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EUROPEAN SURVEY FOR NOx EMISSIONS, 1985

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SUMMARY

Emission estimates are presented for NOx from stationary and mobile sources in Europe. Total emissions of NOx in Europe were estimated to 23.9×10^6 t as NO_2 in 1985 with ca. 50 per cent contribution from Eastern Europe.

Summary of European NOx emissions in 10^3 t/a (as NO_2):

	Stationary sources*	Mobile sources**	Sum
Eastern Europe	7 216	4 442	11 658
Western Europe	4 926	7 267	12 193
Europe	12 142	11 709	23 851

* The following sources were considered: 1) production of electricity in power stations burning hard (bituminous and subbituminous) coals, brown coals including lignites, residual (heavy) and distillate oil and natural gas, 2) metallurgical coke production, 3) cement production in dry and wet kilns, 4) gas works, 5) steel and iron production, 6) coal combustion in central (district) heating and small residential units, and 7) oil and gas combustion in industrial and residential boilers.

** Consumption of gasoline and diesel oil for road traffic, rail traffic, internal navigation and agricultural tractors. Combustion of LPG in road vehicles and emissions from aircraft operations in Western Europe adds about 2% to the mobile emissions given above, for Western Europe (OECD, 1988). NOx emissions from marine navigation in European seas have not been considered in this work. A possible effect of ambient temperature to increase the NOx emissions from gasoline-powered vehicles in the warmed-up mode, with decreasing ambient temperature, has not been taken into account. This effect may increase the total mobile NOx emissions by 0-8% for northern European countries, and less for southern countries.

The NOx emissions were based on the emission factors and statistical data. The emission factors were country specific for stationary sources in Eastern Europe as calculated by Pacyna (1988). For mobile sources, uniform emission factors for each vehicle type and driving mode were used for all countries as calculated (or assessed) by Larssen (1989). Finally, for stationary combustion sources in Western Europe, the emission figures from OECD were used for the assessment of the 1985 emissions (Semb, 1989).

The NOx emissions from stationary sources in Europe were calculated to be equal to the NOx emissions from mobile sources in Europe. The contribution of NOx emissions from stationary sources in Eastern Europe was, however, 60 per cent, and for Western Europe 40 per cent. The spatial distribution of NOx emissions in Europe is also shown in the EMEP grid system of 150 km x 150 km. The NOx emission factors and the NOx emissions in Eastern Europe were then compared with estimates from the EMEP programme and with data from national authorities in Eastern Europe. Good agreement was obtained for GDR, Hungary and to some extend Poland. The largest difference was found for USSR, Albania, Bulgaria, Romania and Yugoslavia. Natural emissions of NOx in Europe were also estimated and it was suggested that they are not significant (below 3 per cent) compared to anthropogenic emissions.

The following can be recommended to: 1) a unified methodology to calculate NOx emission factors, 2) a handbook of NOx emission factors, 3) an atlas of major point sources in Europe, and 4) a methodology to calculate accuracy of NOx emission estimates. It is also concluded that the results from this work can be used as a basis for the national authorities when estimating NOx emissions.

The calculations presented here are based on the best information available to the authors, and may deviate from official national data.

CONTENTS

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1 INTRODUCTION

During the last decade many attempts have been made to understand the role of nitrogen species in adverse effects in the environment, such as acidification of soils and surface waters, forest dieback and changes in ozone concentrations. Various techniques have been employed to assess critical loads for nitrogen species in terrestrial and aquatic ecosystems (e.g. Nilsson and Grennfelt, 1988). Long-range transport models have been developed for photochemical oxidants (e.g. a review by Hov, 1987), and deposition processes (e.g. van Dop, 1987; Sandroni, 1987). Estimates of airborne transboundary transport of nitrogen over Europe have been made by Eliassen et al. (1988).

Most of the recent activity in Europe is organized within programmes of international organizations, such as UN Economic Commission for Europe (UN ECE), European Economic Community (EEC), and Organisation for Economic Co-operation and Development (OECD).

Emission inventories are integral parts of the above issues. During the past few years there has been growing activity in Europe to assess the emissions of nitrogen compounds and particularly the anthropogenic NOx emissions.

The Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (EMEP) has collected information on the emissions of air pollutants from all countries in Europe (e.g. Saltbones and Dovland, 1986). The Executive Body for the Convention on Long-Range Transboundary Air Pollution has organized a NOx Task Force on Technologies for Controlling NOx Emissions from Stationary Sources (ECE, 1986) and Parties to the Convention submit official emission data for agreed pollutants at regular intervals.

The OECD, in its project on Control of Major Air Pollutants (MAP) has studied the large scale formation of oxidants and long-range transport of NOx, VOC and oxidants. During this study an emission inventory has been prepared for the OECD countries, with particular emphasis on OECD-Europe (e.g. Lübkert and Tilly, 1987).

An extended collection of the emission data, including NOx, has been done within the German-Dutch project PHOXA, calculating the distribution of photochemical oxidants in parts of Europe during episodes of air pollution of a few days´ length (van Ham and Builtjes, 1985). The project does not include all countries in Europe and is missing the parts of Eastern and Southern Europe. The PHOXA Emission Data Base for modelling purposes was prepared by TNO by means of emission factors.

The EEC, after several pilot steps entered into co-operation with the OECD within the field of emission inventories (Joerss, 1988a). In implementing the EEC Council´s Decision on the establishment of an environmental information system, the Commission carries out the CORINAIR project (e.g. Bouscaren, 1988) with the aim to set up a uniformly structured Community-wide gridded emission survey including NOx.

The Acid Rain Project at IIASA has developed a set of interactive models called RAINS (Regional Acidification Information and Simulation) to assess long-term acidification in Europe on a regional scale (e.g. Alcamo et al., 1987; Hordijk, 1986). The major emphasis in the emission part of this work was on sulphur. However, in a later phase of the project, a model for estimating NOx emissions in Europe was presented (Lübkert, 1987).

In most cases the above mentioned programmes, atmospheric dispersion models were operated on the emission data generated in the countries and this information was later compiled at ECE, OECD, or EEC. Thus, most of the work has been done by the national authorities and institutions. The emission factors and emission quantities have been discussed at a series of expert workshops organized mostly by OECD (Apeldoorn, the Netherlands, 1984, and Schauinsland, the Federal Republic of Germany, 1986) and ECE (Cologne, the Federal Republic of Germany in 1987 and 1988). Other major meetings discussing the emission data in Europe were the workshops organized by the European

Association for the Science of Air Pollution (EUROSAP) in Paris, 1987 and the IIASA/NILU workshop in Laxenburg, 1988.

Summarizing past activities on emission data for Europe, it can be concluded that main emphasis was placed on the sulphur emission inventorying.

Although the early work to assess the NOx emissions from fossil fuel combustion in Europe by Semb and Amble (1981) has been modified, extended and updated on several occasions, the NOx emissions are less accurately known than the SO_2 emissions in Europe. The major development of NOx emission inventories has been done in Western Europe. Main emission source categories were defined and the NOx emission factors proposed (e.g. Pacyna, 1988b). However, due to difference between Western and Eastern Europe in fuel combustion technologies, industrial processes, engine types and other factors affecting emissions from mobile sources, and control technologies, the West European emission factors cannot be easily extended for Eastern Europe. The available information on NOx emissions and NOx emission factors for Eastern Europe was that from the ECE through the Working Group on Nitrogen Oxides, and the EMEP questionnaires. A variety of NOx emission factors was reported for the same source categories and/or types of fuels in various countries and these inconsistencies made it difficult to establish a uniform emission survey for NOx from all anthropogenic sources in Europe.

The major goal of the project reported here was to present an independent estimate of NOx emissions in Eastern Europe. The project, funded by the German Environmental Protection Agency "Umweltbundesamt", is thus regarded as a contribution to achieve improved data on NOx emissions in Europe. The work is based on emission factors and statistical information on the production of industrial goods and the consumption of fuels in the year 1985. Some emission factors were calculated on the basis of information on the use of fuels, technology, control equipment and principles of physical-chemical processes during the combustion of fuels or industrial production. Some factors were accepted from other emission programmes and then modified along the changes observed for Eastern and Western Europe. The details on emission factors are discussed separately.

In order to obtain the complete European emissions of NOx, the Western European countries were also taken into account. The OECD emission survey (OECD, 1989) was the basis for this task, and the 1980 emission data were extrapolated to obtain a NOx emission survey for stationary sources for the year 1985.

