISIC Divisions 41, 50, 51, 52, 55, 63, 64, 65, 66, 67, 70, 71, 72, 73, 74, 75, 80, 85, 90, 91, 92, 93 and 99.
1.A.4.b	Residential	RESIDENT	All consumption by households, excluding fuels used for transport. Includes households with employed persons (ISIC Division 95) which is a small part of total residential consumption.
1.A.4.b	Non-specified Other	ONONSPEC	Includes all fuel use not elsewhere specified (e.g. military fuel consumption with the exception of transport fuels in international marine bunkers, the domestic air and road sectors and consumption in the above-designated categories for which separate figures have not been provided).

IEA does not provide a split of fuel use in different vehicle types. To make a distinction between light and heavy duty vehicles, we used the approach also applied in EDGAR (see EDGAR 2005) and the TROTREP project where available data on road transport statistics are used to estimate relative fuel dependent contributions of light and heavy duty vehicles respectively.

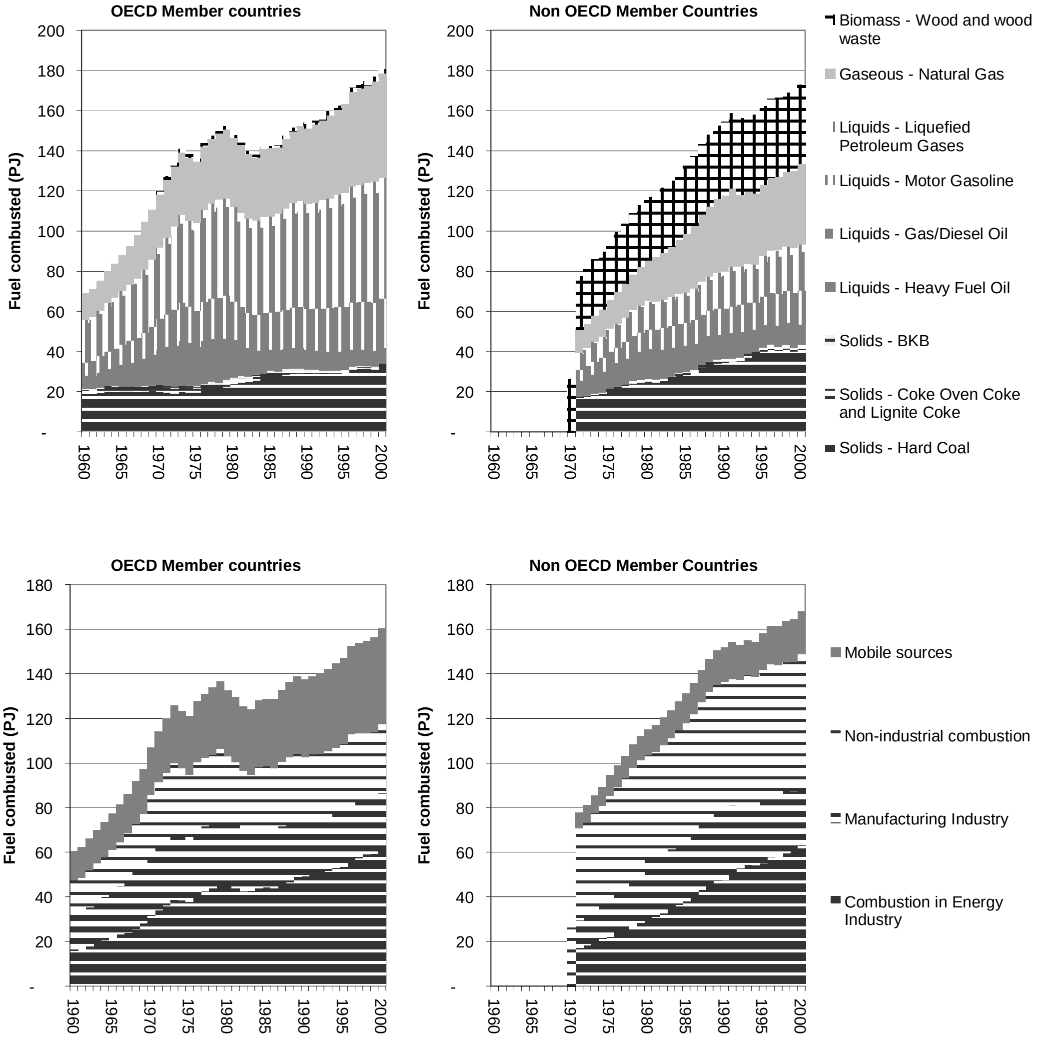


Figure 3 Fuel combustion in OECD (left) and non-OECD members (right) by fuel (top) and by sector (bottom).

Figure 3 presents the fuel combustion in the OECD (1960 -2000) and non-OECD members (1971 – 2000) as derived from this IEA data set. Both groups of countries show a steady increase in the rate of fuel combustion over time. In the OECD countries the averaged growth rate is 2.1 % per year and in the non-OECD countries 2.7 % per year. In the fuel use data for the OECD members, the two oil price shocks in the 1970s are clearly visible. The relative share of natural gas in the fuel supplies of the world has clearly increased over time, both in the OECD countries (from 25 % in the 1960s to 30 % in the 1990s) and in the non-OECD countries (from 15 % in the early 1970s to 25 % in the late 1990s)

The figure also clearly shows that the fuel mix in both groups of countries is quite different and has developed differently over time:

- Motor gasoline and diesel oil comprise about 25 to 30 % of fuel combusted in the OECD countries, whereas in the non-OECD countries it is only 10 to 15 %.

- The relative use of heavy fuel oil and coal decreased from almost 50 % in the early 1960s to about 30 % in the late 1990s in the OECD countries, while in the non-OECD countries the share of these fuels remained more or less constant at around 35 to 40 % of the total.
- In the non-OECD countries wood and wood wastes are an important fuel, while in the OECD member countries wood is hardly used as a fuel.

These changes in the world's energy supply have caused changes in the global emissions of greenhouse gases and air pollutants. Since the changes occurred both in the level of fuel combustion and in the fuel mix, these changes will be different for the different pollutants.

2.3 Technology Data and Emission Factors

Not only the amount and type of fuels are determining the level of emissions of air pollutants and greenhouse gases, but also the technology applied. Such technologies differ between countries. Furthermore, over time new technologies have been developed and existing ones have been improved. These developments also differ in different countries. Based on earlier inventory studies (TROTREP project, http://atmos.chem.le.ac.uk/trotrep/), we defined a large number of technologies to be applied in all fuel combustion activities as described above. All emission factors used are listed in Annex A. Table 2 presents an overview for road transport.

Table 2 Technologies, fuels and emission factors, applied for road transport; the technologies are typical for the croup of countries in the year indicated between brackets and applied between the years defined by the columns "First year" and "Last year".

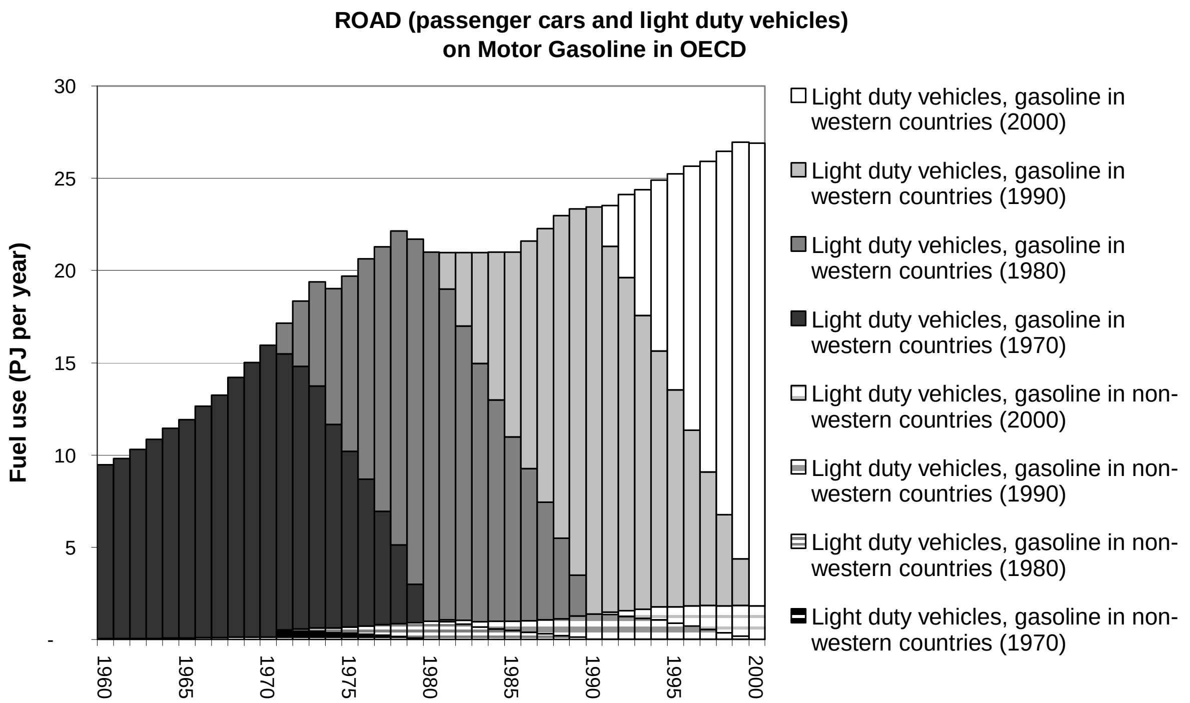
Heavy Duty Vehicles				**Emission factor (kg/TJ)**			
Country Group (typical in year)	**Fuel**	**First Year**	**Last Year**	**CO**	**CO2**	**NMVOC**	**NOX**
non-western countries (1970)	Motor Gasoline	1960	1979	10 000	69 700	1 500	510
non-western countries (1980)	Gas/Diesel Oil	1960	1999	1 000	73 200	500	1 500
	Motor Gasoline	1971	1989	8 400	69 700	1 000	510
non-western countries (1990)	Motor Gasoline	1981	1999	6 400	69 700	690	450
non-western countries (2000)	Gas/Diesel Oil	1981	2001	1 000	73 200	95	1 000
	Motor Gasoline	1991	2001	2 900	69 700	310	330
western countries (1970)	Gas/Diesel Oil	1960	1979	2 800	73 200	330	1 500
	Motor Gasoline	1960	1979	10 000	69 700	1 500	510
western countries (1980)	Gas/Diesel Oil	1971	1989	1 700	73 200	330	1 300
	Motor Gasoline	1971	1989	8 400	69 700	1 000	450
western countries (1990)	Gas/Diesel Oil	1981	1999	700	73 200	140	1 100
	Motor Gasoline	1981	1999	6 400	69 700	690	380
western countries (2000)	Gas/Diesel Oil	1991	2001	320	73 200	63	960
	Motor Gasoline	1991	2001	2 900	69 700	310	330

