NILU OR: 48/89

NILU OR : 48/89
REFERENCE: O-8861
DATE : SEPTEMBER 1989
ISBN : 82-425-0057-6

EMISSIONS OF MAJOR AIR POLLUTANTS EMITTED IN EASTERN EUROPE

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SUMMARY

The report presents estimates of the 1982 emissions of SO_2, NOx, VOC, NH_3, CH_4, CO and N_2O from sources in Eastern Europe. The estimates will be used to test the EURAD model in the EUMAC project of EUROTRAC. The SO_2 emission data were accepted from Eliassen et al. (1988), and the NH_3 emissions from Buijsman et al. (1987). The results of estimates are presented below.

Anthropogenic emissions of major gases in Eastern Europe in 1982 (in 10^3 t).

Country	SO_2 [1] as S	NOx as NO_2	VOC (non-methane)	NH_3 [2]	CH_4	CO	N_2O
Albania	25	28.0	32.8	21.0	0.5	121.7	7.1
Bulgaria	570	278.3	167.2	126.0	3.3	627.5	59.4
Czechoslovakia	1 575	556.9	258.7	170.0	18.7	765.9	112.1
GDR	2 500	857.1	353.6	207.0	26.0	1 020.7	250.0
Hungary	774	268.5	165.6	127.0	6.0	527.9	39.7
Poland	2 150	1 276.1	493.8	405.0	37.5	1 447.6	216.0
Romania	100	737.8	385.7	301.0	17.6	1 176.1	117.5
USSR (Europe)	6 100	7 969.0	5 822.7	1 256.0	322.5	24 009.2	1 788.3
Yugoslavia	657	440.4	290.7	198.0	9.4	929.6	91.4
Total	14 451	12 412.1	7 970.8	2 812.0	441.5	30 626.2	2 681.5

1 from Eliassen et al. (1988).
2 from Buijsman et al. (1987).

CONTENTS

EMISSIONS OF MAJOR AIR POLLUTANTS EMITTED IN EASTERN EUROPE

1 INTRODUCTION

The purpose of this work is to: (1) present the emission estimates for SO_2, NOx, VOC, NH_3, N_2O, CO, and CH_4, (2) relate these emissions to statistical data on the consumption of fossil fuels and the production of various industrial goods, (3) discuss the VOC profiles for various source categories, and (4) present the spatial distributions of emissions of the above constituents within the EMEP grid of 150 km x 150 km. The results of this work form a basis for a European scale transport, transformation and deposition model for atmospheric constitutents within the European Modelling of Atmospheric Constituents (EUMAC) programme of EUROTRAC. The estimates will be used to test the EUMAC model, called EURAD, during the pollution episodes in 1982.

The project has been supported by a research grant from the University of Cologne, Federal Republic of Germany.

2 EMISSIONS OF SO_2

Information on the SO_2 emissions from Eastern Europe has been collected mostly within the UN ECE Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (EMEP). The SO_2 emissions are provided by national authorities to the EMEP Meteorological Synthesizing Centres West (MSC-W) and East (MSC-E), and are used there in modelling the transport of SO_2 over Europe.

Emissions of SO_2 in Europe in 1980 and 1983 are reported by Dovland and Saltbones (1986). They present these emissions on the country-by-country basis, as well as their spatial distribution within the EMEP grid of 150 km x 150 km. As the EURAD model of EUMAC will be tested for episodes in 1982, the SO_2 emissions for 1982 shall be interpolated on the basis of the EMEP emission data for 1981. This interpolation has been prepared and reported by Eliassen et al. (1988). They estimated 3% decrease of SO_2 emissions in Europe between 1981 and 1982 and further 4% decrease between 1982 and 1983.

The 1982 emission data for SO_2 from sources in Eastern Europe are presented in Table 1, and their spatial distribution within the EMEP grid of 150 km x 150 km in Figure 1.

Table 1: SO_2 emissions from anthropogenic sources in Eastern Europe in 1982 (in 10^3 S)*1.

Country	Emission
Albania	25
Bulgaria	570
Czechoslovakia	1 575
GDR	2 500
Hungary	774
Poland	2 150
Romania	100
European USSR	6 100
Yugoslavia	657
Total	14 451

*1 from Eliassen et al. (1988).

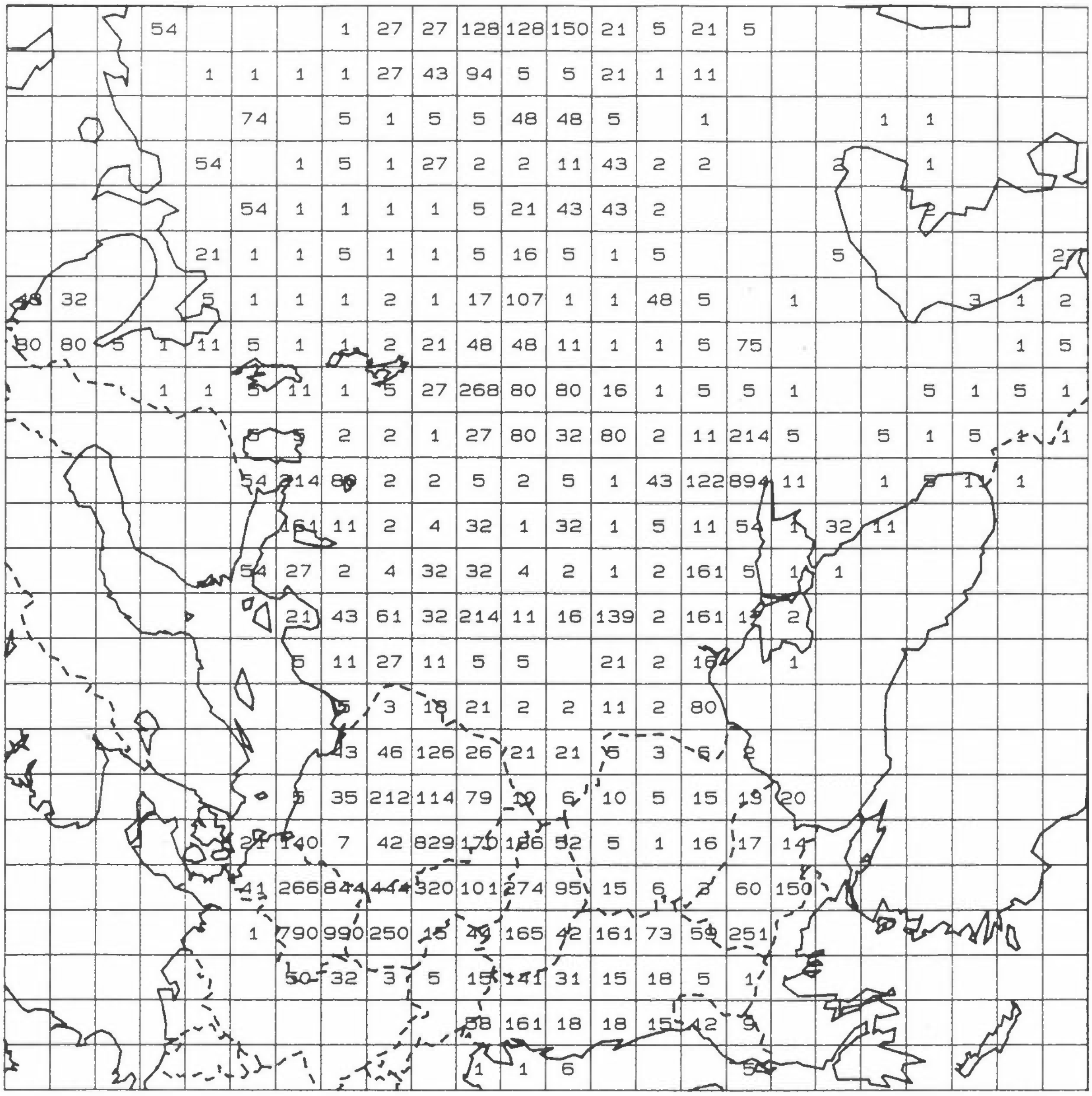

Figure 1: Spatial distribution of SO_2 emissions in Eastern Europe in 1982 within the EMEP grid of 150 x 150 km.
The unit used: 10^3 t.

3 EMISSIONS OF NOx

Recently Pacyna (1988) and Larssen (1989) presented emission surveys for NOx from stationary and mobile sources. Eastern Europe was given special attention.

