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EMISSION OF NITROGEN OXIDES FROM FOSSIL FUEL COMBUSTION IN EUROPE

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1 INTRODUCTION

The main man-made source of nitrogen oxides is the combination of atmospheric nitrogen and oxygen during combustion processes. The oxidation of nitrogen-containing compounds in the fuel give rise to additional nitrogen oxide formation. The conditions favouring formation of nitrogen oxides during combustion are high temperature, long residence time, and excess air.

The emission of nitrogen oxides is usually estimated from fuel consumption data and empirically determined emission factors, i.e. weight of NO_x formed per unit weight of fuel. It is desirable to use existing statistical information to provide a first estimate of the total emission of NO_x in Europe, and the spatial distribution of these emissions, for use in the prediction of concentration fields and deposition.

2 EMISSION FACTORS

The amount of nitrogen oxides emitted per unit of fuel consumed depend on combustion conditions and nitrogen content of the fuel. Emission factors for different fuels and fuel uses reflect this, although the variation in nitrogen content for a particular fuel type is not well known and therefore not taken into account. Table 1 give som emission factors taken from the U.S. EPA compilation and various national surveys of nitrogen oxide emissions.

Table 1: Some emission factors for nitrogen oxides from fuel combustion.

Fuel types and uses	Emission factor, g NO_2/kg fuel			
	EPA (1)	Derwent & Stewart (3)	FRG (4)	Levander (5)
Hard coal				
Power plants	9	10.5	7.2	
Industry	3-7.5	9.2	7.2	
Residential	1.5	3.2		
Lignite				
Power plants	7		3.5**	
Other	3			
Residual fuel oil				
Power plants	15	11.7	11.6	15
Industry	9	12.3-15	7.8	5-10
Distillate fuel				
Residential	3	6	-	3
Diesel oil	52	10.6	15.5	61
Motor gasoline	≈20*	16.2	20.2	29
Natural gas				
Power plants	1.2 g/kcal			
Industry	0.2-0.4 "			
Residential	0.1-0.2 "			

* Pre-1972 car models

** Per unit weight of lignite as consumed, with a water content of 60-60%.

By convention, the sum of $NO+NO_2$ is given in terms of weight equivalents of NO_2 emitted per kg of fuel consumed, although typically more than 90% is emitted as NO. Oxidation of NO to NO_2 with ozone and other oxidants is sufficiently rapid, however, to render a distinction between NO and NO_2 emissions of limited value.
Emission factors given in terms of g NO/kg or even g NO+ g NO_2 have been converted to g NO_2 in Table 1. Emission factors for cars are usually quoted in g/vehicle km, according to certain standardized driving cycles. Conversion to g/kg fuel require some knowledge of the fuel consumption rates on which these figures were based. The EPA figures for post-1972 vehicles reflect increasingly stringent regulations and are not applicable to European conditions. A fuel consumption of 0.17 l/km has been assumed for gasoline vehicles, while the diesel emission factor (1) is an over-all figure for diesel engines. Interestingly, road tests gave a significantly lower emission factor for heavy duty diesel vehicles (2).

Whereas there is broad agreement between the various sets of emission factors for stationary sources, estimated emissions from diesel engines are highly variable. The reason for this, at least partly, is different combustion conditions for different designs of diesel, which vary from low values of $\simeq$ 8 g/kg for light vehicles with indirect injection (5), and up to $\simeq$ 90 g/kg fuel for some turbocharged, high efficiency engines (5).

Levander (5) estimated the total NO_x emission for Sweden using emission factors of 1.9-2.3 g/km for light vehicles and 13.2-22 g/km for heavy diesel powered vehicles. The factors in Table 1 were derived from his estimate of the total NO_x-emissions from gasoline and diesel, respectively, divided by the actual consumption of these fuels. The result is not inconsistent with the emission factors in g/km, and realistic fuel consumption figures.

Burner and combustion chamber designs also have significant impacts on NO_x emissions from stationary sources. Thus, for cyclone-fed coal combustion in large power plants, an emission factor of 27.5 g/kg is given in (1). The general emission factor for thermal power plant is in the range 7-9 g/kg coal, however.