Heavy Duty Vehicles				Emission factor (kg/TJ)			
Country Group (typical in year)	**Fuel**	**First Year**	**Last Year**	**CO**	**CO2**	**NMVOC**	**NOX**
non-western countries (1970)	Motor Gasoline	1960	1979	10 000	69 700	1 500	1 100
non-western countries (1980)	Gas/Diesel Oil	1960	1999	1 000	73 200	500	380
	Motor Gasoline	1971	1989	8 400	69 700	1 000	1 100
non-western countries (1990)	Motor Gasoline	1981	1999	6 400	69 700	690	1 000
non-western countries (2000)	Gas/Diesel Oil	1981	2001	1 000	73 200	95	240
	Motor Gasoline	1991	2001	2 900	69 700	310	620
western countries (1970)	Gas/Diesel Oil	1960	1979	2 800	73 200	330	380
	Motor Gasoline	1960	1979	10 000	69 700	1 500	1 100
western countries (1980)	Gas/Diesel Oil	1971	1989	1 700	73 200	330	330
	Motor Gasoline	1971	1989	8 400	69 700	1 000	1 000
western countries (1990)	Gas/Diesel Oil	1981	1999	700	73 200	140	270
	Motor Gasoline	1981	1999	6 400	69 700	690	760
western countries (2000)	Gas/Diesel Oil	1991	2001	320	73 200	63	220
	Motor Gasoline	1991	2001	2 900	69 700	310	490

The emission factors, used in the TROTREP project are developed, mainly as expert judgements by the TROTREP emissions team at TNO. In this development several international emission factor collections were used and interpreted towards averaged values for a country or a group of countries in specific years. These emission factors were, where possible, checked with national experts. In many cases the emission factors were the same as the ones used in the EDGAR database (Olivier and Berdowski, 2001).

Technologies in our approach were identified from the TROTREP emission factors as unique combinations of emission factors for CO, NO_x, NMVOC and pm10, occurring in the TROTREP database at the selected specific year in two subgroups of countries: OECD members and non-OECD members for stationary combustion and “Western” and “Non-western” countries for road transport. The difference between the two groupings is the attribution of the countries in Central and Eastern Europe, which are members of OECD, but have a completely different vehicle fleet as compared to Western Europe, and OECD members outside Europe.

For some fuel and source category combinations, only one unique technology was identified. For some others ten or more different unique combinations were found. Generally, TROTREP appears to assume more different technologies in OECD countries as compared to non-OECD countries, indicating that the level of detail in the TROTREP database is higher for the former group of countries.



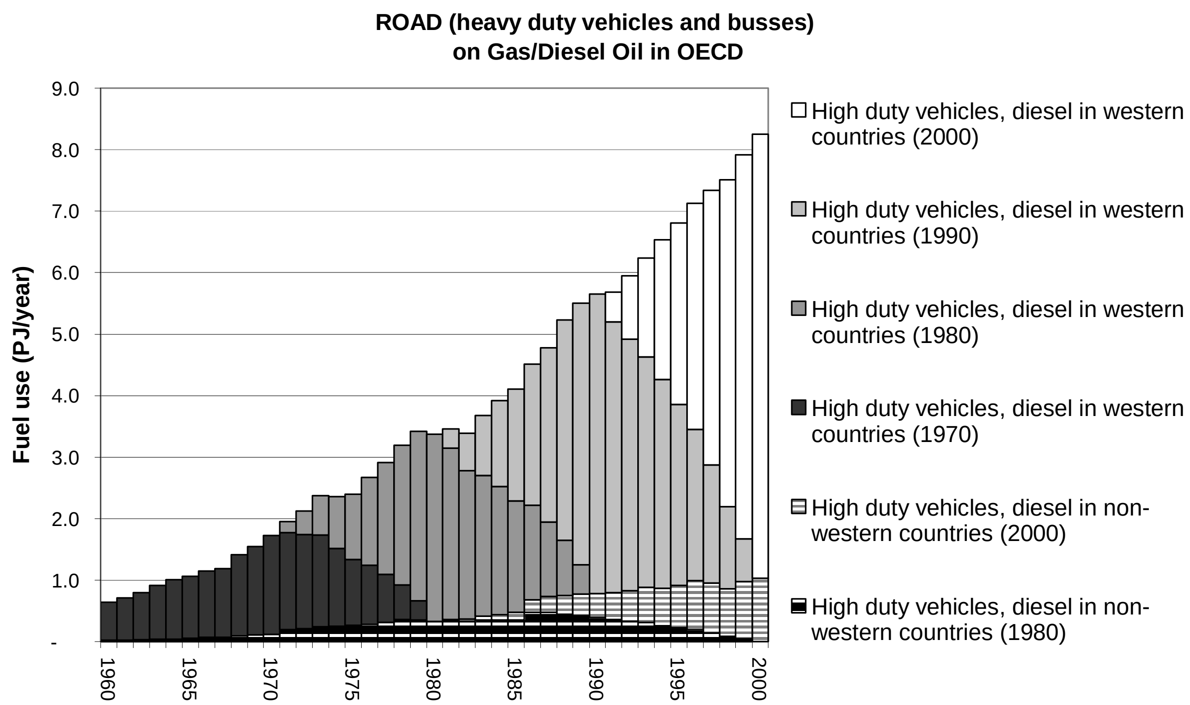


Figure 4 Penetration of successive technologies in road transport: gasoline in passenger cars and light duty vehicles (above) and diesel in heavy duty vehicles (below) in the OECD countries.

2.4 Technology Penetration

In our approach we model the penetration of technologies explicitly by gradually changing the penetrations for two successive technologies during the years between the first and last application of the technology. An example of this is presented in Figure 4 for passenger cars and light duty vehicles on gasoline and heavy duty vehicles on diesel in the developed countries (OECD members). Similar graphs can be produced for all source categories and fuel combinations.

3 Results

3.1 Emission trends 1960 to 2000

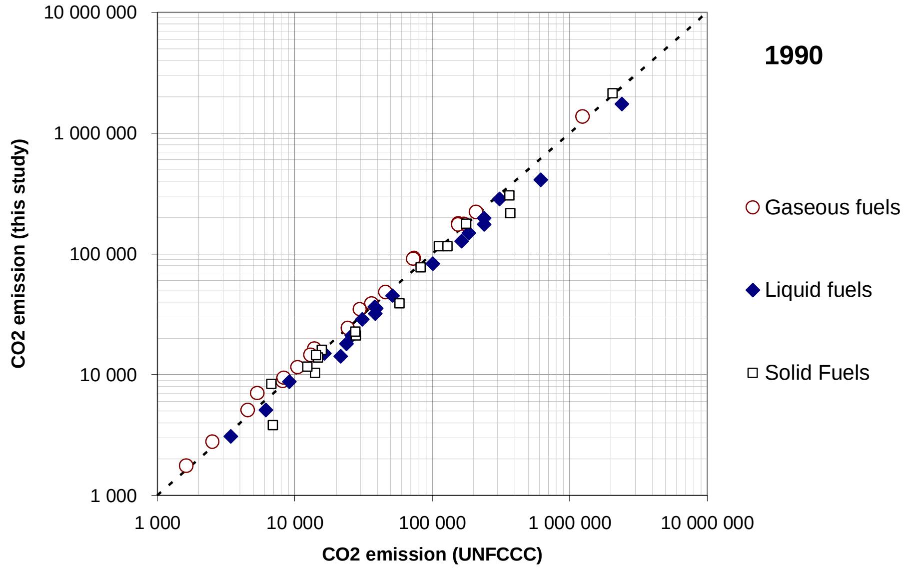
3.1.1 Direct greenhouse gases

Combustion of fossil fuels is the main source of anthropogenic carbon dioxide emissions. Emissions are directly calculated from the fuel combusted, using the emission factors as given in Table 1. These emissions factors are largely independent on the combustion technology and therefore are applied throughout the time series and for all countries. The only way of influencing these emission factors significantly is by introducing carbon capture and carbon storage technologies, which is assumed not to occur in the time span of this study.

Table 3 CO_2 Emission factors by fuel, derived from the1996 IPCC Guidelines.

Fuel Group	**Fuel Name**	**Emission Factor (kg/TJ)**
Solids	BKB	96 200
Solids	Coke Oven Coke and Lignite Coke	105 000
Solids	Hard Coal	96 100
Liquids	Gas/Diesel Oil	73 200
Liquids	Heavy Fuel Oil	76 500
Liquids	Liquefied Petroleum Gases	63 200
Liquids	Motor Gasoline	69 700
Gaseous	Natural Gas	56 000
Biomass	Wood and wood waste	109 700

For a number of countries, carbon dioxide emissions are available from the annual countries' inventory submissions to the United Nations Framework Convention on Climate Change (UNFCCC, http://ghg.unfccc.int/). In Figure 5 the CO_2 emission estimates as derived in this study are compared with those reported by the countries themselves for the years 1990 and 2000. The correspondence between our estimates and the UNFCCC reports is quite good for both years. Since the CO_2 emissions depend on the volume and type of fuels combusted only, this correspondence shows that our estimates of fuel consumption are similar to those of the countries themselves.