The project consists of the following parts: 1) NOx emissions from stationary sources in Eastern Europe, 2) NOx emissions from stationary combustion sources in Western Europe, and 3) NOx emissions from mobile sources in Europe. The results are presented in separate reports by Pacyna (1988a), Semb (1989), and Larssen (1989) for stationary sources in Eastern Europe, stationary sources in Western Europe and mobile sources in Europe, respectively. The present fourth report summarizes the results, discusses difficulties when carrying out the project and recommends future tasks for NOx emission surveys in Europe.

2 EMISSION FACTORS

The emission factors used in the project are discussed by Pacyna (1988a) for stationary sources and by Larssen (1989) for mobile sources.

Two different approaches to emission factors were selected for stationary and mobile sources. Country specific emission factors were applied to estimate the NOx emissions from stationary sources due to large differences in type of fuel and combustion conditions between individual countries. Uniform emission factors were used for each vehicle class and driving mode to estimate the NOx emissions from mobile sources in Eastern and Western Europe. Engine technologies are broadly the same. For light duty vehicles, the available data indicated similar NOx emissions from Eastern and Western European vehicle models. For heavy duty vehicles we had no information which might form a basis for differentiating between Eastern and Western European fleets or national fleets of similar vehicle classes. Our approach of uniform emission factors was a necessity in this project, since very detailed data on national vehicle fleet compositions were not available. For this and other reasons, there may be differences in the emission factors used here and those used by national authorities.

2.1 STATIONARY SOURCES

The following source categories were considered: 1) production of electricity in power stations burning hard (bituminous and subbituminous) coals, brown coals including lignites, residual (heavy) and distillate oil and natural gas, 2) metallurgical coke production, 3) cement production in dry and wet kilns, 4) gas works, 5) steel and iron production, 6) coal combustion in central (district) heating and small residential units, and 7) oil and gas combustion in industrial and residential boilers. Other sources, such as nitric acid production were not considered. Their contribution to NOx emissions is assumed to be relatively insignificant.

Three major mechanisms are responsible for NOx formation: 1) "thermal NOx" by fixation of atmospheric nitrogen in the combustion air, 2) "fuel NOx" by conversion of chemically bound nitrogen in the fuel, and 3) "prompt NOx", taking place in the front of the flame. The mechanisms are described in details by various authors (e.g. ECE, 1986). The results from the Swedish programme on the influence of coal combustion on human health and the environment (KHM, 1982) indicate that as much as 60% of total NOx formed during coal combustion is due to transformation of the fuel nitrogen. This was also assumed throughout the estimates here. Of course, the amounts of "thermal NOx" vs. "fuel NOx" vary due to many parameters, such as combustion conditions (type of boiler, combustion temperature, residence time, air/fuel ratio) and the N-concentration in coals.

The NOx emission factors for coal combustion were calculated separately for various Eastern European countries considering the type and quality of coal and combustion conditions. The following information was considered: 1) the nitrogen content of coal, 2) "thermal NOx" contribution in the "wet bottom" type of boiler is higher than in the other types because of higher temperature, and 3) the rate of conversion of "fuel nitrogen" to NO using the diagram given by Kremer (1982).

Most of oil burned in the East European power plants is imported from the USSR. Rather limited information is available on the quality of this oil. In general, the nitrogen content of residual oil varies from 0.1 to 0.5% and is significantly lower than the content of nitrogen in coals. Measurements in Denmark (Miljøstyrelsen, 1980) have shown that the NOx emission factors for oil-fired power plants are 1.6 times lower than the factors for power plants burning Polish coal. There was no explanation on the origin of this oil but the USSR supplies at least 20% of the crude oil to Denmark. The Danish measurements were used to calculate the NOx emission factor for oil combustion.

The NOx emission factor for natural gas combustion to produce electricity has been accepted after Bakkum and Veldt (1986).

The details about of NOx emission factors used in the project are available from Pacyna (1988a). It was considered of importance to use further these factors to prepare a basis for a handbook of NOx emission factors for major stationary source categories. In the first step the emission factors from this work were compared with the relevant information from other international emission inventories, national programmes, and even local projects including measurements. Very useful information in this connection was obtained through EMEP data collection and particularly the EMEP questionnaires on atmospheric emissions, obtained from the EMEP Chemical Co-ordinating Centre (CCC) at NILU.

Additional information was sought through the following programmes: 1) OECD-MAP (Lübkert, 1987), 2) EEC-CORINAIR (Bouscaren et al., 1986), and 3) PHOXA (Bakkum and Veldt, 1986). The NOx emission factors were also provided from national organizations, such as: United States Environmental Protection Agency (US EPA, 1973), Environment Canada (1986), Deutsches Institut für Wirtschaftsforschung (DIW, 1988), the Norwegian State Pollution Control Authority (SFT, 1987), and the United Kingdom Warren Spring Laboratory (Eggleston and Mc Innes, 1987). Special attention was given to the data obtained from the German Environmental Protection Agency Umweltbundesamt (UBA), as many of the UBA projects were based on measurements. This included collection of NOx emission factors by Joerss and Wycisk (1988 unpublished work), NOx-Minderung (VGB, 1985) and reports by Ratajczak (1983) and Löblich (1985). Generally, the NOx emission factors for stationary sources proposed in this work were in agreement with the factors suggested by the other programmes.

In order to assess the ranges of NOx emission factors, a workshop was organized in co-operation with IIASA in Laxenburg, Austria (proceedings of the workshop are in preparation). A large number of scientists from Eastern and Western Europe presented their results on NOx emission factors and NOx emissions, and commented on the factors used in this work. In a view of these comments, and particularly comments from the Eastern European experts, it was concluded, that no major changes were necessary on the NOx emission factors proposed here for the Eastern European point sources.

Taking into account the NOx emission factors from this work (Pacyna, 1988a), their comparison with the factors from other programmes, and the discussion at the IIASA/NILU Workshop, the ranges of NOx factors were prepared. They are given in Tables 1-4 for electric power plants, heat production, industrial boilers and industrial processes, respectively.

The ranges of NOx emission factors were also presented at the EMEP Workshop on Emission Inventories Techniques, Cologne, May, 1988 (Pacyna, 1988b). They were accepted at this meeting as reference material for the national NOx inventories in Europe, to be prepared along with the technical guidelines for the estimation and reporting of the national emissions of nitrogen oxides.

The NOx emission factor ranges in Tables 1-4 were then used by Semb (1989) to select the factors and to assess the 1985 NOx emissions for Western Europe.

Table 1: NOx emission factors for electric power plants.

Type of fuel, type of boiler	Emission factor	
	g NO_2/GJ	kg NO_2/t
1) Hard coal (bituminous and subbituminous)		
- Pulverized coal fired		
- Dry bottom	250-400	8.0-12.0
- Wet bottom	300-600	12.0-18.0
- Cyclone furnace	500-800	15.0-25.0
- Grate and stoker burners	150-250	3.0- 7.0
2) Brown coal (incl. lignite)		
- Pulverized coal fired	200-250	4.0- 6.0
- Cyclone furnace	200-300	6.0- 8.0
- Grate and stoker burners	150-200	3.0- 4.0
3) Fuel oil, residual	190-350	8.0-14.0
distillate	50-100	2.0- 4.0
4) Peat	200-300	
5) Natural gas	100-200	

The ranges in the two emission factor columns in Table 1 are not related to each other due to the difference of heat values of fuels burnt under different combustion condities.

Table 2: NOx emission factors for heat production (in g NO_2/GJ).

Type of fuel	District heating	Small domestic boilers
Hard coal	150-280	~ 50
Coke	150-280	50-100
Residual oil	120-180	120-180
Gas oil	~ 70	50- 70
LPG		40- 50
Coke-oven gas	~ 100	
Wood	~ 100	50-100

Table 3: NOx emission factors for combustion of fossil fuels in industrial boilers (in g NO_2/GJ).

Type of fuel	Emission factor
Hard coal	150-350
Coke	150-280
Residual oil	120-180
LPG	40-110
Coke oven gas	50-120
Blast furnace gas	50-120
Refinery gas	80-180
"Town" gas	30- 60

Table 4: NOx emission factors for industrial processes.

Industrial process	Unit	Emission factor
1. Coke production	kg NO_2/t coal	0.015-0.020
2. Cement production	kg NO_2/t cement	0.9 -1.4
3. Brick production	kg NO_2/t brick	0.2 -0.7
4. Glass production	kg NO_2/t glass	~7.0
5. Iron & steel manufacturing	kg NO_2/t steel	
- Electric Arc Furnace		0.1 -0.3
- Open Hearth Furnace		0.005-0.05
- Sinter production	kg NO_2/t sinter	~1.5
6. Refineries		
- Boilers and process	kg NO_2/10^3 l oil	4.0 -8.0
heaters	g/GJ	180-300

2.2 MOBILE SOURCES

Emission factors for NOx from mobile sources have been reviewed by Larssen (1988b, 1989). The selected uniform emission factors used in this work for all countries are shown in Table 5.