The following source categories were considered by Pacyna (1988) when calculating the NOx emissions from stationary sources:

1) production of electricity in power stations, burning hard (bituminous and subbituminous) coals, brown coals including lignites, residual (heavy) 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.

The NOx emission factors for combustion of fossil fuels in electric power plants in Eastern Europe are presented in Table 2. These factors were then used together with the statistics on the production of electricity to estimate the NOx emissions from fossil-fuel combustion in electric power plants. The results are shown in Table 3.

Table 2: NOx emission factors for combustion of fossil fuels in electric power plants in Eastern Europe (in g NO_2/GJ_{th}).

Country	Fuel			
	Hard coal	Brown coal (incl. lignite)	Oil	Gas
Albania		253		
Bulgaria		296	240	
Czechoslovakia	319	256	240	110
GDR		285		
Hungary	385	336	240	110
Poland	385	285		
Romania		256	240	110
European USSR	385	285	240	110
Yugoslavia		253		

Table 3: NOx emissions from fossil-fuel combustion in electric power plants in Eastern Europe in 1982.

Country	Production of electricity (GWh)				NOx emission (t NO_2)			
	Hard coal-fired power plant	Brown coal-fired power plant	Oil-fired power plant	Gas-fired power plant	Hard coal-fired power plant	Brown coal-fired power plant	Oil-fired power plant	Gas-fired power plant
Albania		550				900		
Bulgaria		17 340	9 330			53 600	24 600	
Czechoslovakia	11 940	42 200	5 730	4 680	42 000	112 600	15 000	2 000
GDR		90 300				269 400		
Hungary	870	7 260	3 540	550	3 600	25 500	9 300	2 100
Poland	92 000	23 000			389 400	54 800		
Romania		18 940	6 730	31 380		50 600	24 800	13 300
USSR (Europe)	312 000	130 000	446 000	475 000	1 323 400	269 400	1 171 800	203 000
Yugoslavia		34 720				91 700		
TOTAL	416 810	364 310	471 330	511 610	1 758 400	928 500	1 245 500	220 400

The statistical data used in this work were collected from the national statistical yearbooks, and from the UN international statistics (UN, 1986). The national statistical yearbooks are the following:

1. Statisticzeskij godisznik na narodna republika Bulgaria -1982, Komitet za socialna informacja pri ministerskija swet, Sofia, 1983.

2. Statisticka rocenka Ceskoslovenske Socialisticke Republiku -1982, Federalni Statisticky Urad, Cesky Statisticky Urad, Slovensky Statisticky Urad, Praha, 1983.

3. Statistisches Jahrbuch 1982 der Deutschen Demokratischen Republik, Staatlichen Zentralverwaltung für Statistik, Berlin, 1982.

4. Statistical Pocket Book of Hungary -1982, Hungarian Central Statistical Office, Budapest, 1983.

5. Rocznik Statystyczny -1982. Glowny Urzad Statystyczny, Warszawa, 1983.

6. Anuarul Statistic al Republicii Socialiste Romania -1982, Directia Cèntrala de Statistica, Buchuresti, 1982.

7. Narodnoje Hozjaistwo CCCP w 1982 gode, Statisticzeskij ezegodnik, Centralnoje Statisticzeskoje Uprawlenije CCCP, Moskwa, 1983.

8. Statisticki godisnjak Jugoslavije -1982, Socijalisticka Federativna Republika Jugoslavija, Savezni Zawod za Statistiku, Beograd, 1983.

Heat in Eastern Europe is produced mostly by combusting coal of varying quality. The NOx factors for this source category are listed in Table 4. It was difficult to differentiate between small residential burners and larger ones in district heating plants. Thus, the same factors were used for both types of burners resulting in some, difficult to assess, inaccuracies of emission calculations. The NOx emissions are then presented in Table 5.

Table 4: NOx emission factors for combustion of coal to produce heat in Eastern Europe (in kg NO_2/t coal).

Country	Central (district) heating	
	Hard coal	Brown coal (incl. lignite)
Albania	-	-
Bulgaria		4.0
Czechoslovakia		3.0
GDR		4.5
Hungary[1]		4.9
Poland	12.0	3.0
Romania		10.5
European USSR	12.1	3.0
Yugoslavia		3.2

1) A factor of 1.25 g NO_2/kg coal was used for small residential units.

Table 5: NOx emissions from coal combustion to produce heat in Eastern Europe in 1982.

Country	Production of heat (in 10^6 GJ)	NOx emission (in t NO_2)
Albania	n.d.	
Bulgaria	57	28 150
Czechoslovakia	447	114 300
GDR	653	313 000
Hungary	220	71 740
Poland	806	481 200
Romania	667	304 010
USSR (Europe)	5 130	1 378 000
Yugoslavia	153	60 340
TOTAL	8 143	2 750 740

n.d. = no data available

Unfortunately, no data were available to calculate the NOx emission factors for heat production in Albania.

The emissions of NOx during combustion of oil and gas in industrial and residential boilers are considered in Table 6 (emission factors) and Table 7 (emission amounts).

Table 6: NOx emission factors for combustion of oil and gas in industrial and residential boilers in kg NO_2/TJ unless otherwise indicated.

Fuel	Emission factors
1. Residual fuel oil	5*
2. LPG	50
3. Coke oven gas	125
4. Blast furnace gas	125
5. Refinery gas	120
6. "City" gas	60

* in kg NO_2/t residual oil

Table 7: NOx emissions from combustion of oil and gas in industrial and residential boilers in Eastern Europe in 1982.

Country	Consumption of fuel					
	Fuel oil (10^3 t)	LPG (TJ)	Coke oven gas (TJ)	Blast furnace gas (TJ)	Refinery gas (TJ)	"City gas" (TJ)
Albania*	550					
Bulgaria	3 025	3 188	4 000	13 500		
Czechoslovakia	4 840	6 604	68 946	59 966	11 961	
GDR	9 000	12 570	7 400	23 384	22 277	143 300
Hungary	1 090	13 663	6 005	17 838	5 089	
Poland	2 434	8 517	109 641	77 181	9 840	100 000
Romania		11 386	24 000	56 000	43 000	
USSR (Europe)	33 500	433 351	605 000	805 000	573 900	
Yugoslavia	6 000	12 980	19 638	19 078	14 057	
Total	60 439	502 259	844 630	1 071 947	680 124	243 300
Country	**NOx emission (t NO_2)**					
	Fuel oil	LPG	Coke oven gas	Blast furnace gas	Refinery gas	"City gas"
Albania	2 800					
Bulgaria	15 100	200	500	1 700		
Czechoslovakia	24 200	300	8 600	7 500	1 400	
GDR	45 000	600	900	2 900	2 700	8 600
Hungary	5 500	700	800	2 200	600	
Poland	12 200	400	13 700	9 600	1 200	6 000
Romania		600	3 100	7 000	5 200	
USSR (Europe)	167 500	21 700	75 600	100 600	68 900	
Yugoslavia	30 000	600	2 500	2 400	1 700	
Total	302 300	25 100	105 700	133 900	81 700	14 600

*Total consumption of various gases in Albania was 16 500 TJ and the NOx emission of 820 t, assuming an emission factor of 50 g NO_2/GJ.

Major industrial processes resulting in NOx emissions are within the production of coke, cement, and iron and steel. It is important to take into account the technology of iron and steel production, as seen from Table 8, where the NOx emission factors are presented. These factors were then used to calculate the NOx emissions, presented in Table 9.

Table 8: NOx emission factors for fossil fuel combustion in industrial processes.

Process	Unit	Emission factor
1. Coke production	kg NO_2/t coal charged	0.015
2. Cement production	kg NO_2/t cement	1.3
3. Iron and steel manufacturing	kg NO_2/t steel	
- electric arc furnace		0.100
- open heart furnace		0.005

Table 9: NOx emissions from industrial processes in Eastern Europe in 1982.