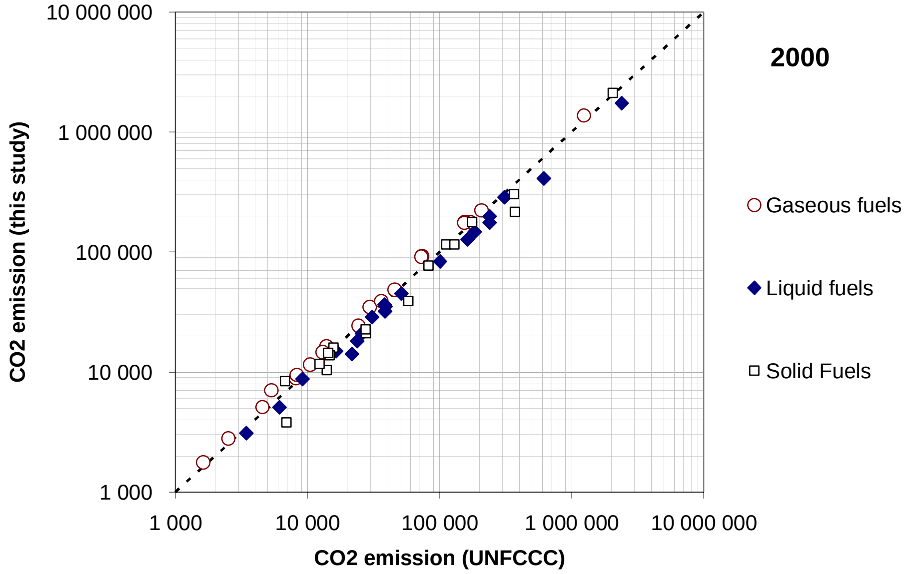


Figure 5 Comparison of the 2000 CO_2 emissions from combustion of solid, liquid and gaseous fuels, estimated in this study, with those reported to UNFCCC for countries where UNFCCC data are available.

Figure 6 shows the development over time of the CO_2 emissions from fuel combustion in the developed and in the developing countries. The emissions generally follow the fuel combustion patterns as given in Figure 3.

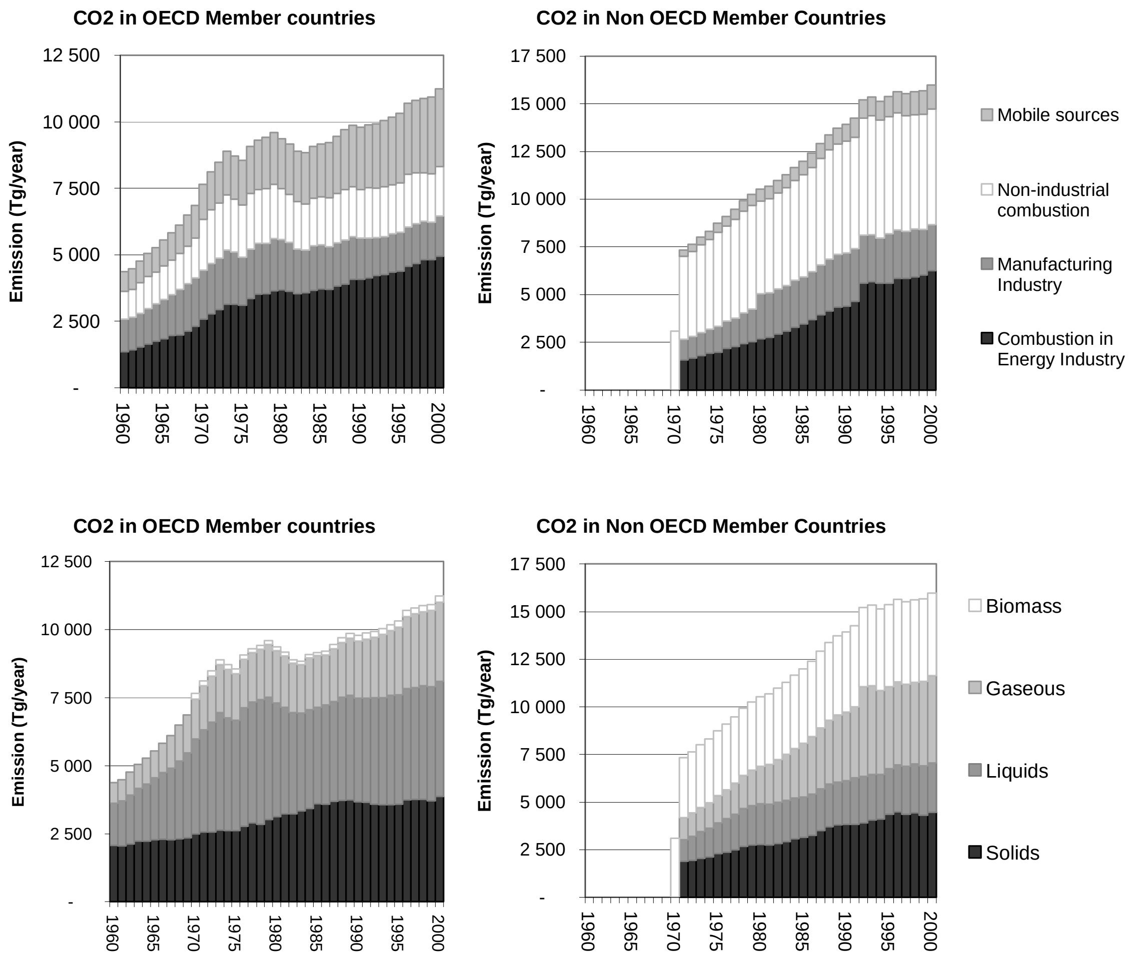


Figure 6 Time series of CO2 emissions by fuel type in the OECD member countries and the non-OECD member countries.

3.1.2 Air pollutant emissions

Apart from greenhouse gases, combustion of fuels is also a major source of a series of air pollutants. In Figure 7 time series of emissions of nitrogen oxides (NO_x), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC) and particulates (PM10) in both the developed countries (OECD member countries) and developing countries (non-OECD members) are presented. Figure 8 presents the source sector split for the same emissions.

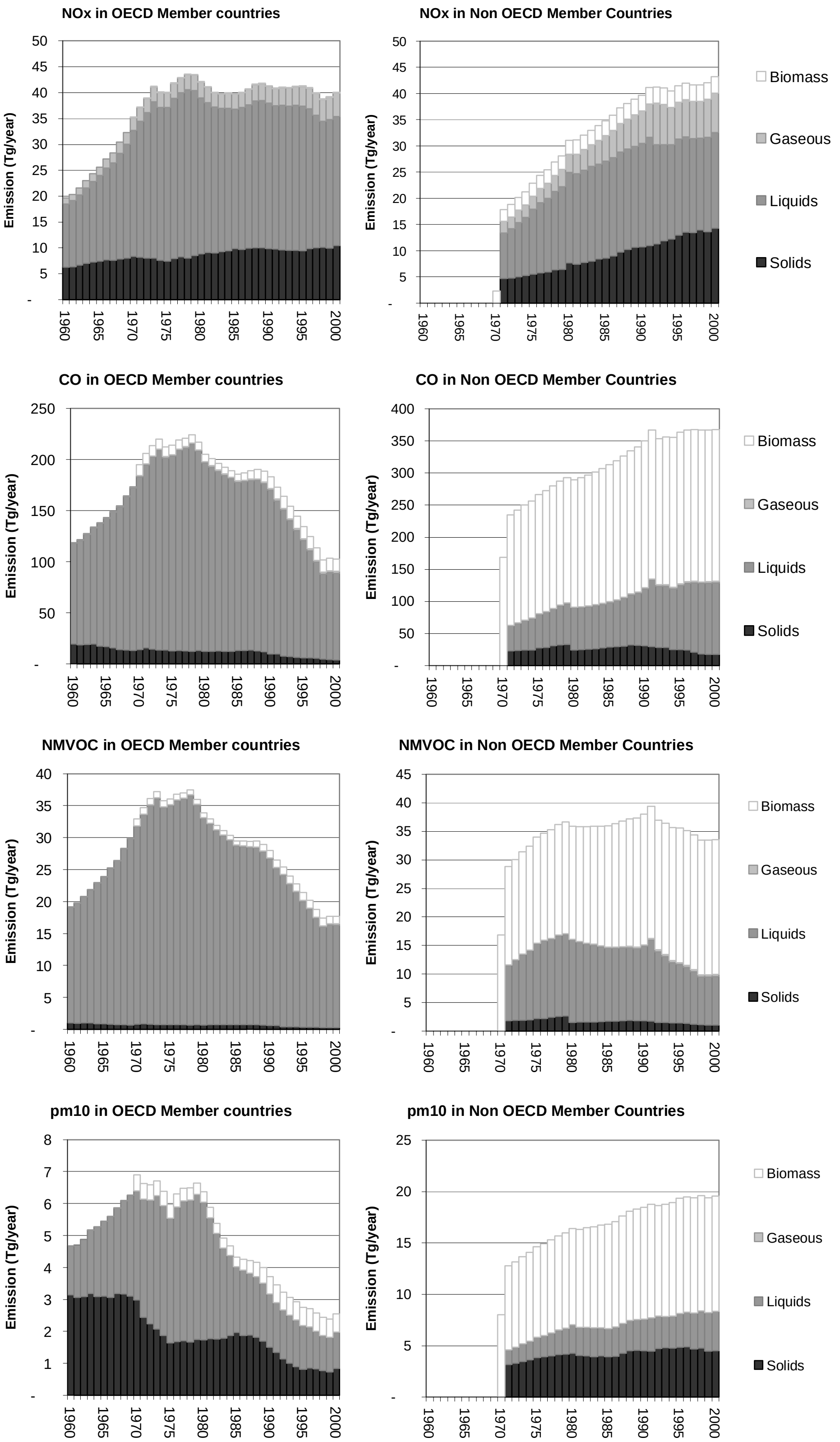


Figure 7 Time series of NO_x, CO, pm10 and NMVOC emissions due to fuel combustion in the industrialized (left) and developing countries (right). Contributions of gaseous, liquid, solid and biomass fuels are given.