It thus appears possible to obtain a reasonable estimate of regional nitrogen emissions from available statistical data on fuel consumption, particularly where a sufficiently detailed breakdown in fuel types and consumption sectors is available, such as in the OECD Energy Statistics (6).

3 ESTIMATED NO_x EMISSIONS FOR INDIVIDUAL COUNTRIES

The emission factors in Table 2 have been chosen to conform with the statistical breakdown. Because of the variability of emissions per unit fuel within each group of combustion sources, for which no specific or detailed information is available, the choice of emission factors is to some extent arbitrary. However, the results show that within OECD Europe the major emissions are associated with transport and electric power production, estimated at 43 and 28 percent, respectively, of the total emissions.

More specific and detailed information on the emission factors for these groups of sources will be essential if the emission estimates are to be improved.

Calculated emissions of NO_x for individual countries are presented in Appendix 1, and summarized in Table 3. It is interesting to compare the calculated national emissions with the total fuel consumption in energy equivalents as given by the UN Statistics (7). It has been assumed that coal and coke used in metallurgical processes does not contribute appreciably to the NO_x emissions, this amount has therefore been subtracted from the energy consumption given by (7).

Figure 1 shows that, although the nitrogen oxide emissions depend on fuel consumption pattern as well as on the total amounts consumed, the ratio of NO_x total emission to energy throughput is remarkably constant within the region. Obviously, as a first estimate, this information may also be used to approximate the emissions of NO_x in countries outside the OECD region.

Because of the uncertainty involved in the application of this emission factor outside the economic region for which it has been deduced, a "conservative" emission factor of 5 kg NO_2/tonne for coal equivalents have been used, and the amounts of coal used in iron and steel production has been estimated from pig iron production figures.
The calculated national emissions are given in Table 4.

4 SPATIAL DISTRIBUTION

Surveys of spatial distribution within countries are already available in some cases (3,4) and are based on location and capacity of power plants, fuel consumption by districts, and distribution of road traffic. Because of the intercorrelation with population density, it is not surprising that there is high correlation between sulphur dioxide and nitrogen oxides emission for grid squares within one country (Figure 2).

In the EMEP emission grid (9), excessive SO_2 emissions occur in certain grid squares due to metal smelters (grid no. 15,26; 17,26; 27,37; 28,37), burning of local fuel with high sulphur contents (22,17 and 23,18) and processing of natural gas with high sulphur content (21,8). The SO_2 emissions in these squares have been reduced by subjective assessment, and the remaining SO_2 emissions have been used to distribute the national emissions of NO_x.
The resulting NO_x emission grid is given in Figure 3.

5 IMPROVING THE EMISSION SURVEY

Many of the assumptions used in estimating the national emissions and their spatial distribution may well be improved. This would require further information to be collected from the countries particularly with respect to emissions from internal combustion engines and from thermal power plants. This information should satisfy certain requirements with respect to consistency between countries, and compatibility with available statistical data. Differences in emission factors between countries should be explainable in terms of different technologies or consumption pattern.

In this emission survey, identical emission factors have been used together with available statistical data to provide an estimated emission field corresponding to the EMEP emission survey for sulphur oxides. Comparison between dispersion model estimates should be carried out to test if the estimated NO_x emissions are consistent with measured air concentrations of NO_2 and HNO_3, and with nitrate in precipitation.

Table 2: Fuel consumption and estimated NO_x emission within OECD Europe.

	Emission factor g/kg	Fuel consumption (Tg)	NO_x emission Tg NO_2
Hard coal			
Power plants	9	133	1.2
Industry	6	22	0.1
Other	2	24	0.05
Brown coal			
Power plants	4	137	0.5
Residual fuel oil			
Power plants	12	69	0.8
Refineries	8	19	0.15
Industry	8	95	0.75
Other	6	27	0.16
Gas diesel oil			
Industry	8	24	0.2
Other	4	121	0.5
Transport	36	46	1.7
Motor gas			
Transport	25	90	2.2
Natural gas	g/kcal:	Tcal:	
Power plants	1	336	0.3
Industry	0.3	642	0.2
Other	0.2	554	0.1
			9.0

Table 3: Estimated NO_x emission from fossil fuel combustion and NO_x producing energy consumption for individual OECD countries in Europe.