Country	Iron and steel manufacturing				Coke production		Gas works	Cement production	
	Electric arc furnace		Open hearth furnace						
	Production (10^3 t)	NOx emission (t)	Production (10^3 t)	NOx emission (t)	Coal consumption (10^3 t)	NOx emission (t)	NOx emission (t)	Production (10^3 t)	NOx emission (t)
Albania					15	v.l.		1 088	1 400
Bulgaria	871	90	293	v.l.	1 274	20		5 614	7 300
Czechoslovakia	2 998	300	5 997	30	10 606	160	10 970	10 325	13 420
GDR	2 244	220	3 785	20	1 226	20	24 000	11 721	15 240
Hungary	437	40	1 988	10	947	10	1 600	4 369	5 680
Poland	2 175	220	6 317	30	17 728	270	1 600	16 035	20 850
Romania	2 702	270	3 969	20	3 513	50		13 931	18 110
USSR (Europe)	16 481	1 650	83 877	420	86 000	1 290	2 400	123 681	160 790
Yugoslavia	1 044	100	1 306	10	3 440	50	440	9 315	12 110
Total	28 952	2 890	107 532	540	124 749	1 870	41 010	196 079	254 900

v.l. = very low

The NOx emissions from stationary sources considered in this work are summarized in Table 10. The production of electricity is by far the major stationary source of NOx emissions in Eastern Europe, followed by coal combustion for heating.

Larssen (1989) calculated the NOx emission factors for mobile sources with special emphasis on the following source categories: 1) road traffic, 2) rail traffic, 3) internal navigation and 4) agriculture. Emission factors were given separately for passenger cars, light duty trucks, heavy duty trucks, buses, motorcycles and mopeds. These factors are shown in Table 11. In addition, the following factors were used: 20 kg NO_2/t fuel for passenger and freight trains, 70 kg NO_2/t fuel for internal navigation, and 50 kg NO_2/t fuel for agriculture.

Table 10: NOx emissions from stationary sources in Eastern Europe in 1982 (in 10^3 t NO_2).

Country	Production of electricity	Industrial processes	Coal combustion for heating	Oil and gas combustion in industrial and residential boilers	Total
Albania	0.9	1.4		3.6	5.9
Bulgaria	78.2	7.4	28.2	17.5	131.3
Czechoslovakia	171.6	24.9	114.3	42.0	352.8
GDR	269.4	39.4	313.0	60.7	682.5
Hungary	40.5	7.4	71.7	9.8	129.4
Poland	444.2	23.0	481.2	42.3	990.7
Romania	88.7	18.4	304.0	15.9	427.0
USSR (Europe)	2 967.6	166.6	1 378.0	434.3	4 946.5
Yugoslavia	91.7	12.7	60.3	37.2	201.9
Totalt	4 152.8	301.2	2 750.7	663.3	7 868.0

Table 11: NOx emission factors for road vehicles (after Larssen, 1989) (in g/kg).

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)					
Diesl trucks	50	55	60 (average)		
Buses	50	60	70 (average)		
Gasoline trucks	20 (gross average)				
Motorcycles and mopeds, gasoline	5.5 (gross average)				

*GVW = Gross Vehicle Weight.

The NOx factors were then used to calculate NOx emissions, presented in Table 12.

Table 12: NOx emissions from combustion of gasoline and diesel oil in mobile sources in Eastern Europe in 1982 (in 10^3 t NO_2).

Country	Road traffic		Rail traffic	Internal navigation	Agriculture	Total
	Gasoline	Diesel				
Albania	9.2	4.6			8.3*	22.1
Bulgaria	66.0	50.0	4.0	2.0	25.0	147.0
Czechoslovakia	60.4	81.9	19.1	3.4	39.3	204.1
GDR	82.6	43.0	14.0	2.0	33.0	174.6
Hungary	35.9	50.0	6.6	7.8	38.8	139.1
Poland	99.0	108.8	9.8	1.8	66.0	285.4
Romania	96.0	110.5	21.1	2.5	80.7	310.8
USSR (Europe)	1 767.0	350.3	106.7**	-	738.5	3 022.5
Yugoslavia	84.7	97.1	5.7	3.8	47.2	238.5
Totalt	2 300.8	896.2	247.0	23.3	1 076.8	4 544.1

* Includes emissions of NOx from agricultural tractors, rail and navigation in Albania.

** Includes emissions of NOx from rail traffic and internal navigation in the European USSR.

The total NOx emissions from anthropogenic sources in Eastern Europe in 1982 are summarized in Table 13. Stationary sources contributed about 63% of NOx emissions, which is quite different from Western Europe, where 60% of NOx is produced by mobile sources (Pacyna et al., 1989).

Table 13: NOx emissions from stationary and mobile sources in Eastern Europe in 1982 (in 10^3 t NO_2).

Country	Stationary sources	Mobile sources	Total
Albania	5.9	22.1	28.0
Bulgaria	131.3	147.0	278.3
Czechoslovakia	352.8	204.1	556.9
GDR	682.5	174.6	857.1
Hungary	129.4	139.1	268.5
Poland	990.7	285.4	1 276.1
Romania	427.0	310.8	737.8
USSR (Europe)	4.946.5	3 022.5	7 969.0
Yugoslavia	201.9	238.5	440.4
Total	7 868.0	4 544.1	12 412.1

The total NOx emissions were then spatially distributed within the EMEP grid, and the results are presented in Figure 2. The spatial distribution for 1982 has been assumed to be the same as the one estimated for 1985 (Pacyna et al, 1989).

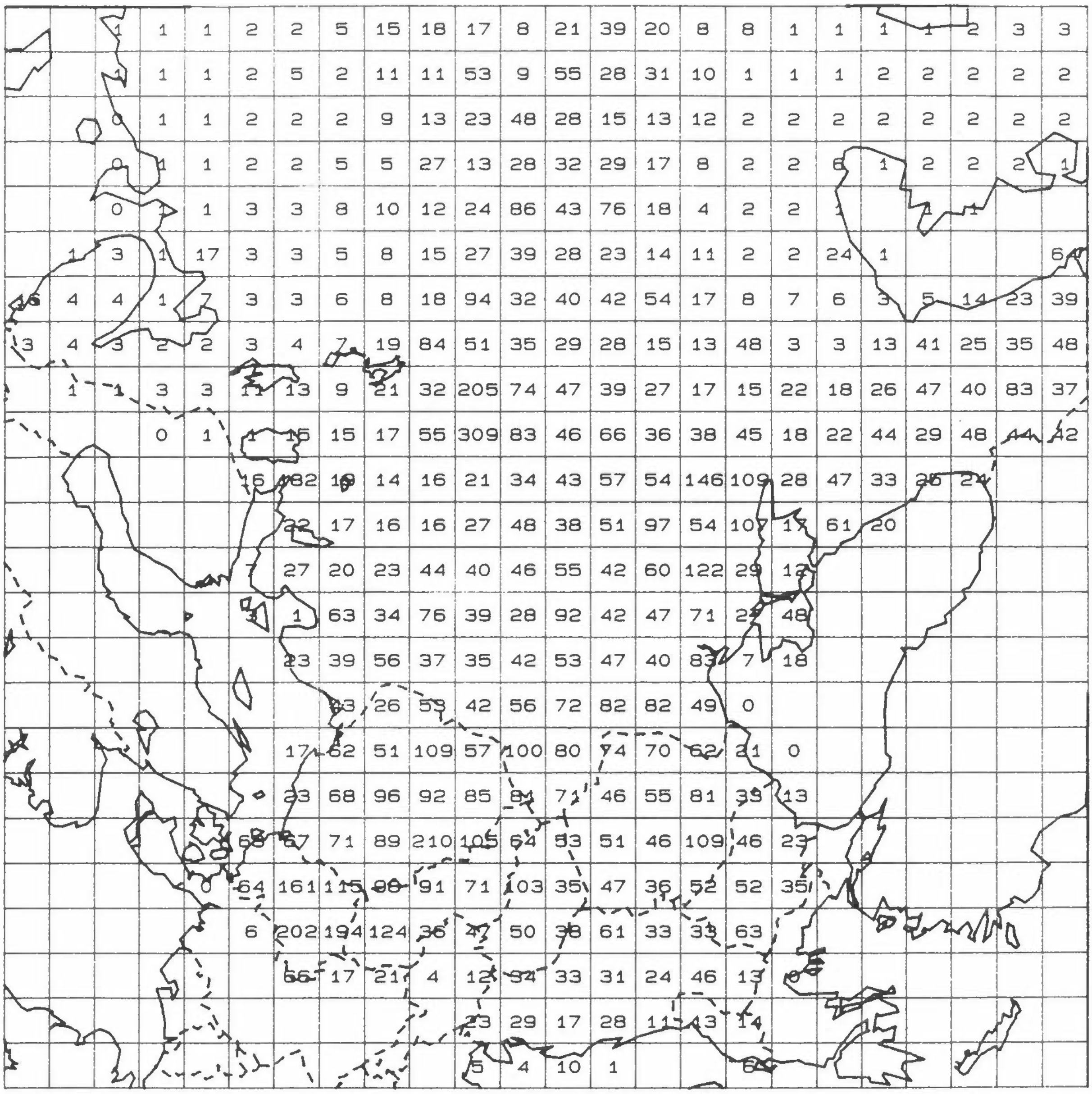

Figure 2: Spatial distribution of NOx emissions in Eastern Europe in 1982 within the EMEP grid of 150 x 150 km.
The unit used: 10^3 t.