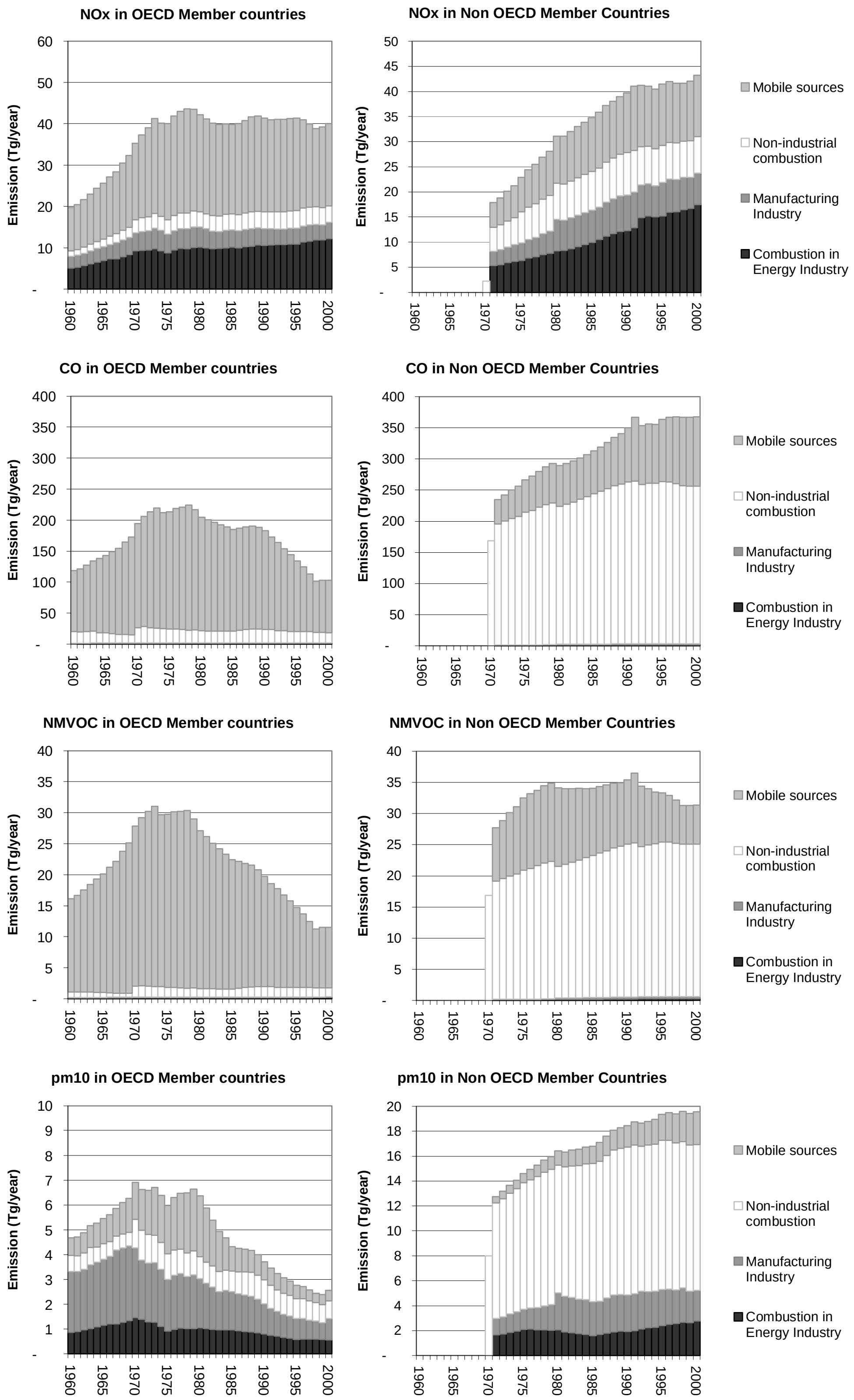


Figure 8 Time series of NO_x, CO and NMVOC emissions due to fuel combustion in the industrialized (left) and developing countries (right). Contributions of different source sectors are given.

The total global emissions of NOx, as estimated in this study correspond relatively well with the one estimated by Hameed and Donlin (1988). These authors report an increase from about 10 Tg nitrogen in 1960 to about 20 Tg nitrogen in 1980. Furthermore Figure 9 compares the estimates of the 1999 NO_x and CO emissions in this study with those reported to the UNECE LRTAP convention (EMEP/LRTAP 2005). Our estimates show a fair agreement with the officially reported emissions, although the differences appear to be larger as for the emissions of CO_2. This is to be expected since the emissions are not only depending upon the fuel, but also upon the technologies used. In the TEAM estimate all OECD are assumed to use the same technology mix for each activity. The same is assumed for all non-OECD members. In the emission reports from the countries, more country specific information will generally be used in the estimates.

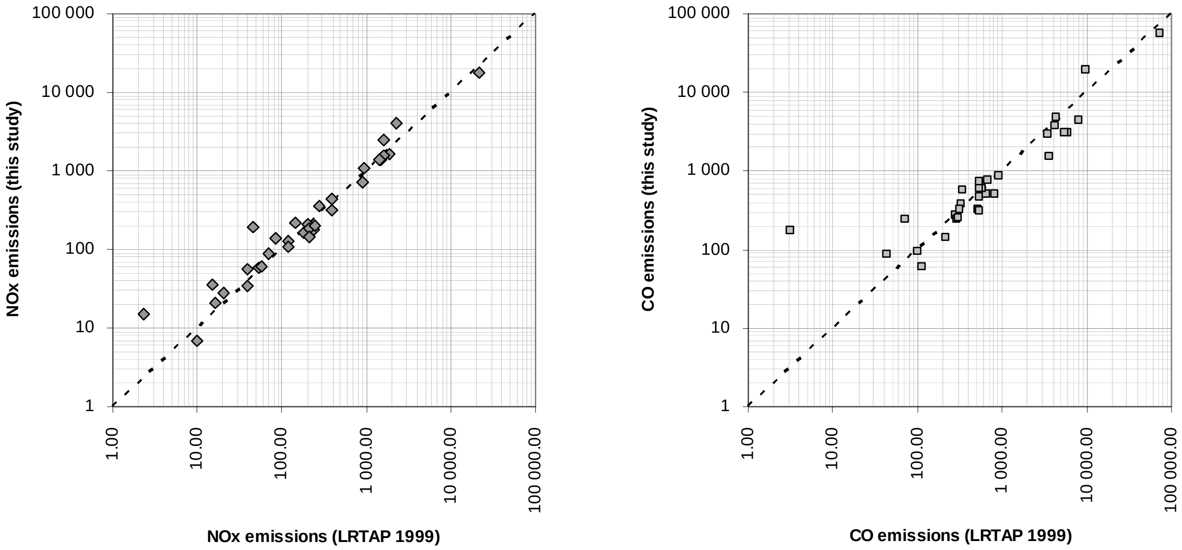


Figure 9 Comparison of the 1999 NO_x (left) and CO (right) emissions from combustion, estimated in this study, with those reported to LRTAP for countries where LRTAP data are available.

The figures clearly show the different contributions of mobile and stationary combustion to the total emissions of the different pollutants. The high share of mobile sources in the emissions of CO and NMVOC in the OECD member countries is also reflected in the high contribution of liquid fuels to these emissions. The non-OECD countries show high contributions to CO, NMVOC and pm10 from the combustion of biomass in non-industrial combustion.

3.2 What-if scenarios

The emission model developed in this paper allows for relatively simple analyses on the contributions of certain developments to the air emissions. In this section we demonstrate the use of the system in assessing the contribution of changes in the road transport sector to the total emissions to air. Changes in the intensity of road transport (gasoline, diesel and Liquefied Petroleum Gas (LPG)) and the introduction of emission abatement technology in gasoline fuelled cars are analysed separately. Finally we apply the model in an assessment what large scale introduction of nuclear energy could have contributed to decrease air emissions.

3.2.1 *Increasing mobility*

Over the past thirty years, the road transport has dramatically increased. This of course is reflected in the fuel use in this sector (Figure 3), that increased more rapidly than the population size. To analyse the contribution of both population growth and increased road transportation, we defined three retrospective scenarios and calculated the resulting emissions of CO2, NOx and CO due to fuel combustion. In these scenarios, different developments are assumed from the early 1970s onwards because of the fact that environmental concerns started to build up from that time and since the two oil price shocks in the 1970s partly obscure a clear picture. These three scenarios are:

- “Historic emissions” as estimated in this study (see Figure 6 and Figure 7)
- “Road transport constant”: the emissions calculated for the case that road transport (motor gasoline, diesel and LPG) would have retained the volume of 1971 in all OECD member countries.
- “Road mobility constant”: the emissions calculated for the case that the mobility (per capita road transport volume) would have remained constant since 1971. The values for fuel use as derived in scenario 2, are scaled with population data from the IEA data set.

In Figure 10 the results of this exercise are presented for the pollutants CO_2, NO_x and CO, both for the emissions from mobile combustion and from all fuel combustion processes.

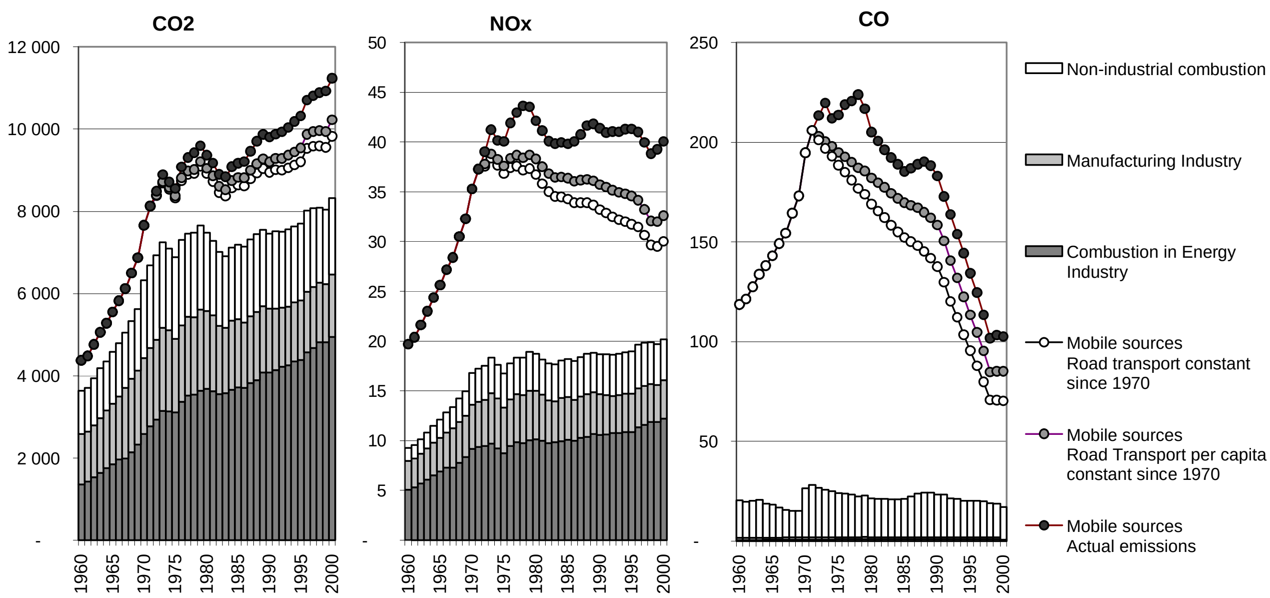


Figure 10 Emissions of air pollutants from fuel combustion in three retrospective scenarios. Bars: contribution of stationary sources; open circles: road transport constant since 1970; grey circles: per capita mobility constant since 1970; black circles: actual emissions.