	Estimated NO_x emission Gg NO_2	Energy consumption 10^6 tonnes coal equiv.	Average emission-factor g NO_2/kg coal equiv.
Austria	150	24	6.3
Belgium	290	50	5.8
Denmark	180	27	6.7
Finland	150	20	7.5
France	1300	190	6.8
FRG	2200	315	7.0
Greece	150	18	8.3
Iceland	10	1	10.0
Ireland	60	10	6.0
Italy	1000	160	6.3
Luxembourg	20	4	5.0
Netherlands	400	77	5.2
Norway	100	9	11.1
Portugal	76	7	10.0
Spain	560	69	8.1
Sweden	250	40	8.2
Switzerland	125	19	6.3
Turkey	175	23	7.4
United Kingdom	1900	280	6.8
	9095	1343	

Table 4: Energy consumption and estimated NO_x emissions for countries outside OECD.

	NO_x-producing energy* 10^3t SKE	Estimated NO_x emissions 10^3t
Albania	1 733	9
Bulgaria	40 035	200
Czechoslovakia	101 145	500
Germany, Dem.Rep.	113 614	570
Hungary	36 785	185
Poland	167 066	840
Romania	77 393	390
USSR	1 354 524	6 800
Yugoslavia	41 208	190
		9 684

* Less hydro and nuclear energy and corrected for coal used in primary iron production. A factor of 0.4 x the pig iron production has been used to estimate the amount of coke consumed in primary iron production.

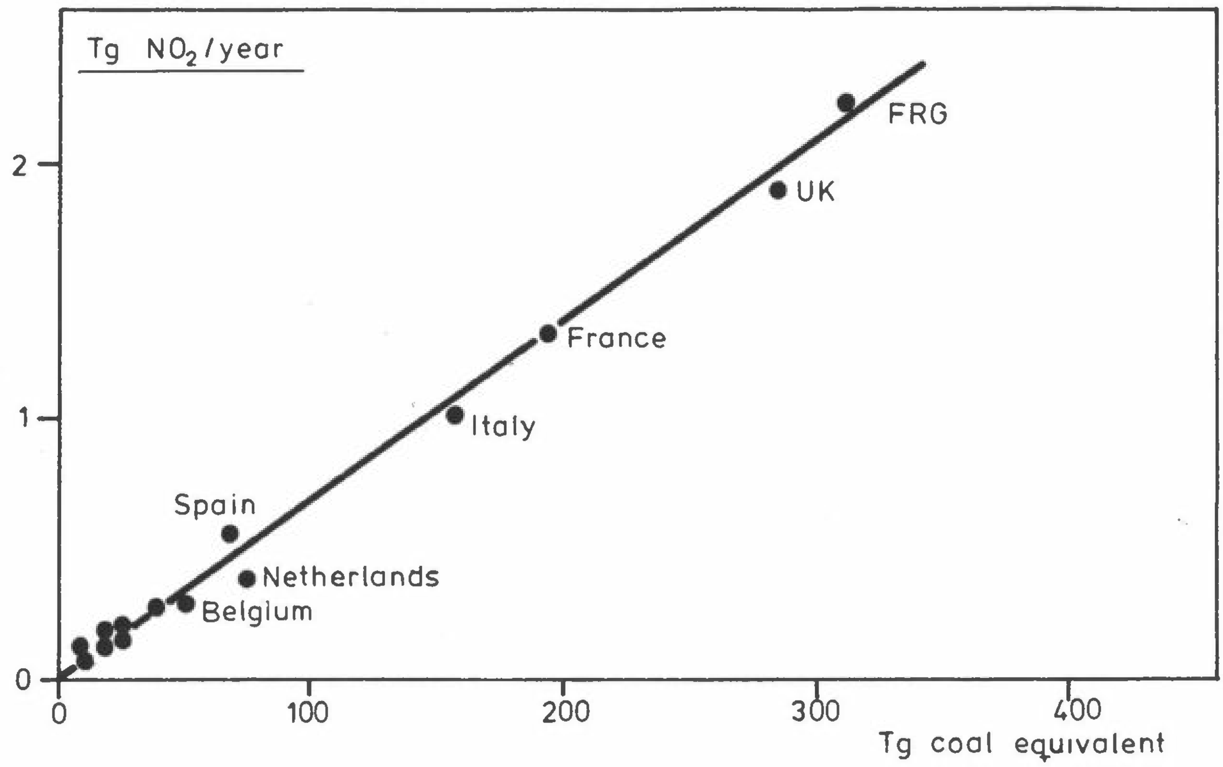

Figure 1: Fossil fuel consumption and estimated NO_x emission for countries within OECD Europe.