4 EMISSIONS OF VOCs

There is only very limited information available on the VOC emissions from Eastern Europe. Most work on inventorying VOC emissions has been done in Western Europe, particularly within the OECD project on Control of Major Air Pollutants (MAP) (e.g. OECD, 1983; Lübkert and Tilly, 1987), and 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 EEC carries out the CORINAIR project (e.g. Bouscaren et al., 1986) with the aim to set up a uniformly structured community-wide gridded emission survey including VOC.

Extensive work has been carried out in USA and Canada (e.g. U.S. EPA, 1988) to prepare VOC emission inventories. The US survey provides information on the acid precursor emissions from more than 130 000 individual point sources and for more than 100 area source categories in each of the 3 100 US counties.

Four major source categories were taken into account here: 1) combustion processes in stationary sources, 2) non-combustion processes in industry, 3) solvent use, and 4) mobile sources.

The Western European, US and Canadian emission surveys were considered when preparing a set of emission factors for this work. Differences in the fuel type, combustion conditions, solvent types, etc. between Eastern and Western Europe were taken into account.

The VOC emission factors for combustion processes in electric power plants are presented in Table 14. Solid and liquid fuels generate some amounts of VOC, while the emissions from natural gas combustion are insignificant (Table 15).

Combustion of oil and gas in industrial and residential boilers in Eastern Europe results in VOC emissions twice as high as those owing to the combustion of fossil fuels in electric power plants. Emission factors and emission amounts for oil and gas combustion in industrial and residential boilers are given in Table 16.

Table 14: VOC emission factors for combustion of fuels in electric power plants in Eastern Europe (in g/GJth).

Fuel	Electric utility	Industrial boilers	Commercial and residential boilers
Coal	5	20	50
Oil	6	10	10
Natural gas	0.5	1.5	

Table 15: VOC emissions from fossil-fuel combustion in electric power plants in Eastern Europe in 1982 (in t)*.

Country	Hard coal-fired power plant	Brown coal-fired power plant	Oil-fired power plant	Gas-fired power plant	Total
Albania		v.l.			v.l.
Bulgaria		910	620		1 530
Czechoslovakia	660	2 200	380	10	3 250
GDR		4 730			4 730
Hungary	50	380	230	10	670
Poland	5 060	960			6 020
Romania		990	620	60	1 670
USSR (Europe)	17 190	4 730	29 300	920	52 140
Yugoslavia		1 810			1 810
Total	22 960	16 710	31 150	1 000	71 820

* Data on production of electricity are given in Table 3.
v.l. = very low.

Table 16: VOC emissions from combustion of oil and gas in industrial and residential boilers in Eastern Europe in 1982 (in t)[1].

Country	Fuel-oil boilers[2]	Gas boilers[3]	Total
Albania	230		230
Bulgaria	1 270	830	2 100
Czechoslovakia	2 030	5 900	7 930
GDR	3 770	8 360	12 130
Hungary	460	1 700	2 160
Poland	1 020	12 210	13 230
Romania		5 380	5 380
USSR (Europe)	14 040	96 690	110 730
Yugoslavia	2 510	2 630	5 140
Total	25 330	133 700	159 030

1 Statistical data are given in Table 7.
2 An emission factor of 10 g/GJ was used, and the heat value of oil was assumed to be 41.9 GJ/t.
3 An emission factor of 40 g/GJ was used for all gases specified in Table 7.

Even higher VOC emissions were calculated for combustion of paraffin and wood in commercial and residential boilers in Eastern Europe in 1982. They are presented in Table 17.

Table 17: VOC emissions from combustion of paraffin and wood in commercial and residential boilers in Eastern Europe in 1982 (in t).

Country	Paraffin[1]		Wood[2]		Total VOC emission
	Consumption (TJ)	VOC emission	Consumption (TJ)	VOC emission	
Albania	3 416	200	16 240	1 620	1 820
Bulgaria	9 394	560	17 545	1 750	2 310
Czechoslovakia	14 603	880	17 790	1 780	2 660
GDR	683	40	7 556	760	800
Hungary	9 138	550	29 182	2 920	3 470
Poland	9 607	580	27 030	2 700	3 280
Romania	38 430	2 310	46 110	4 610	6 920
USSR (Europe	1 436 855	86 210	841 413	84 140	170 350
Yugoslavia	4 099	160	39 960	4 000	4 160
Total	1 526 225	91 490	1 042 826	104 280	195 770

1 An emission factor of 60 g/GJ was used.
2 An emission factor of 100 g/GJ was used, and the wood density was assumed 546 kg/m^3 and heat value 18.5 GJ/t.

The largest amounts of VOCs from combustion processes in Eastern Europe were calculated for the production of heat from coal combustion, as shown in Table 18.

Three major industries are considered as sources of VOC: 1) petroleum industry, 2) petrochemical and chemical industry, and 3) iron and steel manufacturing. In addition, gasoline marketing is also considered. The emission factors, statistical data and emission quantities for the above sources are presented in Table 19. Gasoline marketing and petroleum industry emit the largest amounts of VOCs when compared with other industries.

Table 18: VOC emissions from coal combustion to produce heat in Eastern Europe in 1982[1].

Country	Production of heat (10^6 GJ)	VOC emission (in t)
Albania	n.d.	-
Bulgaria	57	5 700
Czechoslovakia	447	44 700
GDR	653	65 300
Hungary	220	22 000
Poland	806	80 600
Romania	677	67 700
USSR (Europe)	5 130	513 000
Yugoslavia	153	15 300
Total	**8 143**	**814 300**

n.d. = no data available.
1 An emission factor of 100 g/GJ was used.

Table 19: VOC emissions from industrial processes and gasoline marketing in Eastern Europe in 1982.

	Petroleum industry				Petrochemical and chemical industry				Iron and sintering[5]	
	Process emissions[1]		Storage products[2]		Ethene[3]		Polypropylene[4]			
Country	Production (10^3 t)	Emission (t)	Storage (10^3 t)	Emission (t)	Production (10^3 t)	Emission (t)	Production (10^3 t)	Emission (t)	Production (10^3 t)	Emission (t)
Albania	3 500	1 400	2 655	530	n.d.		n.d.		n.d.	
Bulgaria	12 800	5 120	12 070	2 410	200	400	121	730	n.d.	
Czechoslovakia	16 908	6 760	14 820	2 960	533	1 070	246	1 480	n.d.	
GDR	21 802	8 720	20 314	4 060	n.d.		n.d.		n.d.	
Hungary	8 681	3 470	8 880	1 780	256	510	133	800	n.d.	
Poland	13 464	5 390	11 857	2 370	175	350	117	700	8 523	850
Romania	22 666	9 070	23 882	4 780	288	580	196	1 180	n.d.	
USSR (Europe)	500 351	200 140	450 700	90 140	2 132	4 260	981	5 890	n.d.	
Yugoslavia	12 830	5 130	13 990	2 800	168	340	71	430	n.d.	
Total	613 002	245 200	559 168	111 830	3 752	7 510	1 865	11 210	8 523	850

	Steel manufacturing				Gasoline marketing				Total VOC emission t
	Coke oven[6]		Foundry emission[7]		Storage, transfer[8]		Refueling of cars[9]		
Country	Production (10^3 t)	Emission (t)	Production (10^3 t)	Emission (t)	Storage (10^3 t)	Emission (t)	Handling (10^3 t)	Emission (t)	
Albania	15	10	n.d.		250	430	250	700	3 070
Bulgaria	1 274	700	4	10	1 800	3 060	1 800	5 040	17 470
Czechoslovakia	10 606	5 830	456	1 320	1 706	2 900	1 706	4 780	27 100
GDR	1 266	700	401	1 160	3 156	5 370	3 156	8 840	28 850
Hungary	947	520	116	340	1 252	2 130	1 252	3 510	13 060
Poland	17 728	9 750	802	2 330	2 974	5 060	2 974	8 330	35 130
Romania	3 513	1 930	656	1 900	2 725	4 630	2 725	7 630	31 700
USSR (Europe)	86 000	47 300	n.d.		68 500	116 450	68 500	191 800	655 980
Yugoslavia	3 440	1 890	248	720	2 426	4 120	2 426	6 790	22 220
Total	124 789	68 630	2683	7 780	84 789	144 150	84 789	237 420	834 580

n.d. = no data available.
1 Emission factor of 0.4 kg/t crude includes refining operation, storage and handling.
2 Emission factor of 0.2 kg/t product assumed as for conical roofs.
3 Emission factor of 2 kg/t product.
4 Emission factor of 6 kg/t product.
5 Emission factor of 0.1 kg/t sinter.
6 Emission factor of 0.55 kg/t coke.
7 Emission factor of 2.9 kg/t metal.
8 Emission factor of 1.7 kg/t gasoline stored.
9 Emission factor of 2.8 kg/t gasoline handled.