In selecting the emission factors for gasoline-powered passenger cars, we have especially considered results of measurements made during actual driving (Potter and Savage, 1983) and measurements made using actual urban driving modes (Bertilsson, 1979).

Table 5: Selected uniform NOx emission factors (g NO_2/kg) for mobile sources.

ROAD VEHICLES					
Driving mode Average speed, km/h	URBAN 10-50	RURAL 50-80	HIGHWAY/MOTORWAY 80	 100	 120
Passenger cars					
Gasoline					
- 4 stroke	23	41	44	55	62
- 2 stroke	7 (gross average)				
Diesel	15 (gross average)				
Light duty trucks (GVW* < 3.5 t)					
Gasoline	42 (gross average)				
Diesel	15 (gross average)				
Heavy duty vehicles (GVW > 3.5 t					
Diesel trucks	50	55	60 (average)		
Buses	50	60	70 (average)		
Gasoline trucks	20 (gross average)				
Motorcycles and mopeds, gasoline	5.5 (gross average)				
Railway locomotives	20				
Boats, internal navication	70				
Agricultural tractors	50				

* GVW = Gross Vehicle Weight.

For heavy duty diesel vehicles, the selected emission factors are mainly based on measurements carried out in Sweden (Bertilsson et al., 1987) and in FRG (Hassel et al., 1983).

Important additional information is provided by several other authors, i.e. Veldt (1986), ECE (1987a) and by DIW (1988) for 2-stroke engines for passenger cars.

In a recent report by Zierock et al. (1988) emission factors for road vehicles are proposed to be used in the CORINAIR project. In this report, differentiation is made for the technologies corresponding to the different ECE R15 emission regulations, and also for three light duty engine size categories (< 1.4 l, 1.4-2 l, > 2 l). The emission factors proposed are somewhat higher than used in this work. For gasoline-powered passenger cars, the gross average factor is about 8% higher than used in this work for all PC´s, for a traffic activity distribution for 35%/35%/20%/10% in the urban/rural/highway/motorway modes, respectively. For heavy duty diesel powered vehicles, the gross average factor is about 15% higher than used in this work, for a traffic distribution of 34%/33%/33% in the urban/rural/highway modes.

The emission factor for navigation (ship engines) is based on measurements carried out in Norway (Melhus, 1986). Literature from ECE (1987a), OECD (1984), US EPA (1973) was also received.

For railway locomotives and agricultural tractors, the emission factors have been selected based on data reviewed by OECD (1984), ECE (1987a), US EPA (1973) and also by SFT (1987).

In this work the same emission factors are used for Eastern as for Western European countries. The engine technologies are broadly similar. Only a few measurements of emission factors have been reported by East European countries, and they provide no basis for differentiating between Eastern and Western Europe. Indeed, results of measurements on 4-stroke passenger car engines reported by Czechoslovakia and the USSR, using the ECE R15 driving cycle, gave results close to those reported from similar tests carried out in Western Europe.

Details about the emission factor review are presented by Larssen (1989).

3 METHODS FOR CALCULATION OF NOx EMISSIONS FROM MOBILE SOURCES

The following mobile source categories are considered in this work:

- road vehicles
- railway locomotives
- boats, internal navigation
- agricultural tractors.

Thus, emissions from marine navigation and aircraft are not included in this work. It has been estimated that these sources together may contribute some 4% of the NOx emissions from the four mobile source categories considered.

The fuel types considered are gasoline and motor diesel oil. LPG is used to some extent in some countries notably in Italy and the Netherlands, where the use of LPG represents about 4% of the total national mobile NOx emissions (OECD, 1989). According to OECD, NOx emissions from LPG contributes some 0.9% of total mobile NOx emissions in OECD Europe (OECD, 1989).

The emissions are calculated on the basis of reported data on national fuel consumption. The basic model used is as follows:

$$Q\,[\text{kg NOx/y}] = M[\text{tonnes/y}] \cdot p[\text{kg NOx/ton}]$$

This model is used to calculate emissions from railways, internal navigation and agricultural tractors. The annual fuel consumption by each source category is either reported in national and international statistics, or it is estimated based on available statistics on freight volume (ton·km). This is described in detail by Larssen (1989).

A more detailed model is used to calculate emissions from road traffic.

The specific NOx emission (emission per driven length or per fuel unit) consumed from road vehicles depend mainly on the following parameters:

- Fuel type (gasoline/diesel oil)
- Vehicle category (gross vehicle weight, engine size)
- Driving mode (average vehicle speed, speed variation).

NOx emission calculations from road traffic may be based on fuel consumption or traffic activity data. The following calculation models for gasoline and diesel separately were used to calculate NOx emissions on the national level (Larssen, 1988a):

Fuel consumption basis: $$Q = M \sum_i p_i \frac{l_i}{l} \frac{T_i}{T}$$

Traffic activity basis: $$Q = T \sum_i q_i \frac{T_i}{T}$$

where

- i indexes the various vehicle classes and driving modes
- Q is total NOx emission (kg/y)
- M is total fuel consumption for road traffic (metric tonnes/y)
- T is total traffic activity (vehicle-km/y)
- T_i is traffic activity for the i´th vehicle class/driving mode (km/y)
- p_i is NOx emission factor based on fuel consumption for the i´th vehicle class/driving mode (kg/t)
- q_i is NOx emission factor based on driven distance for the i´th vehicle class/driving mode (kg/km)
- l is specific fuel consumption, averaged over all vehicle classes and driving modes (l/km)
- l_i is specific fuel consumption for the i´th vehicle class/driving mode (l/km)

For gasoline-powered engines, both models may be used to calculate Q, on the condition that M and T represents the total fuel consumed and the total traffic activity. For gasoline-powered engines, the emission factors p_i and q_i were considered to be equally well determined as a function of vehicle class and driving mode. However, it is assumed that total fuel consumed nationally is a more accurate figure than independently determined traffic activity figures.

For diesel-powered engines, the fuel based emission factors, p_i, are considerably more stable, i.e. vary much less with vehicle class and driving mode, than the q_i (g/km) emission factors (Larssen, 1988b). Also for diesel oil M is considered a generally more accurate figure than T on the national level.

Thus, the national emissions were calculated using the model based on total fuel consumption, M (tonnes/y). The calculated emissions are proportional to the national fuel consumption figures. The main uncertainties are associated with the emission factors, assuming that the fuel consumption figures reported reflect real consumption. For many Eastern European countries, fuel consumption data for mobile sources are not available, hence estimates were made, extrapolating information from other countries.

The distribution of fuel consumption between the different vehicle/ driving mode categories affect also, if estimated incorrectly, the accuracy of the calculated emissions. For the model used, the calculated total NOx emissions from each fuel type is not, however, very sensitive to moderate errors in this distribution.

For some parameters, the available data basis allow for differentiation between countries. For some parameters, the data basis is not specific enough to allow for differentiation:

- The distribution of vehicles in different categories is calculated from national vehicle statistics.

- In distributing the total traffic activity in driving modes, some differentiation is made for passenger cars, based on available statistics of length of motorways relative to the total road network length.

- We use the same emission factors for each vehicle class/driving mode in all countries. This implies that we do not differentiate on the basis of the distribution of vehicle models, engine size and vehicle weight and age in the national car populations. Such data were not available to us. We believe corrections for differences in these distributions are, for NOx emissions, second order to the corrections made for national differences in vehicle class and driving mode distributions.

The mobile source NOx emissions calculated by this model deviate for some countries from emission figures reported by national authorities. Deviation may be caused by the following factors:

- Differences in emission factors, due to significant deviations in national vehicle fleets from the ones our uniform emission factors are based on.

- Deviations in the distribution of driving modes from the assumed distributions.

- In many cases, national emission estimates have been derived from traffic activity data, and not from fuel consumption. Traffic activity and fuel consumption data are not easily reconciled, particularly not for heavy vehicle transport and diesel fuel.

- Inaccuracies in fuel consumption statistics and estimates used in this work.

Zierock et al. (1988) have proposed very similar methods to be used in calculating road traffic emissions within the CORINAIR project. Within that project national experts in each country are available to evaluate national data on the distribution of traffic activity between the vehicle and drivng mode categories. This makes possible one further step in the model: to iterate the process of distributing the traffic work within vehicle and driving mode categories, until agreement is reached between reported fuel consumption and calculated fuel consumption for each country based on the adjusted traffic activity data and specific fuel consumption data. This last step will improve somewhat the accuracy of the emission estimates, provided the iteration process is based on real conditions.