Since no CO_2 abatement technologies have been introduced in road transport, the development of the emissions of CO_2 reflect the fuel combusted in the sector over time. In the period 1971 to 2000, the emissions of CO_2 from mobile sources in the OECD member countries almost doubled from 1500 in the early 1970s to 2900 kTon per year at the turn of the century. This is about 40% of the increase for all combustion emissions in the same time period. About one third of this increase is due to the increase in population size, about two third is due to the increase in mobility.

Since the 1970s the car fleet has been gradually equipped with newer engine technologies and add-on equipment to abate tail pipe emissions of air pollutants. This is reflected by the observation that the NO_x emissions due to mobile sources in the OECD member countries is back to the early 1970s level by the turn of the century. If however, road transport would not have increased since the early 1970s, the emissions would have been back at the 1960 level. It is also shown that about half of the increase of all emissions from fuel combustion since the early 1970s is due the growth in mobile sources. Again about one third of this is due to the increasing population and two thirds to the increase in mobility.

A similar pictured arises for CO and NMVOC (not shown). Although the emissions of these pollutants have decreased to below the 1960 level, the increases in population size and mobility have partly counteracted these decreases.

3.2.2 *Emission abatement in road transport*

As a second example, Figure 11 presents the influence of introducing emission abatement technologies in road transport, fuelled by motor gasoline in the OECD member countries. Since 1970 gasoline cars have been equipped progressively with several types of catalysts, reducing the emissions of . This section analyses the effects of introduction of these catalysts into the car fleet.

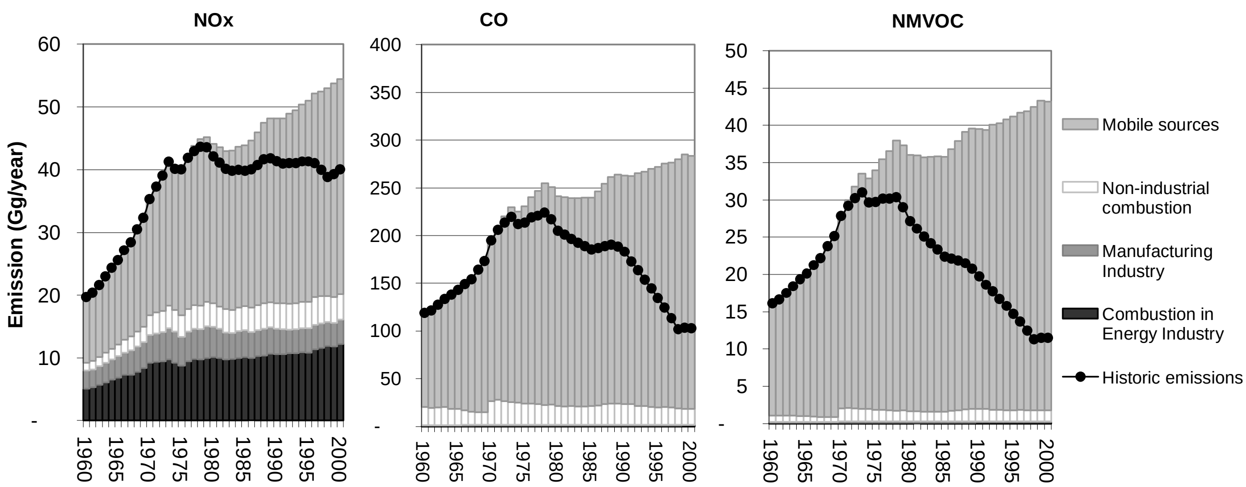


Figure 11 Emissions from fuel combustion in the OECD member countries when emission abatement in gasoline cars had would not have occurred.. Black dots represent the historic emissions.

NO_x emissions from fuel combustion in the OECD member countries could have been about 35 % higher, if the gasoline cars had still been equipped with the technologies of

1971. Emissions of CO from fuel combustion would have been more than twice the actual value and emissions of NMVOC almost three times the actual value.

3.2.3 Nuclear power plants

A third scenario finally investigates the emissions that would have occurred if in the 1970s a complete replacement of coal fired power plants by nuclear power plants was initiated. This scenario assumes that the replacement of coal fired power plants by nuclear ones occurred between 1976 and 1995. Each year within this period, another 5% of the coal power production is replaced by nuclear power production with no emissions of greenhouse gases and air pollutants. Figure 12 presents the results of this scenario.

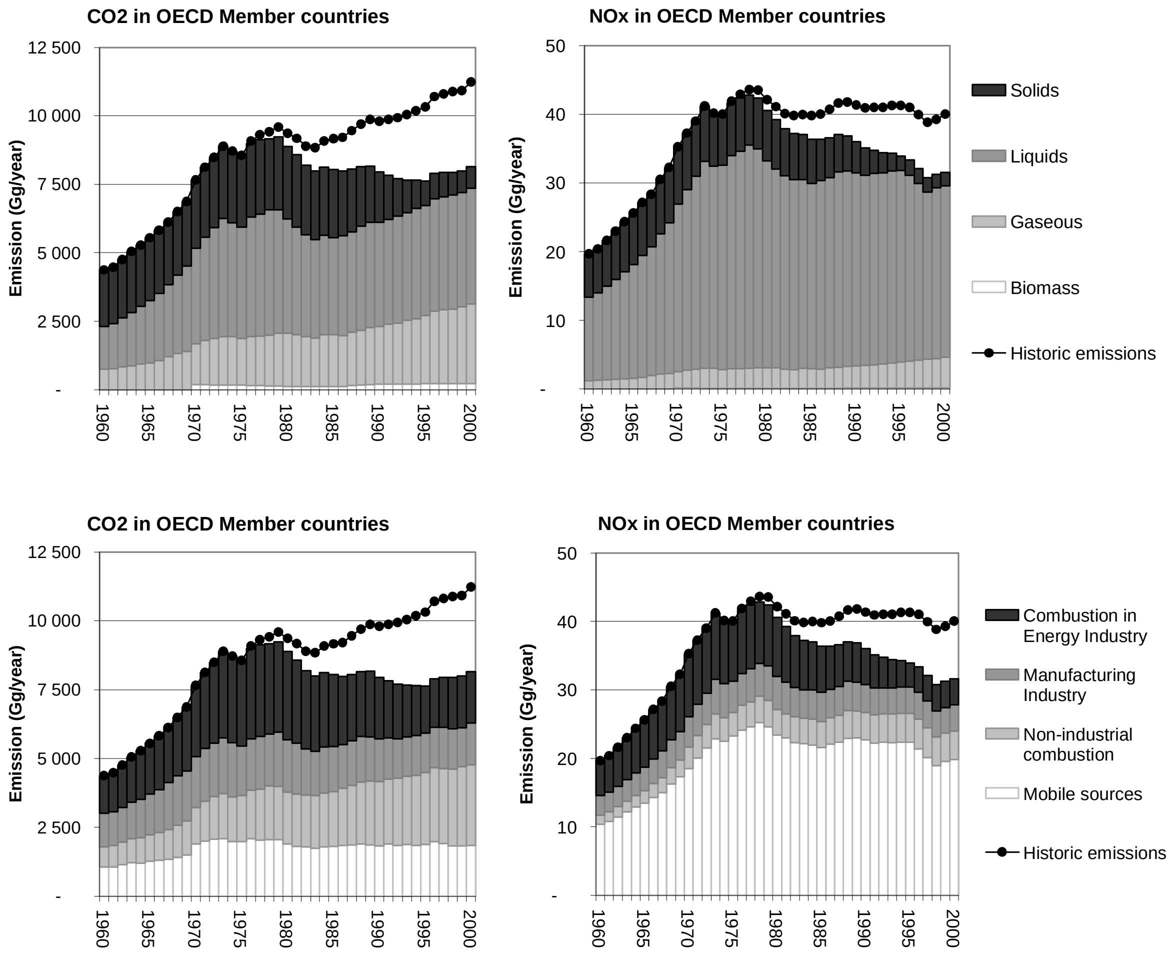


Figure 12 Emissions of CO2 and NOx in OECD countries if nuclear power would have gradually replaced coal fired power plants between 1976 and 1995. Black dots represent the historic emissions.

If nuclear power would have been introduced at a large scale since the 1970s, the emissions of both CO_2 and NO_x would have been reduced significantly below the 1975 level. Since the larger part of the coal in the OECD countries is combusted in power plants, this scenario shows a significant decrease in emissions of CO_2 and NO_x due to the assumed introduction of nuclear power. The contribution of solid fuels to the total

CO_2 emissions in the OECD countries in 2000 would have decreased from 35 % in the "historic" situation to 10 % in the case of introduction of nuclear power plants. For NO_x the contribution of solid fuels would have decreased from 26 % to 6 %.