According to the data from OECD (1987), solvent usage operations contribute approximately 40% of all anthropogenic VOC emissions in OECD-Europe. It is thus important to identify the types of processes which utilize solvents and emission factors which are applicable to these processes. There are two major categories of solvent use operations: industrial solvent use and non-industrial solvent use.

The first category includes many industrial operations in which solvents are used, the major ones being: 1) metal surface coating, 2) degreasing, 3) printing and fabric coating and 4) flatwood paneling. According to the information reported from the FRG and Swedish authorities to OECD (1987), the total amount of solvents used in the industry is evaporated.

It is difficult to estimate the emission factors for VOC from non-industrial solvent use. According to OECD (1987) the following factors can be assumed: 0.25 kg capita/year for dry cleaning, 2.6 for domestic painting and 3.8 for other domestic use. This gives a total emission factor of 6.65 kg/capita/year.

The VOC emission estimates for the solvent use in Eastern Europe in 1982 are given in Table 20.

Mobile sources seem to produce the largest amounts of VOC in Europe. Most of the information has been collected during various OECD-programmes (e.g. OECD, 1983). In addition, some data are available from the Norwegian authorities (SFT, 1987). The above data bases were used to select the VOC emission factors which can be applied to calculate the VOC emissions from mobile sources in Eastern Europe. The selected factors are shown in Table 21. The estimates of the VOC emissions from gasoline-, and diesel-powered engines in Eastern Europe in 1982 are presented in Tables 22 and 23, respectively. No differentiation has been made between the VOC emission factors for two-stroke and four-stroke engines due to a lack of relevant information.

Table 20: VOC emissions from the use of solvents in Eastern Europe in 1982 (in t).

Country	Population 10^6 persons	Non-idustrial use[1]	Industrial use[2]	Total VOC emission
Albania	3.0	9 900	4 950	14 580
Bulgaria	9.2	30 400	15 200	45 600
Czechoslovakia	15.6	51 480	25 740	77 220
GDR	16.7	55 110	27 560	82 670
Hungary	10.8	35 640	17 820	53 460
Poland	37.1	122 430	61 220	183 650
Romania	24.3	80 190	40 100	120 290
USSR (Europe)	190.3	627 990	314 000	941 990
Yugoslavia	23.0	75 900	37 950	113 850
Total	330.0	1 089 040	544 540	1 633 580

1 An emission factor for non-industrial use of solvents in the OECD countries is 6.65 kg/capita/year (OECD, 1987). The solvent production per capita in the OECD countries is ca. twice as high as in the Eastern European countries. Thus, it was assumed that a factor of 3.3 kg/capita/year can be used in this work.

2 Based on the solvent production it was assumed that the industrial use of solvent is only a half of the non-industrial use.

Table 21: VOC emission factors for mobile sources in Eastern Europe (in kg/t fuel used unless indicated).

Source	Emission factor
1) Road traffic	
a) automobiles	
- gasoline-powered	37.0
- diesel-oil-powered	11.0
b) heavy-duty vehicles	
- gasoline-powered	40.0
- diesel-oil-powered	4.5
c) motorcycles	170.0
d) tractors (agriculture)	10.0
2) Inland shipping	5.0
3) Seagoing shipping, harbours	5.0
4) Rail	5.0

Table 22: VOC emissions from gasoline-powered vehicles in Eastern Europe in 1982.

Country	Passenger cars		Heavy-duty vehicles		Motorcycles		Total emission (t)
	Consumption (10^3 t)	Emission (t)	Consumption (10^3 t)	Emission (t)	Consumption (10^3 t)	Emission (t)	
Albania	237[1]	8 770			13	2 210	10 980
Bulgaria	810	29 970	900	36 000	90	15 300	81 270
Czechoslovakia	1 620	59 940			86	14 620	74 560
GDR	1 678	62 090	1 294	51 760	184	31 280	145 130
Hungary	1 060	39 220	125	5 000	67	11 390	55 610
Poland	1 606	59 420	1 130	45 200	238	40 460	145 080
Romania	2 589[1]	95 790			136	23 120	118 910
USSR (Europe)	14 385	532 250	50 690	2 027 600	3 425	582 250	3 142 100
Yugoslavia	2 086	77 180	218	8 720	122	20 740	106 640
Total	26 071	964 630	54 357	2 174 280	4 301	741 370	3 880 280

1 Including consumption of gasoline by Heavy-duty-trucks.

Table 23: VOC emissions from diesel-powered engines in Eastern Europe in 1982.

Country	Passenger cars		Heavy duty vehicles		Rail		Shipping		Agriculture		Total VOC emission (t)
	Consumption (10^3 t)	Emission (t)	Consumption (10^3 t)	Emission (t)	Consumption (10^3 t)	Emission (t)	Consumption (10^3 t)	Emission (t)	Consumption (10^3 t)	Emission (t)	
Albania	13	140	96	430					130[1]	1 300	1 870
Bulgaria	50	550	983	4 420	217	1 090	30	150	500	5 000	11 210
Czechoslovakia	100	1 100	1 617	7 280	962	4 810	52	260	784	7 840	21 290
GDR	0	0	858	3 850	705	3 530	22	110	650	6 500	13 990
Hungary	71	780	988	4 450	311	1 560	105	530	780	7 800	15 120
Poland	186	2 050	2 010	9 060	486	2 430	28	140	1 314	13 140	26 820
Romania	135	1 490	2 233	10 050	1 058	5 290	38	190	1 612	16 120	33 140
USSR (Europe)	2 491	27 400	6 042	27 190	6 678[2]	33 390			14 840	148 400	236 380
Yugoslavia	155	1 710	1 952	8 780	295	1 480	47	240	940	9 400	21 610
Total	3 201	35 220	16 779	75 510	10 712	53 580	322	1 620	21 550	215 500	381 430

1 Including rail + agriculture + shipping.
2 Including rail + shipping.

Table 24 summarizes the estimates of VOC emissions from anthropogenic sources in Eastern Europe. In 1982, the emissions from mobile sources contributed about 53% to the total VOC emissions, followed by the emissions during solvent use - 20%.

Table 24: VOC emissions from anthropogenic sources in Eastern Europe in 1982 (in t).

Country	Stationary combustion	Industrial processes	Sovent use	Mobile sources	Total
Albania	2 050	3 070	14 850	12 850	32 820
Bulgaria	11 640	17 470	45 600	92 480	167 190
Czechoslovakia	58 540	27 100	77 220	95 850	258 710
GDR	82 960	28 850	82 670	159 120	353 600
Hungary	28 300	13 060	53 460	70 730	165 550
Poland	103 130	35 130	183 650	171 900	493 810
Romania	81 670	31 700	120 290	152 050	385 710
USSR (Europe)	846 220	655 980	941 990	3 378 480	5 822 670
Yugoslavia	26 410	22 220	113 850	128 850	290 730
Total	1 240 920	834 580	1 633 580	4 261 710	7 970 790

The total VOC emissions from anthropogenic sources in Eastern Europe were then spatially distributed within the EMEP grid of 150 km x 150 km (Figure 3). As more than 73% of the total emissions were calculated for mobile sources and solvent use, population data were applied to obtain the spatial distribution. This assumption inevitably results in some inaccuracies in the spatial distribution of the VOC emissions. However, it is believed that these inaccuracies are not significant.