4 STATISTICAL DATA

4.1 STATIONARY SOURCES

Statistical data for fuel consumption and production of various products in Eastern Europe have been extracted from national yearbooks for 1985. While the fossil fuel consumption and electricity production data are directly relevant for emission estimates, some of the industrial production data were used to infer consumption of fossil fuel in industrial boilers. Then a break-down of fossil fuel consumption (hard coal, lignite, fuel oil and gas) in sectors was made. The following national yearbooks were used:

1. Statisticzeskij godisznik na narodnma republika Bulgaria -1985, Komitet za socialna informacja pri ministerskija swet, Sofia, 1986.

2. Statisticka rocenka Ceskoslovenske Socialisticke Republiky -1985, Federalni Statisticky Urad, Cesky Statisticky Urad, Slovensky Statisticky Urad, Praha, 1985.

3. Statistisches Jahrbuch 1986 der Deutschen Demokratischen Republik, Staatlichen Zentralverwaltung für Statistik, Berlin, 1986.

4. Statistical Pocket Book of Hungary -1985, Hungarian Central Statistical Office, Budapest, 1986.

5. Rocznik Statystyczny -1985. Glowny Urzad Statystyczny, Warszawa, 1986.

6. Anuarul Statistical Republicii Socialiste Romania -1986, Directia Cèntrala de Statistica, Buchuresti 1986.

7. Narodnoje Hozjaistwo CCCP w 1985 gode, Statisticzeskij ezegodnik, Centralnoje Statisticzeskoje Uprawlenije CCCP, Moskwa 1986.

8. Statisticki godisnjak Jugoslavije -1985, Socijalisticka Federativna Republika Jugoslavija, Savezni Zawod za Statistiku, Beograd 1985.

The OECD Energy Statistics (OECD, 1987b) were used by Semb (1989) to calculate NOx emissions in Western Europe. Since the OECD statistics report consumption data on weight units rather than in heat equivalents, corrections for the heat content of indigenous solid fuels have been made for some countries. The heat values are taken from tabulations in UN (1986). Only fossil fuel is considered, and coke and non-energy products have been left out. Two countries (Finland and Ireland) burn substantial amounts of peat which is not included in the OECD compilation. Other biomass fuels include bark and black liquor used as fuel in wood processing and cellulose plants, and fuel-wood and straw used mainly for residential house heating.

4.2 MOBILE SOURCES

The statistical data used to estimate NOx emissions from mobile sources include information on: 1) car populations in Europe, 2) road traffic activity for the various road vehicle categories, and driving mode distribution, 3) specific fuel consumption for various road vehicle categories, 4) freight and passenger transport statistics for road and rail traffic and internal navigation, and 5) national fuel consumption.

Most of the information on the car populations in Europe was available from the International Road Federation (IRF, 1987), the International Road Transport Union (IRU, 1985), OECD (1987b) and national statistics for the Eastern European countries (as mentioned in 4.1). The following groups of vehicles were considered: passenger cars (PC), light duty trucks (LDT), heavy duty trucks (HDT), total trucks, motorcycles and mopeds.

The distribution of passenger car traffic activity was prepared for the following driving modes: 1) urban traffic (10-50 km/h speed), 2) rural traffic (50-80 km/h), 3) highways (80-100 km/h), and 4) motorways (>100 km/h).

Specific fuel consumption measurements are often performed in connection with emission measurements in emission test laboratories or during actual driving. A number of reports were reviewed by Larssen (1989), e.g. DIW (1987), Veldt (1986), OECD (1987a). The following specific consumption figures are used in this work:

Vehicle category	Specific fuel consumption, l/100 km	Modal consumption, - gasoline, 4-stroke	
Passenger cars,		Urban	: 13.8
- gasoline-powered, 4-stroke, average	10.7	Rural	: 8.8
- gasoline-powered, 2-stroke	5.0	Highway (80-110)	: 8.8
- diesel-powered	8.8	Motorway (120)	: 9.9
Light duty trucks,			
- gasoline-powered	15.0		
- diesel-powered	13.0		
Heavy duty trucks, diesel	30.0		
Buses, diesel	35.0		
MC/mopeds	2.25		

No differentiation was made between countries, although for gasoline-powered passenger cars there is a basis for differentiation due to differences in average vehicle weight. Such information was not available in this work. In the calculation model used in this work, a correction due to differences in average specific fuel consumption is of minor importance.

Road traffic activity data include information on annual average distance driven and total traffic activity for PC, trucks and buses, separately. The data were available from OECD (1987b), IRF (1987) and for some countries from national statistics.

Statistics on freight transport on roads, rail and waterways from IRU (1985) and IRF (1987) were used to estimate fuel consumption in these sectors.

National consumption statistics on gasoline and motor diesel oil were provided by UN (1986) and OECD (1987b). The diesel oil consumption statistics specified for various sectors, such as road traffic, rail traffic, agriculture, are available for the Western Europe countries but far less complete for Eastern Europe. Thus, several assumptions were made when preparing this set of data for Eastern Europe.

Details on the statistical data used here to estimate NOx emissions from mobile sources are given by Larssen (1989).

5 NOx EMISSIONS IN EUROPE

The NOx emission factors and the statistical data and estimates on fuel consumption and industrial production were used to calculate the 1985 NOx emissions in Europe. The estimated emissions are summarized in Table 6. The estimates in Table 6 differ in some cases from official figures reported by national authorities.

It has been estimated that the total anthropogenic emissions of NOx in Europe were ca. 24.0 x 10^6 t as NO_2 in 1985. One half of these emissions was emitted from the stationary sources and the other half from mobile sources. Half of the European emissions came from sources in Eastern Europe and another half from Western Europe. Considering the population data (UN, 1986), the anthropogenic NOx emission are 36.4 kg NO_2/capita in Eastern Europe and 34.7 kg NO_2/capita for Western Europe. The contribution of NOx emissions from stationary sources was 62 per cent for Eastern Europe and 40 per cent for Western Europe.

Table 6: Anthropogenic NOx emissions in Europe in 1985[1].

Country	Stationary sources		Mobile sources[2]		TOTAL
	kt NO_2	% total	kt NO_2	% total	
<u>Eastern Europe</u>					
Albania	6	20	24	80	30
Bulgaria	137	48	147	52	284
Czechoslovakia	353	65	191	35	544
GDR	694	79	182	21	876
Hungary	137	52	128	42	265
Poland	1 076	78	298	22	1 374
Romania	430	63	250	37	680
European USSR	4 167	59	2 944[5]	41	7 111
Yugoslavia	216	44	278	56	494
Sub-total	7 216	62	4 442	38	11 658
<u>Western Europe</u>					
Austria	70	29	170	71	240
Belgium	140	41	202	59	342
Denmark	150	49	157	51	307
Finland	153	53	134	47	287
France	585	33	1 176	67	1 761
FRG	1 160	44	1 457	56	2 617
Greece	100	36	176	64	276
Iceland	1	6	15	94	16
Ireland	42	43	55	57	97
Italy	557	37	929[3]	63	1 486
Luxemburg	6	22	21	78	27
Netherlands	207	45	255[4]	55	462
Norway	35	16	177	84	212
Portugal	64	44	83	56	147
Spain	440	41	625	59	1 065
Sweden	95	29	234	71	329
Switzerland	56	27	154	73	210
United Kingdom	1 065	46	1 246	54	2 311
Sub-total	4 926	40	7 266	60	12 192
TOTAL	12 142	51	11 708	49	23 850

1 The emission estimates are based on the emission factors and official statistical data described in this report and by Pacyna (1989). The emission factors for stationary sources in Eastern Europe were taken from Pacyna (1988) as calculated and for Western Europe from Semb (1989) as estimated. Thus, the emissions for Western Europe may not correspond directly to emission factors or statistical data as given. The estimates may deviate considerably from emission figures reported by national authorities.

2 Combustion of gasoline and motor diesel oil in road traffic, rail traffic, internal navigation and agricultural tractors. The emission factors for mobile sources in whole Europe were taken from Larssen (1989) as calculated or estimated.

3 Plus 38 kt from LPG combustion in road traffic (OECD, 1989).

4 Plus 13 kt from LPG combustion in road traffic (OECD, 1989).

5 Recent estimate of gasoline consumption in passenger cars in USSR of 24 x 10^6 t in 1984 (Wilson, 1986) results in less gasoline available for road freight transport, and thus increased diesel oil consumption for this transport. This would increase the NOx emissions from road diesel traffic in the European USSR by about 300 x 10^3 t/y.

Thus, there are no large differences in NOx emissions between Eastern and Western Europe on a total basis. The differences begin when comparing the individual countries in Western and Eastern Europe. The contribution of NOx emission from mobile sources exceeds the contribution from stationary sources in all Western European countries.