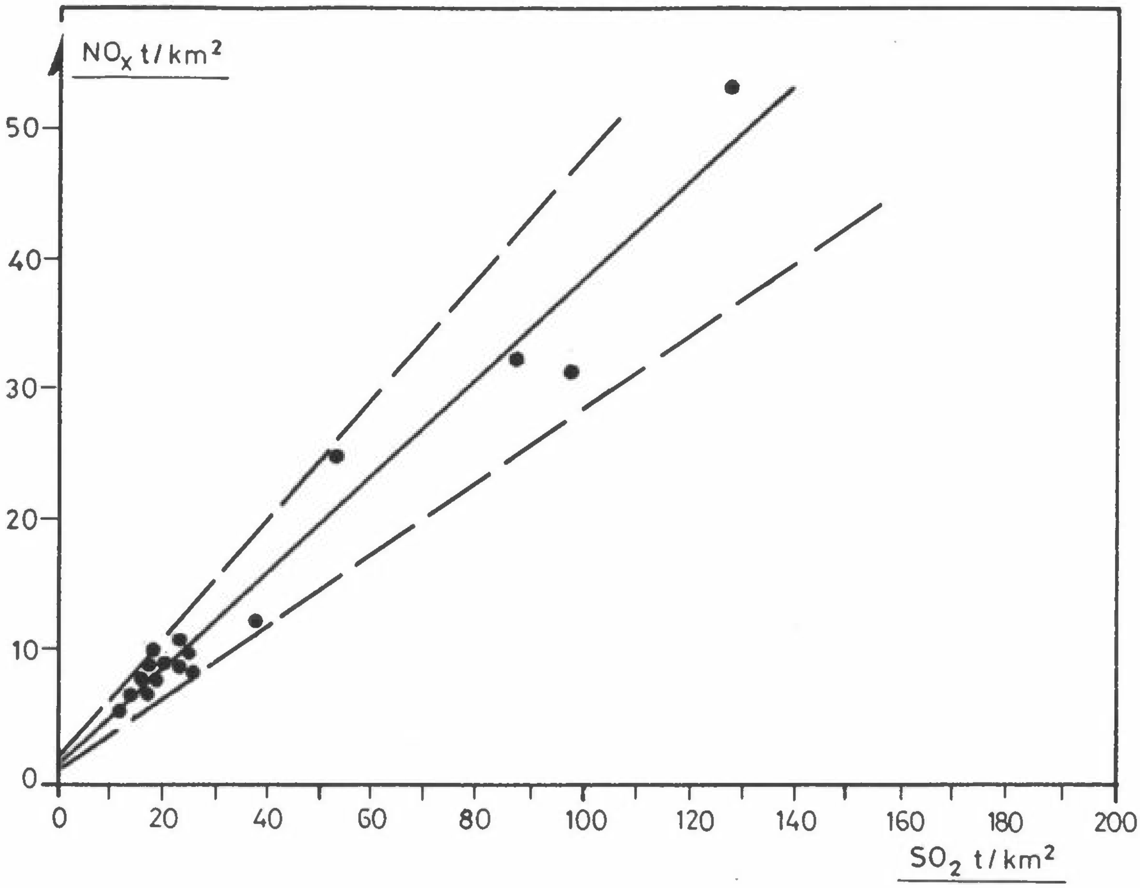

Figure 2: SO_2 and NO_x emissions in individual grid squares within the Federal Republic of Germany, Based on data from reference (4).