The EURAD model requires chemical speciation of VOCs. The following groups and species are considered in this work: 1) alkanes, including ethane, propane, and buthane, 2) alkenes, including ethene and propene, 3) aromatics, including toluene, benzene and xylene, 4) formaldehyde, and 5) higher aldehydes and ketones. The VOC profiles for emissions from various anthropogenic sources were obtained on the basis of literature reviews by Veldt et al. (1988) and CONCAWE (1986) and were discussed with the experts from Eastern Europe. The final version of the profiles is presented in Table 25. The VOC species in Table 25 are the major species for a given source category. However, for many source categories there are also species which are not indicated in Table 25. Thus, for these categories, a sum of percentage contributions (horisontal lines) is below 100%, e.g. 80% for stationary coal combustion.

Table 25: VOC profiles for emissions from various sources[1] (in %).

Source	Alkanes[2]	Alkenes[3]	Aromatics[4]	Formaldehyde	Ketones & higher aldehydes
1. Stationary combustion					
a) coal	36	24	20		
b) oil	69	13	6	6	
c) natural gas	48	28		16	
d) paraffin	69	13	6	6	
e) wood	4	32	35	8	
2. Industrial processes					
a) petroleum industry	86.5	6	7.5		
b) ethene & polypropylene production		100			
c) steel & iron production					
- sintering and foundries	9	81			
- coke oven	27	62	11		
d) gasoline marketing	89	7	4		
3. Solvent use	24		20		22
4. Mobile sources					
a) gasoline	13	18	55		
b) diesel-oil	44	2	54		

1 only non-methane hydrocarbons are considered.
2 Include: ethane, propane, buthane.
3 Include: ethene, propene.
4 Include: benzene, toluene and xylene.

Then the emissions of alkanes, alkenes, aromatics, formaldehyde, and higher aldehydes and ketones were calculated on the basis of the VOC profiles in Table 25 and the VOC emissions estimated for anthropogenic sources. These calculations are presented in Tables 26 to 30 for alkanes, alkenes, aromatics, formaldehyde, and ketones and higher aldehydes, respectively. The total emissions of the above species were then spatially distributed within the EMEP grid of 150 km x 150 km using the population data. The spatial distributions of emissions are shown in Figures 4 to 8 for alkanes, alkenes, aromatics, formaldehyde and ketones and higher aldehydes, respectively.

Table 26: Emission of alkanes from anthropogenic sources i Eastern Europe in 1982 (in t).

Country	Stationary combustion					Petroleum industry	Iron & steel production		Gasoline marketing	Solvent use	Mobile sources		Total
	Coal	Oil	Natural gas	Paraffin	Wood		Sintering	Coke oven			Gasoline	Diesel	
Albania	v.l.	160		140	60	1 670		v.l.	1 000	3 560	1 430	820	8 840
Bulgaria	2 380	1 500	400	390	70	6 510		190	7 210	10 940	10 570	4 930	45 090
Czechoslovakia	17 120	1 660	2 840	610	70	8 410		1 930	6 840	18 530	9 690	9 370	77 070
GDR	25 210	2 600	4 010	30	30	11 050		500	12 650	19 840	18 870	6 160	100 950
Hungary	8 070	480	820	380	120	4 540		230	5 020	12 830	7 230	6 650	46 370
Poland	31 180	700	5 860	400	110	6 710	80	3 260	11 920	44 080	18 860	11 800	134 960
Romania	24 730	430	2 610	1 590	180	11 980		1 030	10 910	28 870	15 460	14 580	112 370
USSR (Europe)	192 570	29 900	46 850	59 480	3 370	251 090		12 770	274 340	226 080	408 470	104 010	1 608 930
Yugoslavia	6 160	1 730	1 260	110	160	6 860		700	9 710	27 320	13 860	9 510	77 380
Total	307 420	39 160	64 650	63 130	4 170	308 820	80	20 610	339 600	392 050	504 440	167 830	2 211 960

v.l. = very low.

Table 27: Emission of alkenes from anthropogenic sources in Eastern Europe in 1982 (in t).

Country	Stationary combustion					Petroleum industry	Petrochemical and chemical industry	Iron & steel production		Gasoline marketing	Mobile sources		Total
	Coal	Oil	Natural gas	Paraffin	Wood			Sintering	Coke oven		Gasoline	Diesel	
Albania	v.l.	30		30	520	120			10	80	1 980	40	2 810
Bulgaria	1 590	250	230	70	560	450	1 130		440	570	14 630	220	20 140
Czechoslovakia	11 410	310	1 650	110	570	580	2 550		4 430	540	13 420	430	36 000
GDR	16 810	490	2 340	10	240	770			1 150	990	26 120	280	49 200
Hungary	5 380	90	480	70	930	320	1 310		530	390	10 010	300	19 810
Poland	20 790	130	3 420	80	860	470	1 050	760	7 490	940	26 110	540	62 640
Romania	16 490	80	1 520	300	1 480	830	1 760		2 370	860	21 400	660	47 750
USSR (Europe)	128 380	5 630	27 330	11 210	26 920	17 420	10 150		29 330	21 580	565 580	4 730	848 260
Yugoslavia	4 110	330	740	20	1 280	480	770		1 620	760	19 200	430	29 740
Total	204 960	7 340	37 710	11 900	33 360	21 440	18 720	760	47 370	26 710	698 450	7 630	1 116 350

v.l. = very low.

Table 28: Emission of aromatics from anthropogenic sources in Eastern Europe in 1982 (in t).

Country	Stationary combustion				Petroleum industry	Coke oven emissions	Gasoline marketing	Solvent use	Mobile sources		Total
	Coal	Oil	Paraffin	Wood					Gasoline	Diesel	
Albania	v.l.	10	10	570	140	v.l.	50	2 970	6 040	1 010	10 800
Bulgaria	1 320	110	30	610	560	80	320	9 120	44 700	6 050	62 900
Czechoslovakia	9 510	140	50	620	730	790	310	15 440	41 010	11 500	80 100
GDR	14 010	230	v.l.	270	960	200	570	16 530	79 820	7 550	120 140
Hungary	4 490	40	30	1 020	390	90	230	10 690	30 590	8 160	55 730
Poland	17 320	60	30	950	580	1 330	540	36 730	79 790	14 480	151 810
Romania	13 740	40	140	1 610	1 040	420	490	24 060	65 400	17 900	124 840
USSR (Europe)	106 980	2 600	5 170	29 450	21 780	5 200	12 330	188 400	1 728 160	127 650	2 227 720
Yugoslavia	3 420	150	10	1 400	590	290	440	22 770	58 650	11 670	99 390
Total	170 790	3 380	5 470	36 500	26 770	8 400	15 280	326 710	2 134 160	205 970	2 933 430

v.l. = very low.

Table 29: Emissions of formaldehyde from combustion sources in Eastern Europe in 1982 (in t).

Country	Oil	Natural gas	Paraffin	Wood	Total
Albania	10		10	130	150
Bulgaria	110	130	30	140	310
Czechoslovakia	140	950	50	140	1 280
GDR	230	1 340	v.l.	60	1 630
Hungary	40	270	30	230	570
Poland	60	1 950	30	220	2 260
Romania	40	870	140	370	1 420
USSR (Europe)	2 600	15 620	5 170	6 730	30 120
Yugoslavia	150	420	10	320	900
Total	3 380	21 550	5 470	8 340	38 740

v.l. = very low.

Table 30: Emissions of ketones and higher aldehydes from solvent use in Eastern Europe in 1982 (in t).

Country	Emission
Albania	3 270
Bulgaria	10 030
Czechoslovakia	16 990
GDR	18 190
Hungary	11 760
Poland	40 400
Romania	26 460
USSR (Europe)	207 240
Yugoslavia	25 050
Total	359 390

It is difficult to discuss the importance of natural emissions of VOC compared with the VOC emissions from anthropogenic sources because only limited data exist in the literature. Two sources are considered in this work: the releases of terpens from coniferous trees and the release of isoprene from deciduous forest. The following factors are suggested: 1.6 kg terpens/$km^2 \cdot h$ for coniferous forest and 0.25 kg isoprene/$km^2 \cdot h$ for deciduous forest.

The emission estimates are presented in Table 31.

Table 31: VOC emissions from natural sources in Eastern Europe in 1982.