In Eastern Europe, this is also the case for Albania, Bulgaria, and Yugoslavia.

The production and consumption of electricity in Albania is only 1/6 of the average in Europe resulting in very low emissions of NOx from the stationary combustion sources.

Yugoslavia belongs to the tourism oriented countries, receiving around 6.0×10^6 tourists in 1985. In addition, the internal tourism is also large, e.g. Yugoslavia has the highest statistics on annual average distance driven in Eastern Europe (Larssen, 1989).

It is interesting to note the NOx emissions from stationary sources in the European USSR. The electricity production in the European USSR is produced mostly in conventional thermal power plants (77 per cent) and the large emissions from this sector is not surprising. The emissions of NOx from mobile sources in the European USSR are mostly due to the traffic activity of trucks and passenger cars.

In Czechoslovakia, GDR, Poland and Romania the largest NOx emissions came from combustion of fossil fuels in various stationary sources. This is not surprising, as the average rate of thermal electricity production per capita is very high for these countries (ranging from 3.0 to 5.6 MWh/capita). In addition, the wet-bottom type of boilers is the most commonly used in the power plants, and this type of boiler produces very high amounts of NOx per unit of fuel burned (see Table 1).

The total emissions from Western Europe were considered together with the emissions from Eastern Europe when preparing the spatial distribution. The spatial distribution of the NOx emissions within the EMEP grid of 150 km x 150 km is shown in Figures 1-3 for the emissions from stationary sources, mobile sources and totals, respectively. The NOx emissions from point sources in Eastern Europe were spatially distributed on the basis of their geographical coordinates. A list of these sources with NOx emissions is given by Pacyna (1988a). The NOx emissions from area sources and mobile sources in Eastern Europe were distributed according to the population density. Finally, the OECD spatial distribution of the 1980 NOx emissions in the OECD-Europe countries (OECD, 1989) was the basis for distributing the NOx emissions in Western Europe.

6 COMPARISON OF NOx EMISSION ESTIMATES IN EUROPE

One of the most important questions about any kind of emission estimates is their accuracy. The estimates of uncertainty of a given emission survey consist of three parts: 1) uncertainties of base statistics, 2) uncertainties of emission factors, and 3) uncertainties of disaggregation factors.

As the present project has focused on emission estimates for Eastern Europe, it was felt premature to elaborate a model tó estimate the uncertainties. This issue should be taken as the follow-up step of the work presented here. However, the emission estimates in this work have been compared with other data available from international programmes and national authorities.

The NOx emission factors for stationary sources in Eastern Europe reported by various authors, were compared by Pacyna (1988) and a good agreement was already concluded. It should be mentioned, however, that more than 70% of the total electricity production in the European conventional power plants comes from single-fired installations (e.g. hard coal power plants), ca. 25% from dual-fired installations (mainly hard coal/petroleum products and petroleum products/natural gas) and the rest from triple-fired installations (mainly hard coal/petroleum products/natural gas). The use of multi-fired installations makes the emission calculations more uncertain and results in some minor overestimation, because very often hard coal emission factors are used to assess emissions from hard coal/natural gas-fired power plants (natural gas does not contain chemically bound nitrogen). It was impossible to differentiate between the electricity production in single-, dual-, and triple-fired installations in this work.

It should also be noted that the stationary source emissions for Western Europe (Semb, 1989) include only combustion source emissions. Thus, the industrial process emissions are not included, what may result in some underestimation.

The NOx emission factors for mobile sources were reviewed by Larssen (1989). Account was taken of all available literature and measurement results. Most emission measurements are performed in emission test laboratories, and certain driving modes or driving conditions are defined, to simulate as well as possible average real driving conditions in the traffic. This applies to both light duty and heavy duty vehicles. Thus, when applying the emission factors from standardized laboratory tests to calculate emissions from real driving, the question of representativity of the standardized test driving modes has to be addressed. Only limited data are available on driving modes in real traffic, i.e. the composition for an average vehicle of driving at constant speed (at what speed?); accelerations, decelerations, and idling, for urban, rural and highway driving, respectively. Two investigations are available, where actual driving modes are taken account of, when measuring/calculating emission factors, namely one Swedish (Bertilsson, 1979) and one British (Potter and Savage, 1983). This is discussed by Larssen (1988). In choosing emission factors for this work, special attention was given to these investigations. Thus, for passenger cars in urban driving, the emission factors of this work (23 g/kg corresponding to 2.2 g/km), are somewhat higher than factors usually reported for the ECE R15 test cycle (1.6-1.8 g/km). The reason for this is the large increase in NOx emissions during moderate to strong accelerations, which seems to be present to a larger extent in real urban driving than in the ECE cycle.

Another source of uncertainty is the possible effect of ambient temperature on the NOx emissions from gasoline-powered cars with warmed up engines. Several investigations have reported an increase in NOx emissions as ambient temperature decreases, with up to 40% increase as temperature decreases from 20^{0}C to 0^{0}C (see Larssen, 1988). For countries of Northern Europe, this may result in up to 10-15% increase in the annual NOx emissions from gasoline cars, and thus up to 8% increase in total mobile source emissions.

For heavy duty vehicles, only laboratory-based measurements are available. Thus, the representativity of laboratory-based measurements for emissions in real traffic is uncertain. This uncertainty is the same in this work as in other projects.

The incomplete statistical data base for mobile sources in Eastern Europe represents a source of uncertainty, as discussed by Larssen (1988). Because of lack of data on car populations and fuel consumption for various source categories, we have to rely on estimates, based on statistics for other countries where data were available.

The NOx emission estimates in this work can be compared with other estimates within the ECE emission activity. The results are shown in Table 7, and the data for Eastern Europe are particularly interesting. Very good agreement was obtained for the emission estimates for GDR, Hungary and Poland.

According to the 1988 Statistical Yearbook of GDR the 1986 and 1987 emissions of NOx in this country were 955 kt of which 345 kt from mobile sources. The difference between our results (876 kt) and the GDR value of 955 kt is due to the difference for NOx emissions from mobile sources in the country (182 kt in Table 6). There is no information on how the emission of 345 kt from mobile sources was estimated, so it is difficult to compare this number with 185 kt in our work. It should be noticed, that 74% of the NOx emissions from mobile sources in GDR come from combustion of gasoline and diesel oil in road traffic. As there is a large population of 2-stroke engines in GDR (Larssen, 1989) and these engines produce only 1/3 of NOx compared to 4-stroke engines, the NOx emission from mobile sector in GDR is relatively low. The data from DIW (1988) seem to confirm this, indicating that only 96 kt NOx was emitted from mobile sources in GDR in 1982.

Table 7: NOx emission estimates presented in this work and within the ECE programmes for 1985 (in kt NO_2 unless indicated).

Country	This work	EMEP - MSC-W (Eliassen et al., 1988)	ECE (1987b)	EMEP Questionnaires EMEP CCC	This work kg NO_2/ capita
Eastern Europe					
Albania	30	9			10.3
Bulgaria	284	150	150[2]		31.6
Czechoslovakia	544	1 127	1 127		35.1
GDR	876	955		955[4]	52.5
Hungary	265	300	270[2]	270	24.8
Poland	1 374	1 500	840	1 500	37.2
Romania	680	390			29.7
European USSR	7 111	2 930[1]	2 930[1]	2 930[1]	37.2
Yugoslavia	494	190			
Western Europe					
Austria	240	216	216	206	31.6
Belgium	342	385	385		34.6
Denmark	307	238	238		60.2
Finland	287	240	250	248[3]	58.6
France	1 761	1 693	1 693		32.1
FRG	2 617	2 900	2 900	3 000[5]	42.8
Greece	276	150	150[3]		27.9
Iceland	16	12	12		66.7
Ireland	97	68	68		27.7
Italy	1 486	1 595	1 387-1 537[3]		26.1
Luxemburg	27	22	22		77.8
Netherlands	462	537	522[3]	480	32.0
Norway	212	223	215		51.5
Portugal	147	192	192[3]		18.8
Spain	1 065	950	779-1 122		27.5
Sweden	329	301	305		39.5
Switzerland	210	214	214		32.7
United Kingdom	2 311	1 840	1 690[2]	2 617	41.6

1 European part of the USSR within EMEP.
2 1984 data.
3 1983 data.
4 1987 data.
5 1986 data.

This source estimates the total NOx emission in GDR 570 kt NO_2 in 1982. The total emission is too low due to very low emission factor employed to calculate NOx emissions from electric power plants in GDR (150 kg NO_2/TJ). Recently this factor was corrected to 230 kg NO_2/TJ (DIW, 1988) resulting in total emissions of 710 kt in 1982.