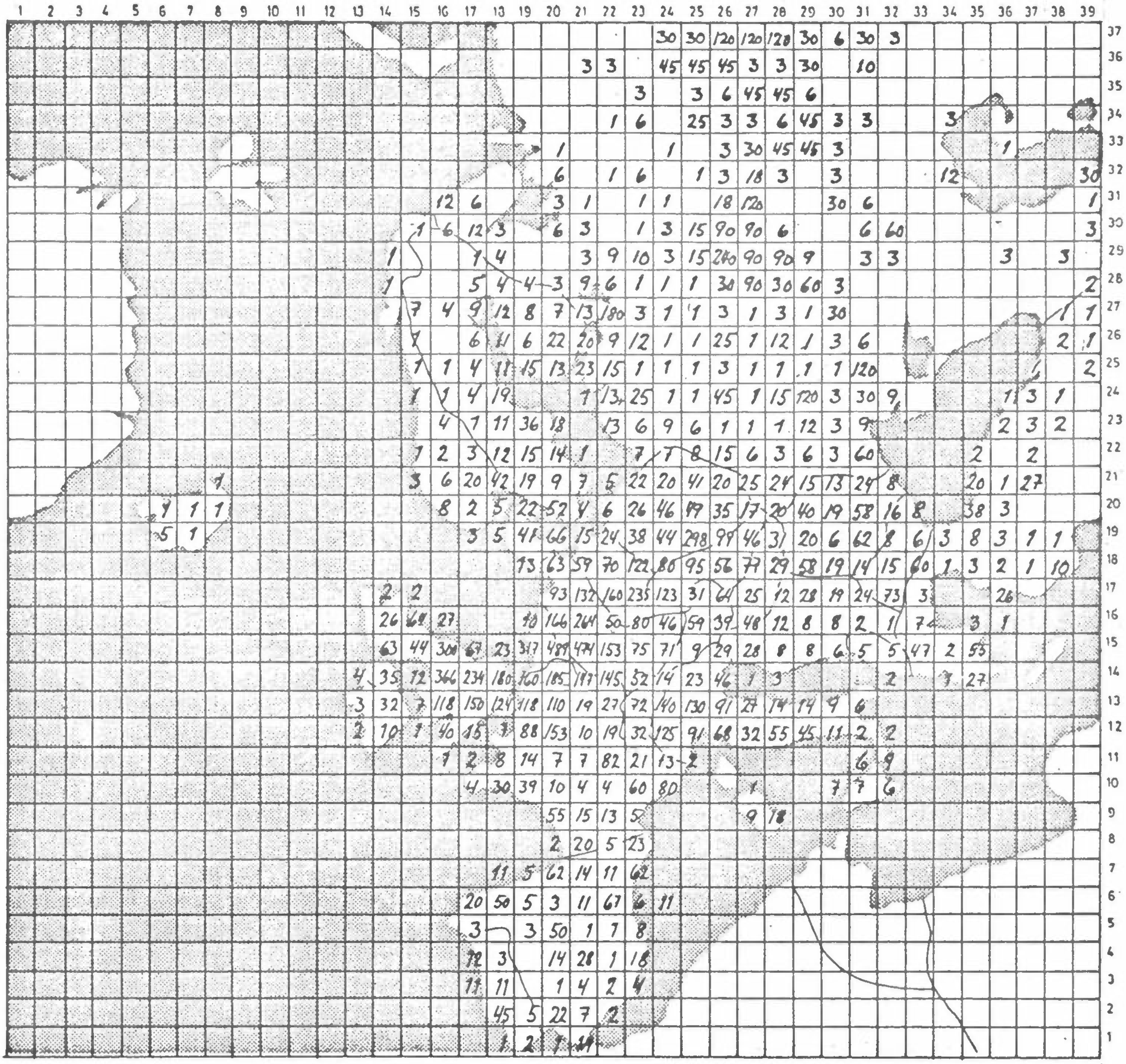

Figure 3: Estimated NO_x emission field (10^3 t NO_2/a).

APPENDIX

ESTIMATED NO_x EMISSIONS FOR INDIVIDUAL COUNTRIES WITHIN OECD EUROPE

(8) United Nations — World energy supplies 1972-1976. New York 1978.

(9) Dovland, H. Saltbones, J. — Emissions of sulphur dioxide in Europe in 1978. Lillestrøm 1978. (EMEP/CCC-report 2/79.)