Country	Forest area, 10^3 ha		Emission, t		Total emission t
	Coniferous	Broad-leaved	Isoprene[1]	Terpens[2]	
Albania	n.d.	n.d.			26 000[3]
Bulgaria	1 200	2 100	45 990	168 190	214 180
Czechoslovakia	2 942	1 636	35 830	412 350	448 180
GDR	2 275	680	14 890	318 860	333 750
Hungary	227	1 410	30 880	31 820	62 700
Poland	6 895	1 759	38 520	966 400	1 004 920
Romania	1 710	4 830	105 780	239 670	345 450
USSR (Europe)	96 000	55 600	1 217 640	13 455 360	14 673 000
Yugoslavia	1 210	7 915	173 340	169 600	342 940
Total	112 459	75 930	1 662 870	15 762 250	17 451 120

n.d = no data.
1 An emission factor of 1.6 kg terpens/km^2 h for conifereous forest
2 An emission factor of 0.25 kg isoprene/km^2 h for broad-leaved forest
3 From Saltbones and Lien (1987).

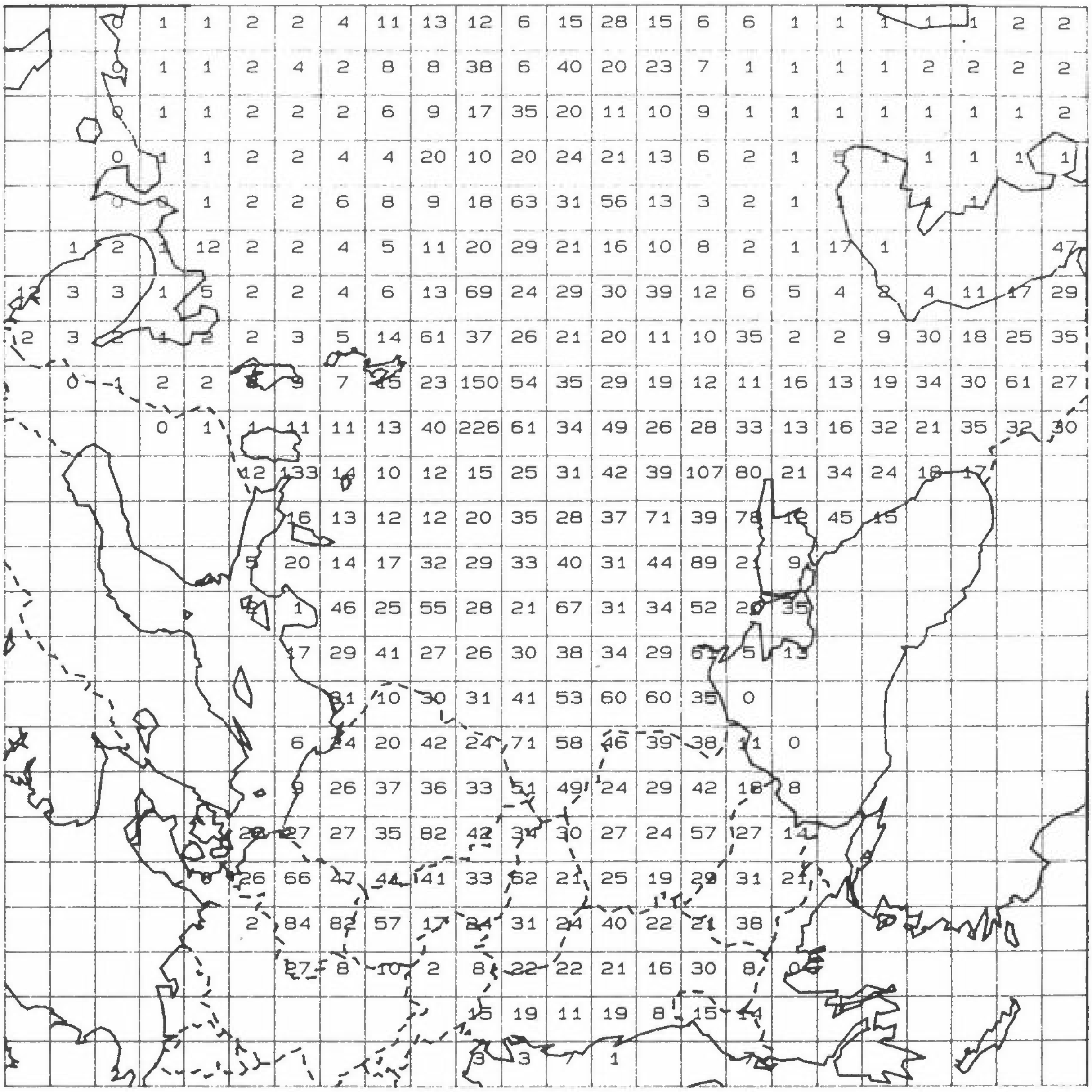

Figure 3: Spatial distribution of VOC emissions in Eastern Europe in 1982 within the EMEP grid of 150 x 150 km.
The unit used: 10^3 t.

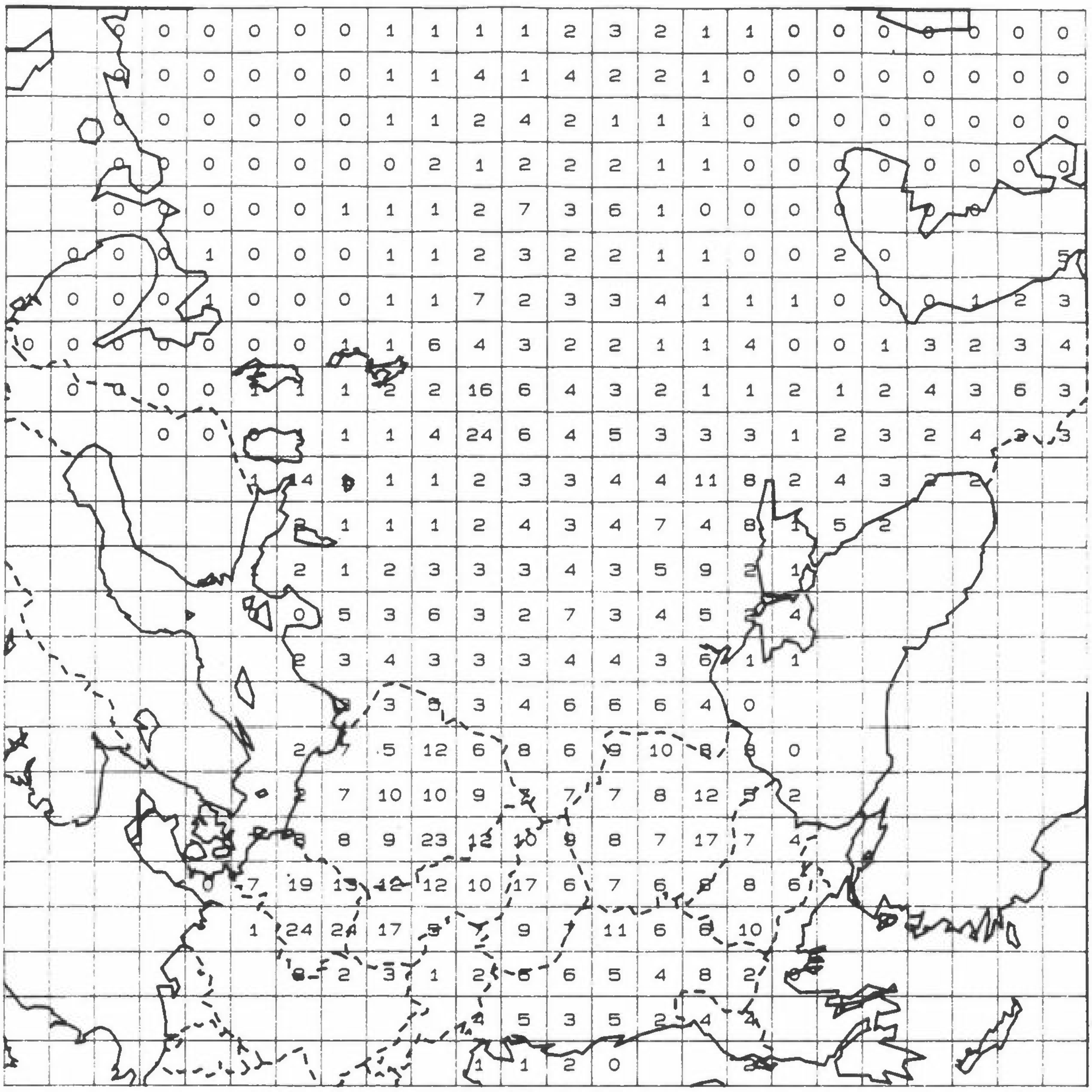

Figure 4: Spatial distribution of alkanes emissions in Eastern Europe in 1982 within the EMEP grid of 150 x 150 km.
The unit used: 10^3 t.