The estimates for Poland in this work agree well with the information provided to the EMEP Chemical Coordinating Centre by the Polish authorities (EMEP questionnaires) and by Jagusiewicz (1988) indicating emission of 1 500 kt in 1985. An independent survey for 1982 by Cofala and Bojarski (1987) suggests ca. 1 100 kt, thus ca. 20 per cent less than our estimate for 1985. The difference may be due to the emission factors for combustion of fossil fuels in "great consumers" (the term after Cofala and Bojarski, 1987). The factors assumed by Cofala and Bojarski (1987) are too low considering the type of burners which are used in the Polish power plants.

It is interesting to observe that the data from this work are in a good agreement with the data reported by the national authorities, namely data from Poland, Hungary and GDR reported to EMEP CCC (in Table 7).

A large disagreement exists between the NOx estimates for the Soviet Union in this work and the data from the EMEP programme. It is difficult to explain this difference. In other to support our estimates, the total NOx emission in the European countries were divided by population and the results are also shown in Table 7. The NOx emission per person in the Soviet Union (37.2 kg NO_2) is very close to the average in Europe (34.7 kg NO_2/capita) and even closer to the average in Eastern Europe (36.4 kg NO_2/capita). If the EMEP values are taken into account, the NOx emission per person in the Soviet Union will be only 15.3 kg NO_2, thus far less than the values for other East European countries except Albania. Considering the use of fossil fuels in the Soviet Union to produce electricity and heat and gasoline and diesel oil consumption in the transport sector, as given by Pacyna (1988a) and Larssen (1989), it can be suggested that the NOx emission calculates in this work are not overestimates.

Our estimates for Czechoslovakia are only half of the estimates provided by the Czechoslovakian authorities. These authorities provided information on emission factors which are extremely high for the production of steam and electricity (27.5 kg NO_2/t fuel for cyclone type of boilers, often found in Czechoslovakia, and only 8.3 kg NO_2/t hard coal in this work).

For the rest of the Eastern European countries, the NOx emission estimates in this work are significantly higher than the EMEP estimates. It should be mentioned, however, that very limited information is available to compare our results for Albania, Bulgaria, Romania, and Yugoslavia. The EMEP estimates in Table 7 for these countries are not provided by the respective national authorities, but were taken from Semb and Amble (1981) assuming no changes between 1979 and 1985. Our survey seems to be the first source of information about emissions of NOx in the above countries.

One major factor affecting the accuracy of emission estimates is related to the complete list of sources that need to be taken into account.

Nitric acid and nitrogen fertilizer production causes emission of NOx. The emission factor of 2.2 kg NO_2/t nitric acid may be calculated on the basis of measurements by Hoftyzer and Kwanten (1972) for high-pressure plants with one absorption unit. The authors suggest that the addition of a second absorption unit may reduce the NOx emission factor to 0.8 g NO_2/t nitric acid.

The emission factor relative to ammonium nitrate fertilizer production can be set at 4.9 kg/t fertilizer-N.

Using the above mentioned emission factors and the information on the production of nitric acid and nitrogen fertilizers in 1983, NOx emission of 70 kt in Western Europe and 50 kt in Eastern Europe can be estimated.

7 NATURAL SOURCES OF NOx

Emissions of NOx from natural sources in Europe are not included here.

Emissions of N_2O, NO and NO_2 may occur from soils, as they are intermediates in soil denitrification and nitrification processes. Galbally and Roy (1978) measured NO emissions from grassland in Australia, finding emission rates of ~3 $ng/m^2 \cdot s$, corresponding to ca. 1 $g/m^2 \cdot year$.

Johansson and Granat (1984) measured emission rates in Sweden of 0.1-62 ng NO-N/m^2s from fertilized arable land, and up to 17 ng/m^2s for an unfertilized area. The corresponding yearly emission rates were estimated to be 60 mg/m^2 and 20 mg/m^2 for fertilized and unfertilized areas, respectively. Slemr and Seiler (1984) measured both NO and NO_2 emissions, also from arable land, in Spain and in FRG. Over a one-month period losses of NO-N + NO_2-N at the Spanish site ranged from 47 mg N/m^2 for unfertilized bare soil, to ~600 mg N/m^2 for a plot fertilized with urea (1 g/m^2). At Fintken in Germany, losses of NO up to 154 mg/m^2 were observed from bare soil after adding 1 g N/m^2 as NH_4Cl. Johansson (1984) found very low NO emissions (<0.3 ng NO-N/$m^2 \cdot$s) for unfertilized forest soil, increasing to ~4 ng/$m^2 \cdot$s for forest soils fertilized with $Ca(NO_3)_2$.

These measurements can only be used to make an order-of-magnitude estimate for NOx emissions for arable and forested areas in Europe. The area of arable land in Europe is 2 900·10^3 km including 1 500·10^3 km in the USSR. Assuming a factor of 60 mg/m^2, a yearly emission of 500 kt NO_2 can be estimated for whole Europe, which accounts for only 2 per cent of the anthropogenic emissions of NOx in Europe.

There are also NOx emissions during agricultural burning and forest fires.

Burning of straw and stubble is not common agricultural practice in Europe, except in some countries such as France and Italy. It can be assumed that ca. 300 g/m^2 of dry material is combustible, containing <0.5 per cent N.

The NOx emission factor depends on the dryness of the straw and under very dry condition 2 to 5 g NO_2/kg may be assumed. Galbally (1985) assumes an "N-conversion efficiency" of ca. 10 per cent. Since the N content in his studies is 0.5 to 1.0 per cent, this gives slightly higher emission factors. Taking into account a factor of 2 g NO_2/kg, and assuming 10 per cent of the arable land being burned in Europe, one estimates a yearly emission of 180 kt, thus less than 1 per cent of the anthropogenic emissions of NOx in Europe. Forest fires in

Europe occur mostly on a very limited scale, at most involving some thousand km^2. In forest fires, only part of the standing biomass burn - the trunks remain. Assuming a burning biomass of 2 kg/m^2, the NOx emissions from a 1 000 km^2 forest burn could be 4 kt. Clearly, this is a negligible source on an annual or average basis.

8 CONCLUSIONS, APPLICATION OF RESULTS AND RECOMMENDATIONS FOR FUTURE STUDIES

The present work is the first detailed emission survey for NOx from anthropogenic sources in Eastern Europe on a regional scale. Most of the NOx emission factors used for stationary sources were calculated individually for sources in Eastern Europe, however, often on the basis of measurements in Western Europe. In such cases adjustments were made for the differences between technologies used in Western and Eastern Europe, e.g. for boilers in large electric power plants. Thus, the NOx emission factors and the NOx supplementary emission values estimated for Eastern Europe can be regarded as reference material for national authorities when preparing information on NOx emissions and on strategies of NOx emission reduction. This is particularly important in a view of the recent Protocol on the Control of Emissions of Nitrogen Oxides or their Transboundary Fluxes.

It is interesting to relate the NOx emission estimates to the consumption of fossil fuels in Europe. This comparison is presented in Figure 4. A sharp increase of gas and oil consumption in Europe between 1960 and 1975 is clearly followed by the increase of NOx emissions. In the 1980´s the consumption of gas and oil slightly decreases while the consumption of solid fuels increases. This results in rather constant level of NOx emissions in Europe. Concerning Eastern Europe, the yearly increase of the use of coal in conventional thermal power plants is 2 per cent by average. This increase is due to the increasing demand of electricity (ca. 1 per cent yearly) and the decrease of heat values in some coals (e.g. 1 per ent decrease yearly for Polish coals).

The results from this work and particularly the large body of information collected during the project suggest the following future activities for improving NOx emission estimates:

1. Unified methodology to calculate NOx emission factors.
   A major goal should be to prepare a tool enabling one to estimate emission factors for sources or even source categories where information is missing in a given country. The proposed methodology should include various models, diagrams and mathematical equations necessary to obtain the NOx emission factors. For example, for stationary sources, various mass balance models can be applied, together with the equations relating the NO_2 concentrations in exhaust gases to the N_2 and O_2 contents of coals and then the NOx emission factors. There already exists a body of information in the literature and it is proposed to systematize the models, diagrams and equations in a form of one methodology and to make this methodology useful for the Eastern European countries.

2. Handbook of NOx emission factors.
   The ranges of emission factors proposed in this work should be used to prepare a handbook of NOx emission factors with various source categories as chapters of the handbook. Each chapter (source category) may consist of: (1) a short description of the source category with major emphasis on sources of NOx emission, (2) a methodology of the NOx emission factor estimates, relevant to the given source category, (3) tables and/or diagrams with the NOx emission factors and (4) a reference list.