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(3) Derwent, R.G. Stewart, H.N.M. — Air pollution from oxides of nitrogen in the United Kingdom. *Atmos. Environ.* 7, 385-401 (1973).

(4) Räumliche Erfassung der Emissionen ausgewählter luftverunreinigender Stoffe. Bonn, Bundesministerium des Innern, 1976.

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(7) OECD — Energy statistics 1974/1976. Paris 1978. Organisation for economic co-operation and development.

	Fac-tor	Greece 10^3t cons.	Greece Em	Spain cons.	Spain Em	Portugal cons.	Portugal Em	Turkey cons.	Turkey Em
Hard coal									
P.plants	9	-		5525	49,7	186	1,7	1052	9,5
Ind.	6	114	0,7	2735	16,4	48	0,3	243	1,5
Other	2	4	0	247	0,5	11	0	242	0,5
Patent fuel	2	-		127	0,3	1	0	-	-
Brown coal									
P.plants	4	15317	61,3	3110	12,4	-	-	2391	9,6
B.K.B.	2	90	0,2	-	-	-	-	20	0
Res. fuel oil									
P. plants	12	1395	16,7	7540	90,5	774	9,3	1182	14,2
Ref.	8	319	2,6	1583	12,7	265	2,1	554	4,4
Ind.	8	1781	14,2	10382	83,1	1447	11,6	2084	16,7
Other	6	322	1,9	866	5,2	53	0,3	218	1,3
Gas/Diesel oil									
Ind.	8	154	1,2	150	1,2	100	0,8	130	1,0
Other	4	1402	5,6	2305	9,2	123	0,5	1108	4,4
Trans.	36	567	20,4	4518	162,6	805	29,0	1791	64,5
Motor gas	25	948	23,7	4532	113,3	795	19,9	1927	48,2
Natural gas		10^9 kcal							
P.plants	1*	-		4284	4,3	-		-	
Ind.	0,3*	-		5627	1,7	-		-	
Other	0,2*	-		744	0,1	-		-	
Σ			149		563		76		176

* kg/10^6 kcal

	Factor	Germany (10^3t) Cons	Em	Netherlands		Belgium		United Kingdom	
Hard coal									
P. Plants	9	31584	284.3	98	0.9	2646	23.8	74780	673.0
Ind.	6	2869	17.2	54	0.3	298	1.8	9684	58.1
Other	2	2746	5.5	160	0.3	2068	4.1	13513	27.0
Patent fuel	2	1426	2.9	8	-	385	0.8	1287	2.6
Brown coal									
P. Plants	4	109764	439,1	-	-	-	-	-	-
B.K.B	2	5889	11.8	14	-	23	-	-	-
Res. fuel oil									
P. Plants	12	4684	56.2	757	9.1	3482	41.8	12594	151.1
Ref.	8	3921	31.4	1646	13.2	255	2.0	3342	26.7
Ind.	8	16375	131.0	1209	9.7	1948	15.6	14139	113.1
Other	6	1483	8.9	669	4.0	1344	8.1	3435	20.6
Gas/diesel oil									
Ind.	8	6143	49.1	514	4.1	916	7.3	4950	39.6
Other	4	41206	164.8	3214	12.9	5880	23.5	5734	22.9
Trans.	36	8517	306,6	2443	87,9	1459	52,5	7347	264,5
Motor gas	25	19999	500.0	3476	86.9	2795	69.9	15783	394.6
Natural gas				10^9 kcal					
P. Plants	1*	123980	124.0	109583	109.6	19824	19.8	21621	21.6
Ind.	0.3*	162729	48.8	90544	27.2	45923	13.8	125595	37.7
Other	0.2*	82894	16.6	149610	29.9	21949	4.4	166646	33.3
Σ			2198		396		290		1886