4 Discussion and Conclusions

In this paper an emission inventory model TEAM, explicitly including economic, technological and behavioural aspects is developed that reproduces national emissions reported to international conventions to a precision that is well suited for studies at continental and global scales. In principle the correspondence with such national reports can be improved by adding more country specific information to the system. In a separate paper (Pulles et al, 2005) this has been done for dioxin emissions in Central Europe in a study aimed at quantifying the uncertainties in the national total emissions. A similar treatment of the uncertainties has not yet been performed for this study.

The advantage of the TEAM approach is, in agreement with Bond et al (2004), that differences between regions now are explicitly modelled as differences in technologies applied in different branches of the economy and time series of emission factors are replaced by the replacements of one technology by another. By doing this, these time series are based on physical changes in the real world, rather than on implied emission factors.

The explicit modelling of technology selections in the emission model, introduced in this paper, results in a clear and transparent tool to investigate the contributions of several developments in society, economy and technology to the trends in emissions. In this study such developments were assessed for the OECD member countries:

- By manipulating the activity data, the model allows to separate the contribution of different societal contributions to the total emissions. The changes in population size and in per capita mobility were assessed by setting the activity rate for road transport constant since 1970 and relative to population size (Figure 10).
- By selecting the 1970 technology for all gasoline and LPG fuelled road transport for all years between 1970 and 2000, an estimate was obtained of the emissions that would have occurred when catalysts would have not been introduced.
- By gradually replacing all solid fuel fired power plants by nuclear power plants the potential of nuclear power generation in reducing emissions of CO2 and NOx was estimated.

These relatively simple and transparent scenario assumptions show the strengths of this emission inventory model. The distinction between developments in economy, technology and behaviour increases the understanding of emission trends in a comprehensive and integrated manner.

The system as described here can relatively easily be further developed. Two examples of such a development are already implemented as a post processor to

- increase the spatial resolution;
- increase the chemical resolution; a post processor on TEAM is developed to speciate the NMVOC emissions in eighteen separate volatile organic compounds as input in atmospheric chemistry models.

These post processors obviously could be avoided by increasing the spatial resolution of the activity data in the database directly or by speciating the NMVOC emission factors for each individual technology directly in the emission factors table. Since only limited data on high resolution spatial activity data and on high resolution chemical identity of NMVOC emissions is available, this would not increase the accuracy of the spatially or chemically resolved inventory.

A similar post processor was developed to increase the temporal resolution needed for the application in the RETRO project, where a seasonal resolution was needed. Since the model runs for this project spanned the period 1960 to 2000, a separate post processor was developed to extrapolate or interpolate data for a number of countries, sector or fuels to obtain consistent 40 year time series for all sectors, all countries and all pollutants. This post processor also enables smoothing of time series inconsistencies, caused by data gaps or changes of definitions in the energy statistics.

An intriguing possible development is adding cost data to the table of technologies. The technology selection then will not only allow for cost effectiveness studies, comparing different scenarios in a rather straight forward way, but will also enable the implementation of technology selection strategies aimed at least costs optimizations, both in retrospective and prospective studies.

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Annex A Emission Factors overview

The table below presents all emission factors, used in this study. Each row of eemission factors represents a specific technology available and used between the years as indicated. As is discussed in section 2.4 technologies are assumed to replace each other gradually over time.

CRF/NFR Code	CRF/NFR Name	Fuel Group	Country Group	First Year	Last Year	CO	CO2	NMVOC	NOX	PM10
1.A.1.a	public electricity and heat production	Gaseous	EU15	1960	1984	20	56000	4	110	0.2
				1976	2000	20	56000	4	100	0.2
				1991	1998	30	56000	4	80	0.2
			New EU10	1960	1994	20	56000	4	110	0.2
				1976	2000	20	56000	4	100	0.2
				1994	2000	30	56000	4	80	0.2
			non-EU OECD	1960	1984	20	56000	4	110	0.2
				1976	2000	20	56000	4	100	0.2
				1992	2000	30	56000	4	80	0.2
			non-OECD	1971	1974	20	56000	4	140	0.2
					1994	20	56000	4	110	0.2
				1986	2000	20	56000	4	100	0.2
				1988	2000	30	56000	4	80	0.2
		Liquids	EU15	1960	1974	18	149700	5	540	25
				1971	1984	18	149700	5	445	20
				1976	2000	18	149700	5	400	20
				1984	1987	20	73200	2	80	5
				1978	2000	30	76500	3	175	40
			New EU10	1960	1974	15	76500	3	240	20
				1965	1994	3	73200	2	300	5
				1969	2000	20	73200	2	80	5
				1970	2000	30	76500	3	175	40
				1971	1984	18	149700	5	445	20
					2000	15	76500	3	240	40
				1976	2000	18	149700	5	400	20
				1986	2000	3	73200	2	280	5
			non-EU OECD	1960	1974	18	149700	5	540	25
				1971	1984	18	149700	5	445	20
				1976	2000	18	149700	5	400	20
				1974	1999	30	76500	3	175	40
				1975	2000	20	73200	2	80	5
			non-OECD	1971	1974	3	73200	2	310	5
					1994	3	73200	2	300	5
					2000	35	149700	5	320	45
				1986	2000	3	73200	2	280	5
				1990	2000	30	76500	3	175	40
		Solids	EU15	1960	1974	75	393800	6	1480	290
				1971	1984	75	393800	6	1210	105
				1976	1994	75	393800	6	1100	105
					2000	130	96500	20	150	180
				1986	1994	16.2	105000		270	6
					1997	39.7	288800	6	730	39
				1995	2000	150	96100	20	210	180

CRF/NFR Code	CRF/NFR Name	Fuel Group	Country Group	First Year	Last Year	CO	CO2	NMVOC	NOX	PM10
				1996	2000	35	288800	6	730	39
			New EU10	1960	1974	55	297600	4	1165	210
					2000	300	201100	40	420	360
				1970	2000	130	96500	20	150	180
				1971	1984	55	297600	4	935	75
				1976	1994	55	297600	4	850	75
				1982	1984	20	96100	2	425	180
					1994	20	96100	2	385	70
				1986	1994	20	96200	2	250	30
					1997	72.1	489900	8	1360	115
				1992	1994	35	192700	4	570	150
					1997	23.5	192700	4	520	150
				1996	1998	10	96200	2	260	80
					2000	65	490200	8	1470	177
				1997	2000	10	96200	2	230	8
			non-EU OECD	1960	1974	35	192600	4	740	140
				1971	1984	35	192600	4	605	50
				1976	1994	35	192600	4	550	50
				1982	1999	150	96100	20	210	180
				1986	1997	27.4	192600	4	500	31
				1996	2000	25	192600	4	500	31
			non-OECD	1971	1974	35	192600	4	820	360
					1984	35	192600	4	740	360
				1976	1994	35	192600	4	670	140
				1986	1997	27.4	192600	4	620	140
				1996	1997	16.2	105000		360	70
					2000	50	393800	6	1320	290
				1990	1994	20	96200	2	285	80
					1997	12.3	96200	2	260	80
					2000	300	201100	40	420	360
				1989	2000	130	96500	20	150	180
1.A.1.b	petroleum refining	Gaseous	EU15	1970	1997	30	56000	4	120	0.2
				1986	2000	20	56000	4	120	0.2
			New EU10	1960	1997	30	56000	4	120	0.2
				1986	2000	20	56000	4	120	0.2
			non-EU OECD	1960	1997	30	56000	4	120	0.2
				1986	2000	20	56000	4	120	0.2
			non-OECD	1971	1997	30	56000	4	120	0.2
				1986	2000	20	56000	4	120	0.2
		Liquids	EU15	1960	2000	50	149700	5	275	195
			New EU10	1960	2000	30	76500	3	175	190
				1976	2000	20	73200	2	100	5
			non-EU OECD	1960	2000	50	149700	5	275	195
			non-OECD	1971	2000	50	149700	5	275	195
		Solids	EU15	1970	1979	100	96100	20	270	60
					1992	75	96500	20	150	60
				1986	1992	50	96500	20	150	60
				1992	1995	125	192400	40	300	120
			New EU10	1970	1997	100	96100	20	270	60

CRF/NFR Code	CRF/NFR Name	Fuel Group	Country Group	First Year	Last Year	CO	CO2	NMVOC	NOX	PM10
				1986	2000	75	96100	20	270	60
				1988	1991	175	210000	40	540	120
			non-EU OECD	1981	1997	100	96100	20	270	60
				1986	1998	75	96100	20	270	60
			non-OECD	2000	2000	75	105000	20	270	60
1.A.1.c	manufacture of solid fuels and other energy industries	Gaseous	EU15	1960	1984	20	56000	4	110	0.2
					1997	30	56000	4	160	0.2
					2000	30	56000	4	80	0.2
				1976	2000	20	56000	4	100	0.2
				1986	2000	20	56000	4	160	0.1
				1973	2000	30	56000	4	50	0.2
			New EU10	1960	1994	20	56000	4	110	0.2
					1997	30	56000	4	160	0.2
					2000	60	112000	8	130	0.4
				1976	2000	20	56000	4	100	0.2
				1986	2000	20	56000	4	160	0.1
			non-EU OECD	1960	1997	30	56000	4	160	0.2
					2000	30	56000	4	80	0.2
				1976	2000	20	56000	4	100	0.2
				1986	2000	20	56000	4	160	0.1
				1988	2000	30	56000	4	50	0.2
				1974	1984	20	56000	4	110	0.2
			non-OECD	1971	1974	20	56000	4	140	0.2
					1994	20	56000	4	110	0.2
					1997	30	56000	4	160	0.2
					2000	30	56000	4	80	0.2
				1986	2000	20	56000	4	100	0.2
				1991	2000	30	56000	4	50	0.2
				1990	2000	20	56000	4	160	0.2
		Liquids	EU15	1960	1974	15	76500	3	240	20
					1999	30	76500	3	210	40
				1970	2000	70	222900	7	2880	50
				1971	1984	15	76500	3	170	15
				1976	2000	68	299400	10	650	65
				1974	1974	3	73200	2	300	5
					1984	3	73200	2	250	5
			New EU10	1960	1974	15	76500	3	240	20
				1965	1994	3	73200	2	300	5
					2000	50	149700	5	1575	45
				1970	2000	20	73200	2	80	5
				1971	1984	18	149700	5	420	20
					2000	30	76500	3	1400	40
				1976	2000	18	149700	5	375	20
				1992	2000	18	149700	5	520	45
				1980	2000	20	73200	2	100	5
			non-EU OECD	1976	1984	20	73200	2	100	5
					1989	30	76500	3	210	40
					2000	18	149700	5	375	20
				1994	2000	60	153000	6	1575	80
				1974	1974	18	149700	5	540	25