3. Seasonal/monthly variations of NOx emissions.
   The emission estimates in this work are annual data. Their application to model the transport of NOx during pollution episodes is therefore limited. A procedure should be prepared to translate the annual emissions to hourly or daily emissions. Such a procedure should be based on detailed data collected in different parts of Europe.

4. Methodology to calculate accuracy of NOx emission estimates. This methodology can be elaborated using the information on NOx emission factors from this work and suggestions by Eggleston (1988), and particularly by Joerss (1988b) on estimating upper and lower limits of the representative factors with consideration of all relevant influencing parameters. It should be indicated, however, that the problem is complicated and only some ideas are available at present.

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The estimates presented here are based on the best information available to the authors, and may deviate from official national data.

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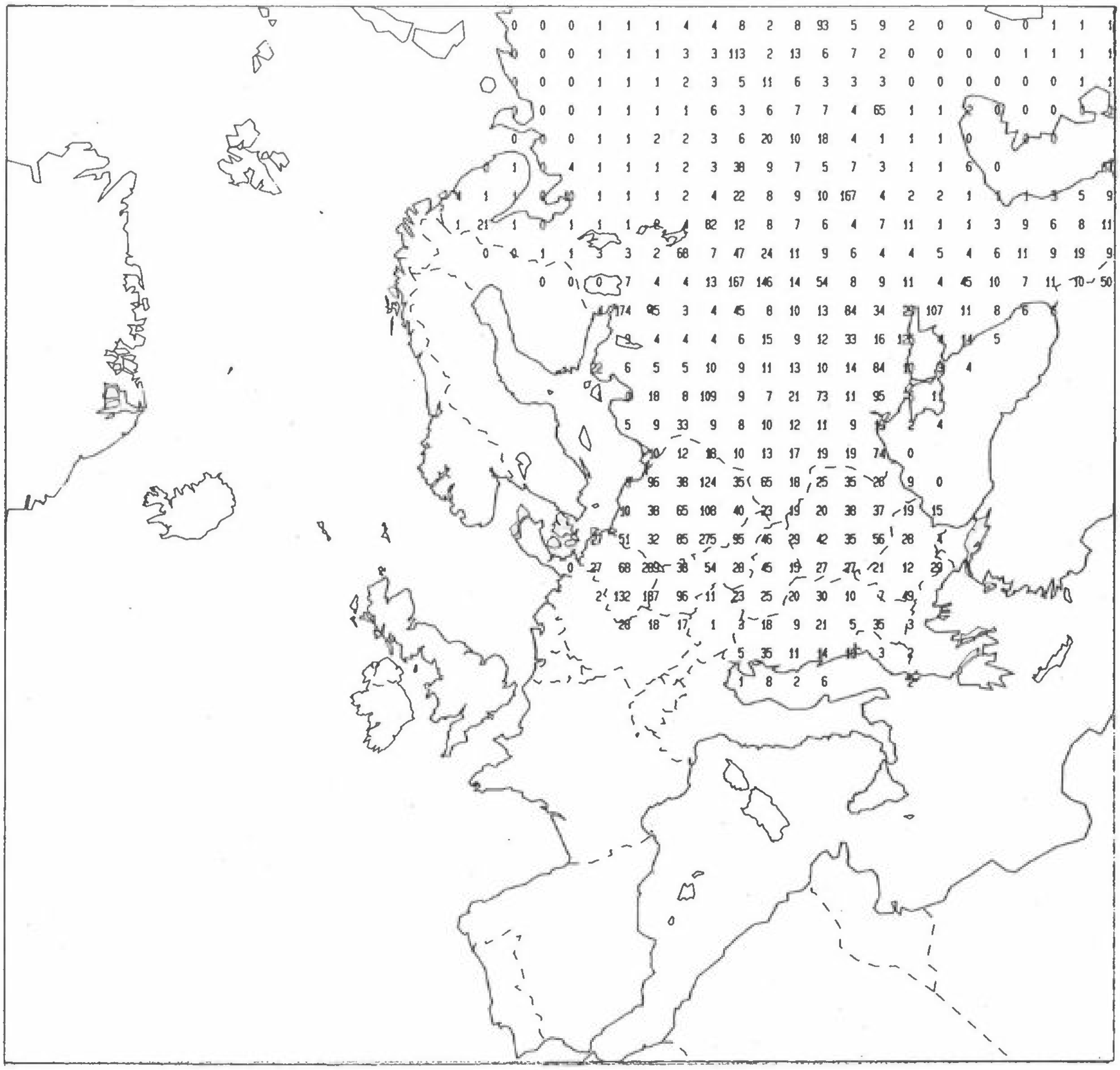

Figure 1: Spatial distribution of NOx emissions from stationary sources in Eastern Europe in 1985 within the EMEP grid of 150 km x 150 km (in 10^3 t as NO_2).

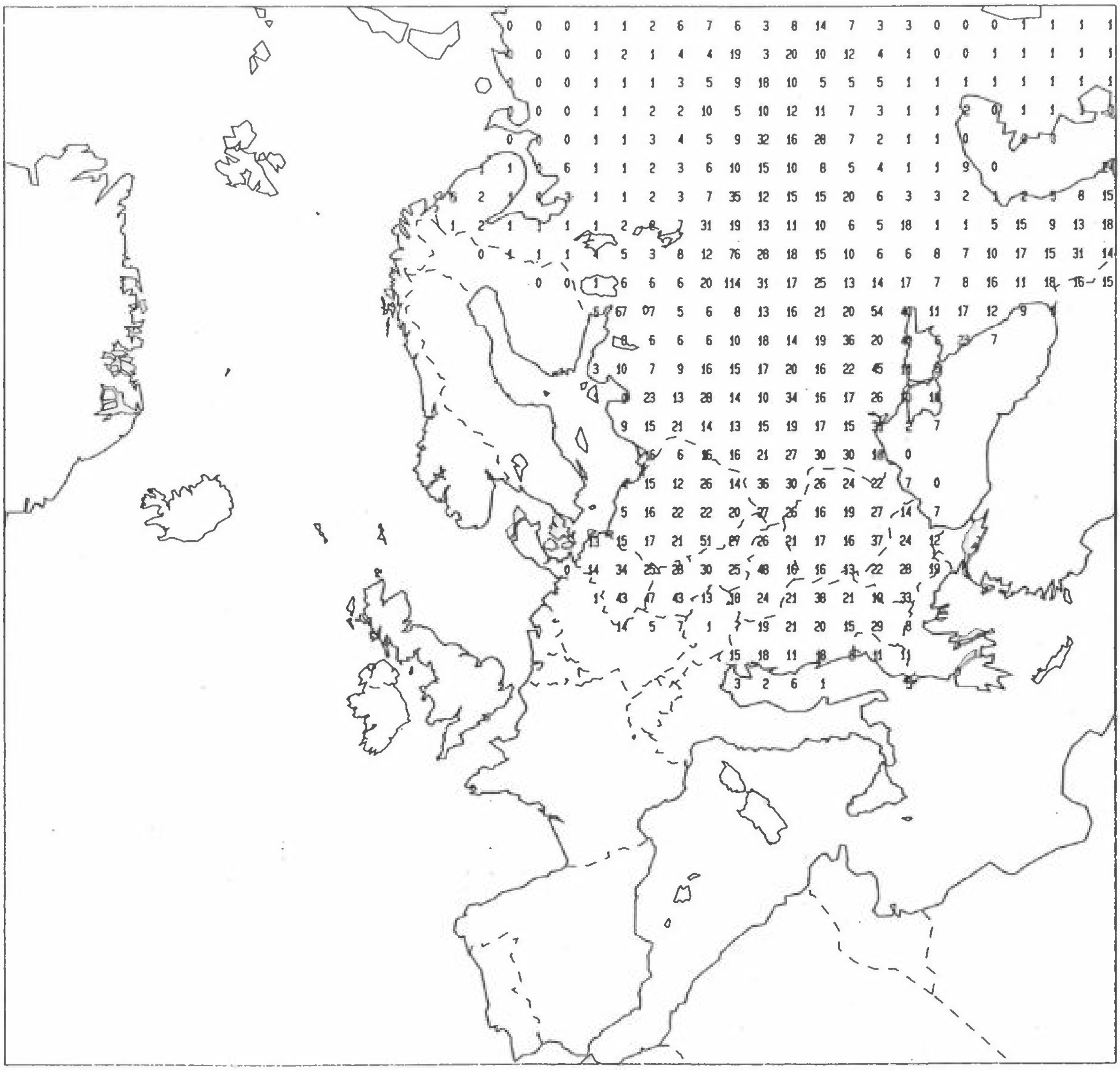

Figure 2: Spatial distribution of NOx emissions from mobile sources in Eastern Europe in 1985 within the EMEP grid of 150 km x 150 km (in 10^3 t as NO_2).