* kg/10^6 kcal

	Factor	Austria		Denmark		Finland		France	
Hard coal									
P. Plants	9	33	0.3	2632	23.7	1840	16.6	12011	108.1
Ind.	6	47	0.3	488	2.9	882	5.3	3329	20.0
Other	2	197	0.4	47	0.1	73	0.1	3440	6.9
Patent fuel	2	31	0.1	-	-	-	-	2772	5.5
Brown coal									
P. Plants	4	2627	10,5	-	-	-	-	2597	10,4
B.K.B.	2	331	0.7	20	-	-	-	180	0.4
Res. fuel oil									
P. Plants	12	727	8.7	2920	35.0	910	10.9	10688	128.3
Ref.	8	40	0.3	124	1.0	-	-	3656	29.2
Ind.	8	2051	16.4	1222	9.8	2260	18.1	15767	126.1
Other	6	1656	9.9	1857	11.1	1174	7.0	2358	14.1
Gas/diesel oil									
Ind.	8	77	0.6	565	4.5	453	3.6	5154	41.2
Other	4	1509	6.0	4209	16.8	2772	11.1	24874	99.5
Trans.	36	725	26,1	1021	36,7	1012		7757	279,3
Motor Gas	25	2140	53.5	1623	40.6	1367	34.2	15261	381.5
Natural gas				10^9 kcal					
P. Plants	1*	8389	8.4	-	-	2341	2.3	28877	28.9
Ind.	0.3*	21461	6.4	-	-	4547	1.4	70134	21.0
Other	0.2*	4648	0.9	-	-	-	-	62219	12.4
			149		182		148		1313

* kg/10^6 kcal

	Factor	Ireland		Luxembourg		Norway		Sweden	
Hard coal									
P. Plants	9	48	0.4	7	0.1	23	0.2	-	-
Ind.	6	-	-	509	3.1	384	2.3	279	1.7
Other	2	550	1.1	8	-	35	0.1	30	0.1
Patent fuel	2	-	-	1	-	-	-	-	-
Brown coal									
P. Plants	4	-	-	-	-	-	-	-	-
B.K.B.	2	-	-	40	0.1	-	-	15	-
Res. fuel oil									
P. Plants	12	1212	14.5	62	0.7	4	-	1627	19.5
Ref.	8	11	0.1	-	-	-	-	243	1.9
Ind.	8	1023	8.2	445	3.6	1275	10.2	4906	39.2
Other	6	59	0.4	8	-	190	1.1	4349	26.1
Gas/Diesel oil									
Ind.	8	179	1.4	64	0.5	609	4.9	852	6.8
Other	4	569	2.3	330	1.3	1011	4.0	6042	24.2
Trans.	36	277	10,0	95	3,4	1288	46,4	1333	48,0
Motor Gas	25	799	20.0	180	4.5	1148	28.7	3248	81.2
Natural gas				10^9 kcal					
P. Plants	1*	-	-	789	0.8	-	-	-	-
Ind.	0.3*	-	-	2397	0.7	-	-	-	-
Other	0.2*	-	-	627	0.1	-	-	-	-
			59		19		98		249

* kg/10^6 kcal

	Factor	Switzerland		Iceland		Italy		
Hard coal								
P. Plants	9	-	-	-	-	1009	9.1	
Ind.	6	97	0.6	-	-	217	1,3	
Other	2	19	-	-	-	196	0,4	
Patent fuel	2	17	-	-	-	41	0,1	
Brown coal								
P. Plants	4	-	-	-	-	1362	5,4	
B.K.B	2	47	0.1	-	-	35	0,1	
Res. fuel oil								
P. Plants	12	412	4.9	25	0.3	18271	219,3	
Ref.	8	57	0.5	-	-	2987	23,9	
Ind.	8	984	7.9	56	0.4	15460	123,7	
Other	6	241	1.4	-	-	5380	32,3	
Gas/Diesel oil								
Ind.	8	1276	10.2	-	-	1715	13,7	
Other	4	5004	20.0	144	0.6	13115	52,5	
Trans.	36	461	16,6	185	6,7	4816	173,4	
Motor Gas	25	2444	61.1	86	2.2	11208	280,2	
Natural gas		10^9 kcal						
P. Plants	1*	-		-	-	18968	19,0	
Ind.	0.3*	2339	0.7	-	-	110468	33,1	
Other	0.2*	2345	0.5	-	-	62231	12,4	
			125		10		1000	

* kg/10^6 kcal

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ABSTRACT (max. 300 characters, 5-10 lines)

Yearly emissions of nitrogen oxides in 150x150 km grid squares have been estimated on the basis of fuel consumption data and emission factors.

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