CRF/NFR Code	CRF/NFR Name	Fuel Group	Country Group	First Year	Last Year	CO	CO2	NMVOC	NOX	PM10
					1984	18	149700	5	420	20
				1975	2000	40	146400	4	1480	10
			non-OECD	1971	1974	3	73200	2	310	5
					1994	3	73200	2	300	5
					2000	115	375900	13	3295	130
				1986	2000	3	73200	2	280	5
				1978	2000	20	73200	2	100	5
				1980	2000	30	76500	3	210	40
		Solids	EU15	1960	1997	275	297600	60	910	120
					2000	150	96100	20	210	180
					1987	150	105000	20	210	180
					1990	130	96200	20	150	210
					1993	130	96500	20	150	180
				1970	1974	75	393800	6	1320	290
					1997	75	96200	20	250	30
				1971	1984	75	393800	6	1150	150
				1976	1994	55	288800	6	770	125
					1990	20	105000		270	25
				1986	1997	39.7	288800	6	700	84
					2000	200	297300	60	910	20
					1990	16.2	105000		240	6
				1996	2000	35	288800	6	700	84
				1987	2000	50	96500	20	250	70
			New EU10	1960	1974	75	393800	6	1320	290
					1997	100	105000	20	330	25
					2000	560	393800	80	720	750
				1965	1997	175	192600	40	580	95
				1971	1984	75	393800	6	1150	150
				1976	1994	75	393800	6	1040	150
				1986	1997	130.9	498800	26	1270	96
					1999	50	96500	20	250	70
					2000	75	96100	20	330	6
				1992	1994	35	192600	4	600	140
					1997	16.2	96100	2	320	70
				1995	1997	12.3	96200	2	230	80
				1996	1997	10	96200	2	230	80
					2000	65	489900	8	1260	160
				1997	1997	75	96200	20	250	80
					1998	50	96200	20	250	80
			non-EU OECD	1960	1997	100	105000	20	330	25
					2000	150	96100	20	210	180
					1993	130	96500	20	150	180
				1976	1994	35	192600	4	520	95
				1986	1997	27.4	192600	4	470	76
					2000	75	105000	20	330	6
				1996	2000	25	192600	4	470	76
				1997	1997	16.2	105000		240	6
					2000	15	105000		240	6
				1974	1974	35	192600	4	660	140
					1984	35	192600	4	575	95

CRF/NFR Code	CRF/NFR Name	Fuel Group	Country Group	First Year	Last Year	CO	CO2	NMVOC	NOX	PM10
			non-OECD	1971	1974	20	96100	2	430	180
					1984	20	96100	2	380	180
					1997	275	297600	60	910	210
					2000	280	192600	40	360	360
				1976	1994	20	96100	2	345	70
				1986	1997	27.4	192600	4	550	140
					2000	200	297600	60	910	210
				1992	1994	20	96200	2	255	80
					1997	12.3	96200	2	230	80
				1996	2000	50	393800	6	1100	290
				1997	1997	75	96200	20	250	80
					1999	50	96200	20	250	80
				1987	1994	20	105000		345	70
					1997	16.2	105000		320	70
				1980	2000	150	105000	20	210	180
				1990	2000	130	96200	20	150	210
				1985	1994	15	96500	2	255	70
1.A.2.a	iron and steel	Gaseous	EU15	1960	1997	30	56000	4	120	0.2
				1986	2000	20	56000	4	120	0.1
			New EU10	1960	1997	30	56000	4	120	0.2
				1986	2000	20	56000	4	120	0.1
				1992	2000	20	56000	4	120	0.2
			non-EU OECD	1960	1997	30	56000	4	120	0.2
				1986	2000	20	56000	4	120	0.1
			non-OECD	1971	1997	30	56000	4	120	0.2
				1986	2000	20	56000	4	120	0.2
		Liquids	EU15	1960	2000	50	149700	5	275	195
			New EU10	1960	2000	50	149700	5	275	195
			non-EU OECD	1960	2000	50	149700	5	275	195
			non-OECD	1971	2000	50	149700	5	275	195
		Solids	EU15	1960	1994	75	96500	20	150	60
					1997	275	297300	60	690	154
				1986	1994	50	96500	20	150	60
					2000	200	297300	60	690	21
			New EU10	1960	1997	200	201100	40	540	120
				1965	1997	75	96500	20	150	60
				1986	2000	200	297600	60	690	74
				1992	2000	75	105000	20	270	60
				1993	1996	75	96100	20	270	60
				1972	1984	75	96200	20	150	34
			non-EU OECD	1960	1997	200	201100	40	540	120
				1986	2000	150	201100	40	540	14
				1972	1983	75	96500	20	150	60
			non-OECD	1971	1997	275	297600	60	690	180
				1986	2000	200	297600	60	690	180
				1992	1997	75	96200	20	150	60
					2000	50	96200	20	150	60
1.A.2.b	non-ferrous metals	Gaseous	EU15	1965	1997	30	56000	4	120	0.2
				1986	2000	20	56000	4	120	0.1

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			New EU10	1960	1997	30	56000	4	120	0.2
				1986	2000	20	56000	4	120	0.1
				1992	2000	20	56000	4	120	0.2
			non-EU OECD	1971	1997	30	56000	4	120	0.2
				1986	2000	20	56000	4	120	0.1
			non-OECD	1971	1997	30	56000	4	120	0.2
				1986	2000	20	56000	4	120	0.2
		Liquids	EU15	1960	2000	50	149700	5	275	195
			New EU10	1960	2000	50	149700	5	275	195
			non-EU OECD	1970	2000	50	149700	5	275	195
			non-OECD	1971	2000	50	149700	5	275	195
		Solids	EU15	1960	1997	200	201100	40	540	120
				1970	1997	150	192700	40	300	120
				1986	2000	250	393800	80	840	81
			New EU10	1960	1997	200	201100	40	540	120
				1965	1997	75	96500	20	150	60
				1986	2000	200	297600	60	690	74
				1994	1999	75	96100	20	270	60
			non-EU OECD	1960	1997	100	96100	20	270	60
				1986	2000	200	297600	60	690	74
				1972	1997	175	201500	40	420	120
			non-OECD	1971	1997	200	201100	40	540	120
				1981	1997	75	96500	20	150	60
				1986	2000	200	297600	60	690	180
				1992	1996	75	96200	20	150	60
					1999	50	96200	20	150	60
1.A.2.c	chemicals	Gaseous	EU15	1960	1997	30	56000	4	120	0.2
				1986	2000	20	56000	4	120	0.1
			New EU10	1960	1997	30	56000	4	120	0.2
				1986	2000	20	56000	4	120	0.1
				1992	2000	20	56000	4	120	0.2
			non-EU OECD	1960	1997	30	56000	4	120	0.2
				1986	2000	20	56000	4	120	0.1
			non-OECD	1971	1997	30	56000	4	120	0.2
				1986	2000	20	56000	4	120	0.2
		Liquids	EU15	1960	2000	50	149700	5	275	195
			New EU10	1960	2000	50	149700	5	275	195
			non-EU OECD	1960	2000	50	149700	5	275	195
			non-OECD	1971	2000	50	149700	5	275	195
		Solids	EU15	1960	1997	275	297600	60	690	180
				1970	1997	75	96200	20	150	60
				1986	2000	250	393800	80	840	81
			New EU10	1960	1997	275	297600	60	690	180
				1961	1970	75	96200	20	150	60
				1986	2000	200	297600	60	690	74
				1992	1994	75	96100	20	270	60

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				2000	2000	75	105000	20	270	60
			non-EU OECD	1960	1997	75	96500	20	150	60
				1970	1997	200	201100	40	540	120
				1986	2000	200	297600	60	690	74
			non-OECD	1971	1997	275	297600	60	690	180
				1986	2000	200	297600	60	690	180
				1992	1997	125	192400	40	300	120
1.A.2.d	pulp, paper and print	Gaseous	EU15	1960	1997	30	56000	4	120	0.2
				1986	2000	20	56000	4	120	0.1
			New EU10	1965	1997	30	56000	4	120	0.2
				1986	2000	20	56000	4	120	0.1
				1992	2000	20	56000	4	120	0.2
			non-EU OECD	1971	1997	30	56000	4	120	0.2
				1986	2000	20	56000	4	120	0.1
			non-OECD	1971	1997	30	56000	4	120	0.2
				1986	2000	20	56000	4	120	0.2
		Liquids	EU15	1960	2000	50	149700	5	275	195
			New EU10	1960	2000	30	76500	3	175	190
				1967	2000	20	73200	2	100	5
			non-EU OECD	1970	2000	50	149700	5	275	195
			non-OECD	1971	2000	50	149700	5	275	195
		Solids	EU15	1960	1997	100	96100	20	270	60
				1970	1997	250	297700	60	570	154
				1986	2000	250	393800	80	840	81
			New EU10	1960	1997	200	201100	40	540	120
				1965	1997	75	96500	20	150	60
				1967	1968	75	96200	20	150	34
				1986	2000	200	297600	60	690	74
				1993	2000	75	96100	20	270	60
				1996	1997	75	105000	20	270	60
			non-EU OECD	1960	1997	100	96100	20	270	60
				1970	1997	75	96500	20	150	60
				1986	2000	200	297600	60	690	74
				1978	1997	100	105000	20	270	60
			non-OECD	1971	1997	100	96100	20	270	60
				1981	1997	75	96500	20	150	60
				1986	2000	200	297600	60	690	180
				1996	1997	75	96200	20	150	60
					1999	50	96200	20	150	60
				1980	1997	100	105000	20	270	60
1.A.2.e	food processing, beverages and tobacco	Gaseous	EU15	1960	2000	30	56000	4	120	0.2
			New EU10	1960	2000	30	56000	4	120	0.2
			non-EU OECD	1970	2000	30	56000	4	120	0.2
			non-OECD	1971	2000	30	56000	4	120	0.2
		Liquids	EU15	1960	2000	50	149700	5	275	195
			New EU10	1960	2000	20	73200	2	100	5
				1961	2000	30	76500	3	175	190