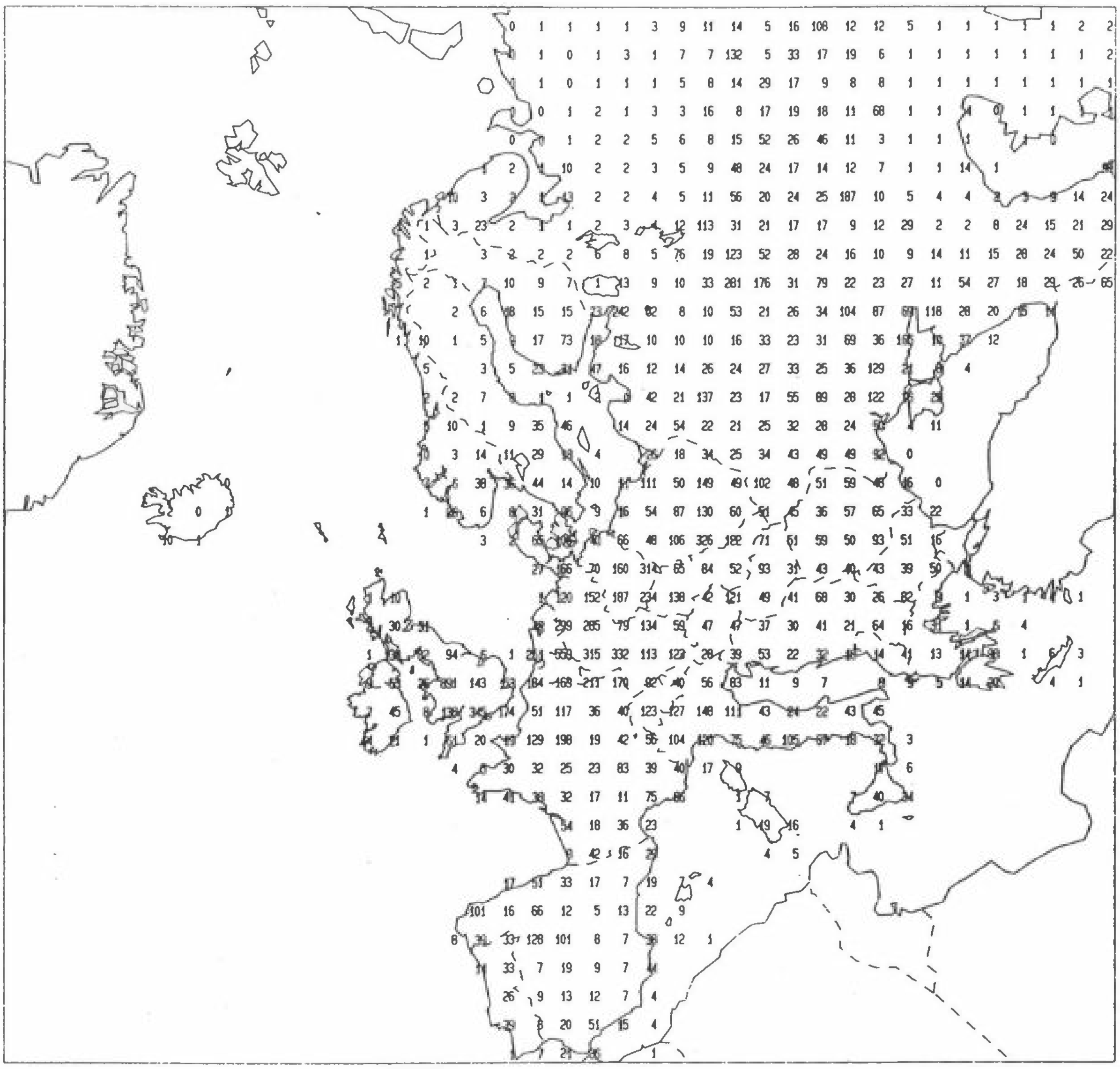

Figure 3: Spatial distribution of NOx emissions in Europe in 1985 within the EMEP grid of 150 km x 150 km (in 10^3 t as NO_2).

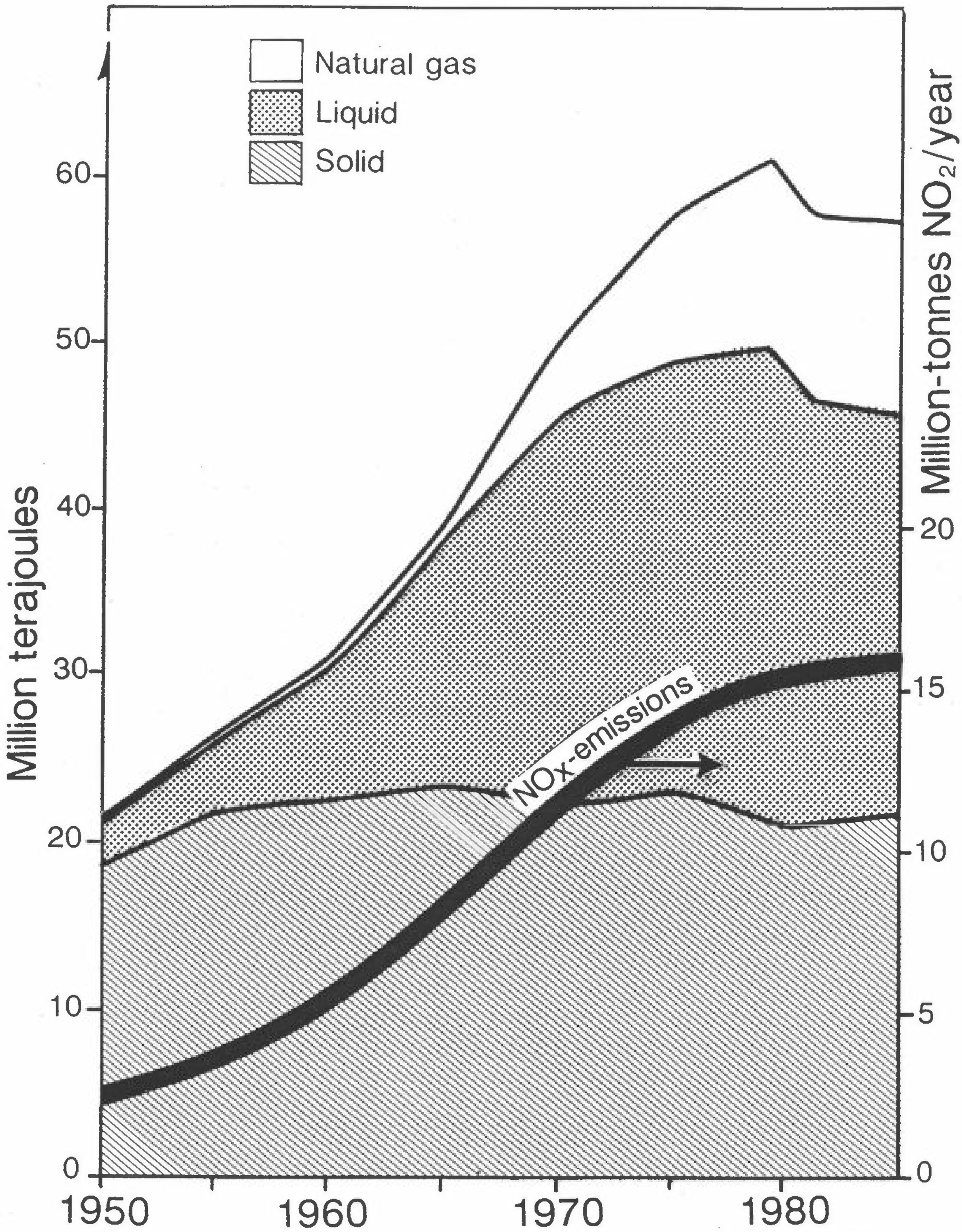

Figure 4: Consumption of fossil fuels and NOx emission in Europe without the European Soviet Union.

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ABSTRACT (max. 300 characters, 7 lines)
Emission estimates are presented for NOx from stationary and mobile sources in Europe with particular emphasis on Eastern Europe. Total emissions of NOx in Europe were estimated to 23.9 10^6 t as NO_2 in 1985 with ca. 50 per cent contribution from Eastern Europe.

* Kategorier: Åpen - kan bestilles fra NILU A
Må bestilles gjennom oppdragsgiver B
Kan ikke utleveres C