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			non-EU OECD	1970	2000	50	149700	5	275	195
			non-OECD	1971	2000	50	149700	5	275	195
		Solids	EU15	1960	2000	150	96100	20	270	250
				1970	2000	410	297700	60	570	750
			New EU10	1960	2000	560	393800	80	840	1000
			non-EU OECD	1960	2000	150	96100	20	270	250
				1980	2000	150	105000	20	270	250
				1972	2000	130	96500	20	150	250
			non-OECD	1971	2000	430	297600	60	690	750
				1990	2000	130	96200	20	150	250
1.A.2.f	other (please specify in a covering note)	Gaseous	EU15	1960	2000	90	168000	12	250	0.6
				1986	2000	40	112000	8	200	0.4
			New EU10	1960	2000	90	168000	12	250	0.6
				1986	2000	40	112000	8	200	0.4
			non-EU OECD	1960	2000	30	56000	4	120	0.2
				1971	2000	60	112000	8	130	0.4
				1986	2000	40	112000	8	200	0.4
			non-OECD	1971	2000	90	168000	12	250	0.6
				1986	2000	40	112000	8	200	0.4
		Liquids	EU15	1960	2000	120	372600	12	3155	395
			New EU10	1960	2000	120	372600	12	3155	395
			non-EU OECD	1960	2000	50	149700	5	275	195
				1970	2000	70	222900	7	2880	200
			non-OECD	1971	2000	120	372600	12	3155	395
		Solids	EU15	1960	1997	100	96100	20	270	100
					2000	710	489900	100	1050	2000
				1969	1997	100	105000	20	270	100
				1970	1997	350	393800	80	720	400
					2000	150	105000	20	210	400
				1986	1999	75	105000	20	210	35
					2000	325	489900	100	1050	245
			New EU10	1960	1996	130	96200	20	150	400
					1997	550	594900	120	1260	600
					2000	730	498700	100	1110	2000
				1986	2000	475	691000	140	1530	380
				1992	1997	50	96200	20	150	100
					2000	150	201100	40	480	200
			non-EU OECD	1960	1997	100	96100	20	270	100
					2000	580	393700	80	900	1600
				1970	1997	100	96100	20	210	100
				1986	1991	75	105000	20	210	35
					2000	275	393700	80	900	205
				1972	1997	175	201500	40	420	200
					2000	150	105000	20	210	400
				1983	1991	100	105000	20	210	100
			non-OECD	1971	1997	300	297200	60	750	300
					2000	860	594900	120	1260	2400
				1986	2000	350	498700	100	1110	500

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				1979	1997	75	96500	20	150	100
				1980	1997	100	105000	20	210	100
				1990	1997	75	96200	20	150	100
					2000	50	96200	20	150	100
1.A.3.b.i	r.t., passenger cars	Liquids	EU15	1960	1974	3800	63200	488	287	
					1979	12800	142900	1830	1480	
				1971	1979	3400	63200	488	287	
					1989	10100	142900	1330	1330	
				1976	1984	3000	63200	488	287	
				1981	1989	2600	63200	488	287	
					1999	7100	142900	830	1030	
				1986	1994	2200	63200	488	287	
				1991	1997	1450	63200	488	287	
					2000	3220	142900	373	710	
				1996	2000	1000	63200	488	287	
			New EU10	1960	1979	10000	69700	1500	1100	
					1999	1000	73200	500	380	
				1971	1979	12800	142900	1830	1480	
					1989	18500	212600	2330	2430	
				1981	1999	13500	212600	1520	2030	
					2000	1000	73200	95	240	
				1991	2000	6120	212600	683	1330	
				1992	1994	2300	63200	488	287	
					1997	1550	63200	488	287	
				1996	2000	1100	63200	488	287	
			non-EU OECD	1960	1974	3800	63200	488	287	
					1979	22800	212600	3330	2580	
					1999	1000	73200	500	380	
				1971	1979	3400	63200	488	287	
					1989	18500	212600	2330	2430	
				1976	1984	3000	63200	488	287	
				1981	1989	2600	63200	488	287	
					1999	13500	212600	1520	2030	
					2000	1000	73200	95	240	
				1986	1994	2200	63200	488	287	
				1991	1997	1450	63200	488	287	
					2000	6120	212600	683	1330	
				1996	1997	1550	63200	488	287	
					2000	2100	126400	976	574	
			non-OECD	1971	1979	22800	212600	3330	2580	
					1989	18500	212600	2330	2430	
					1999	1000	73200	500	380	
				1981	1999	13500	212600	1520	2030	
					2000	1000	73200	95	240	
				1991	2000	6120	212600	683	1330	
				1992	1997	1550	63200	488	287	
				1996	2000	1100	63200	488	287	
				1977	2000	2300	63200	488	287	
1.A.3.b.iii	r.t., heavy duty vehicles	Liquids	EU15	1960	1979	12800	142900	1830	2010	
				1971	1989	10100	142900	1330	1750	

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				1981	1999	7100	142900	830	1480	
				1991	2000	3220	142900	373	1290	
			New EU10	1960	1979	10000	69700	1500	510	
					1999	1000	73200	500	1500	
				1971	1979	12800	142900	1830	2010	
					1989	18500	212600	2330	2260	
				1981	1999	13500	212600	1520	1930	
					2000	1000	73200	95	1000	
				1991	2000	6120	212600	683	1620	
			non-EU OECD	1960	1979	22800	212600	3330	2520	
					1999	1000	73200	500	1500	
				1971	1989	18500	212600	2330	2260	
				1981	1999	13500	212600	1520	1930	
					2000	1000	73200	95	1000	
				1991	2000	6120	212600	683	1620	
			non-OECD	1971	1979	22800	212600	3330	2520	
					1989	18500	212600	2330	2260	
					1999	1000	73200	500	1500	
				1981	1999	13500	212600	1520	1930	
					2000	1000	73200	95	1000	
				1991	2000	6120	212600	683	1620	
1.A.3.b.v	r.t., gasoline evaporation	Liquids	EU15	1960	1984			319		
				1981	1989			334		
				1986	1994			350		
				1991	1997			263		
				1996	2000			230		
			New EU10	1960	1984			319		
				1981	1989			334		
				1986	1994			350		
				1991	1997			263		
				1996	2000			230		
			non-EU OECD	1960	1984			319		
				1981	1989			334		
				1986	1994			350		
				1991	1997			263		
				1996	2000			230		
			non-OECD	1971	1984			319		
				1981	1989			334		
				1986	1994			350		
				1991	1997			263		
				1996	2000			230		
1.A.4.a	commercial / institutional	Gaseous	EU15	1960	2000	70	56000		50	0.2
			New EU10	1960	2000	70	56000		50	0.2
			non-EU OECD	1960	2000	70	56000		50	0.2
			non-OECD	1971	2000	70	56000		50	0.2
		Liquids	EU15	1960	2000	100	149700	6	225	55
			New EU10	1965	2000	30	73200	3	50	5
				1980	2000	70	76500	3	175	50
			non-EU	1960	2000	100	149700	6	225	55

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			OECD							
			non-OECD	1971	2000	100	149700	6	225	55
		Solids	EU15	1970	2000	11000	393800	605	290	580
			New EU10	1960	2000	7500	297300	405	230	380
				1965	2000	3500	96500	200	60	200
			non-EU OECD	1960	2000	2500	96100	200	85	120
				1982	1999	1500	105000	5	85	120
				1972	2000	3500	96500	200	60	200
			non-OECD	1971	2000	4000	201100	205	170	240
				1990	2000	7000	192700	400	120	340
1.A.4.b	residential	Biomass	EU15	1970	2000	6000	110000	600	80	285
			New EU10	1970	2000	6000	110000	600	80	285
			non-EU OECD	1970	2000	6000	110000	600	80	285
			non-OECD	1970	2000	6000	110000	600	80	285
		Gaseous	EU15	1960	2000	70	56000	7	50	0.2
			New EU10	1960	2000	70	56000	7	50	0.2
			non-EU OECD	1960	2000	70	56000	7	50	0.2
			non-OECD	1971	2000	70	56000	7	50	0.2
		Liquids	EU15	1960	2000	100	149700	6	225	55
			New EU10	1965	2000	100	149700	6	225	55
			non-EU OECD	1960	2000	100	149700	6	225	55
			non-OECD	1971	2000	100	149700	6	225	55
		Solids	EU15	1960	2000	21000	586100	1005	435	840
				1970	2000	3500	96500	200	60	200
			New EU10	1960	2000	11500	393800	605	290	580
				1965	1996	2500	96100	200	85	120
					2000	10500	192700	400	120	340
			non-EU OECD	1960	1974	3500	96500	200	60	200
					2000	15000	393800	605	290	580
				1971	1991	2500	96100	200	85	120
			non-OECD	1971	2000	21000	586400	1005	435	900
				1989	2000	3500	96200	200	60	140
1.A.4.c	agriculture / forestry / fishing	Gaseous	EU15	1970	2000	70	56000	7	50	0.2
			New EU10	1960	2000	70	56000	7	50	0.2
			non-EU OECD	1977	2000	70	56000	7	50	0.2
			non-OECD	1971	2000	70	56000	7	50	0.2
		Liquids	EU15	1960	2000	100	149700	6	2800	55
			New EU10	1960	2000	100	149700	6	2800	55
			non-EU OECD	1960	2000	100	149700	6	2800	55
			non-OECD	1971	2000	100	149700	6	2800	55
		Solids	EU15	1960	2000	2500	96100	200	210	120

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				1970	2000	8500	297700	405	510	460
			New EU10	1960	2000	11000	393800	605	720	580
			non-EU OECD	1985	1998	3500	96500	200	150	200
				1975	2000	2500	96100	200	210	120
			non-OECD	1971	2000	4000	201100	205	420	240
				1981	2000	3500	96200	200	150	140
				1989	2000	3500	96500	200	150	200