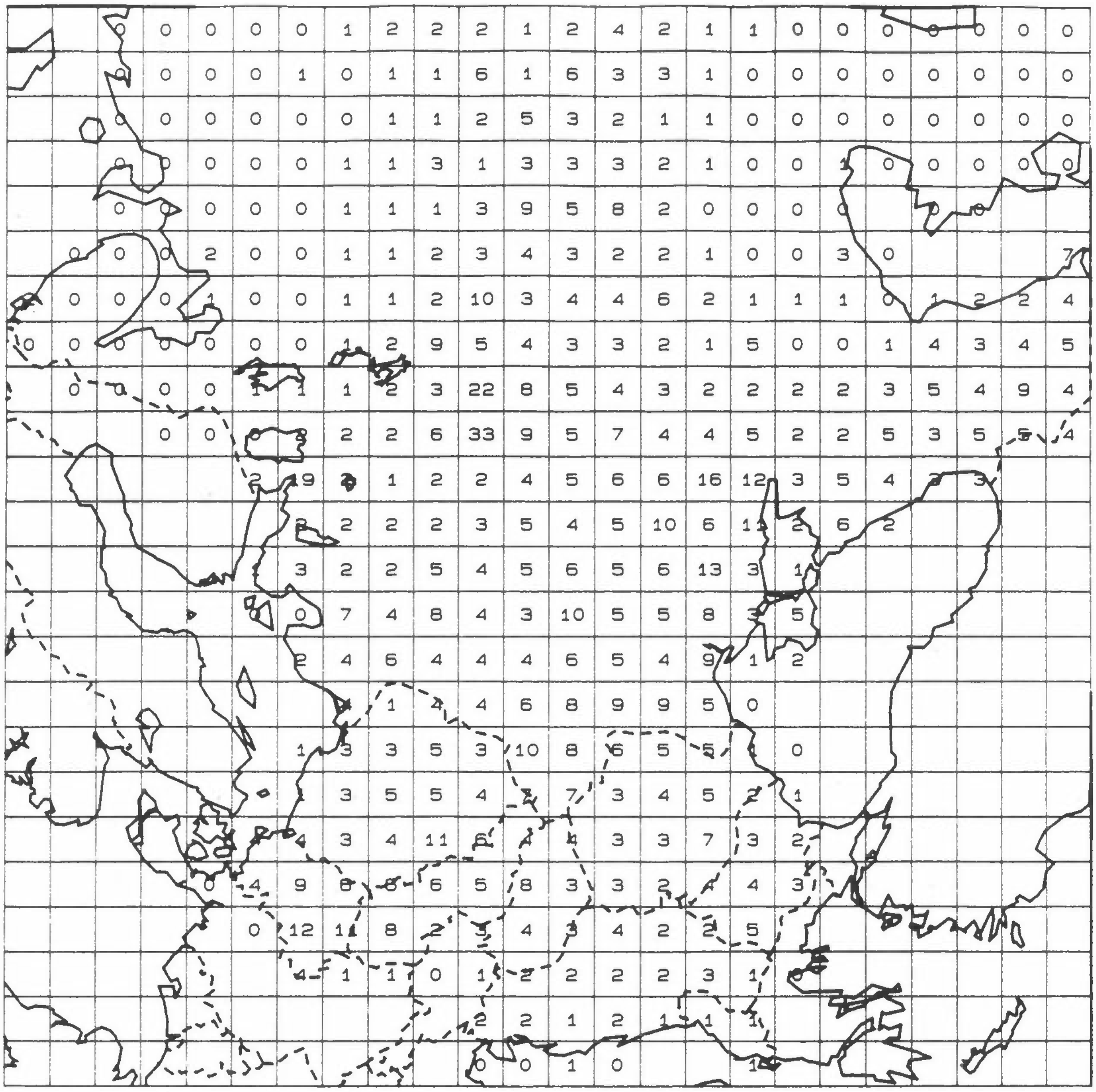

Figure 5: Spatial distribution of alkenes emissions in Eastern Europe in 1982 within the EMEP grid of 150 x 150 km.
The unit used: 10^3 t.

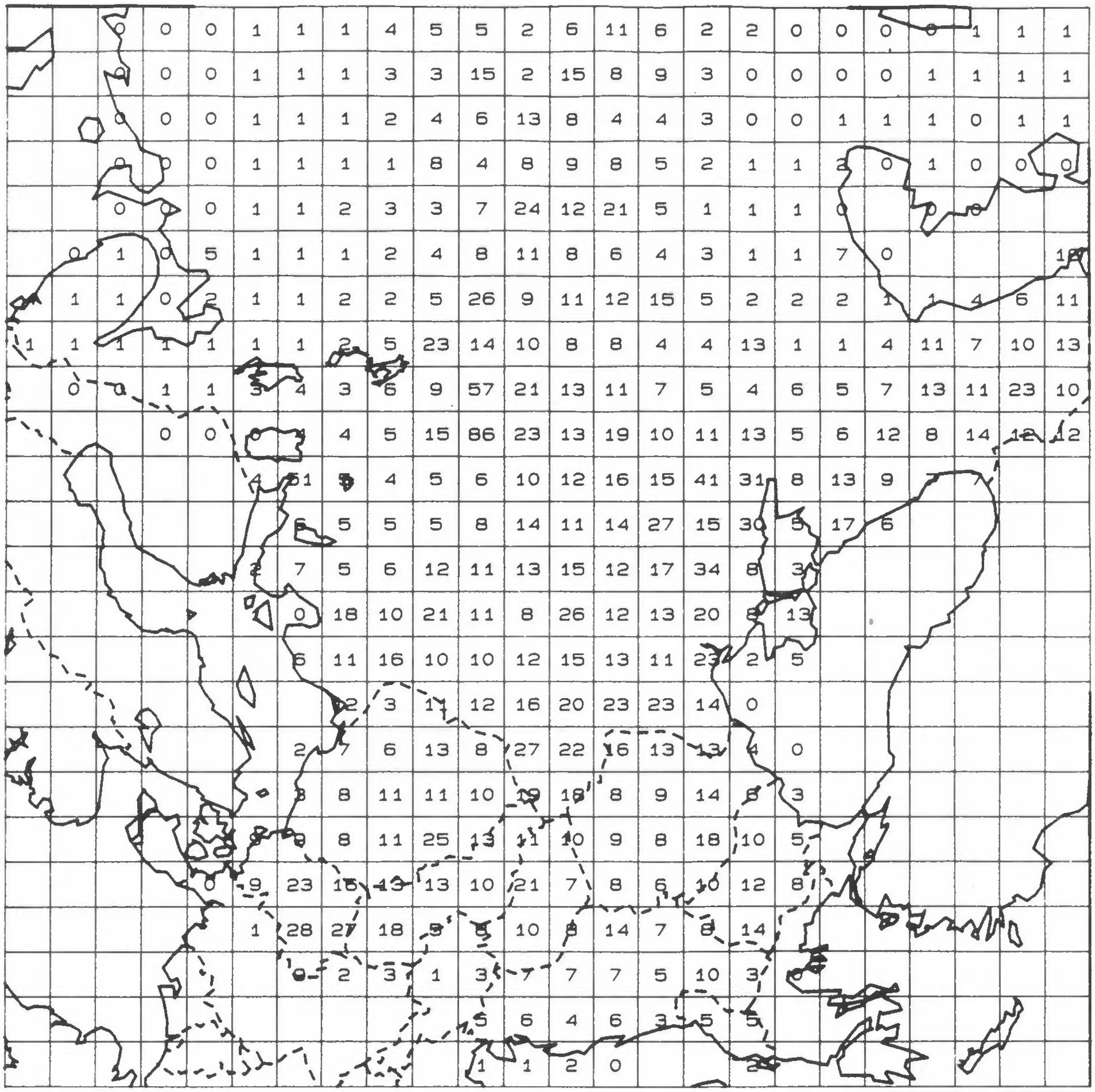

Figure 6: Spatial distribution of aromatics emissions in Eastern Europe in 1982 within the EMEP grid of 150 x 150 km. The unit used: 10^3 t.

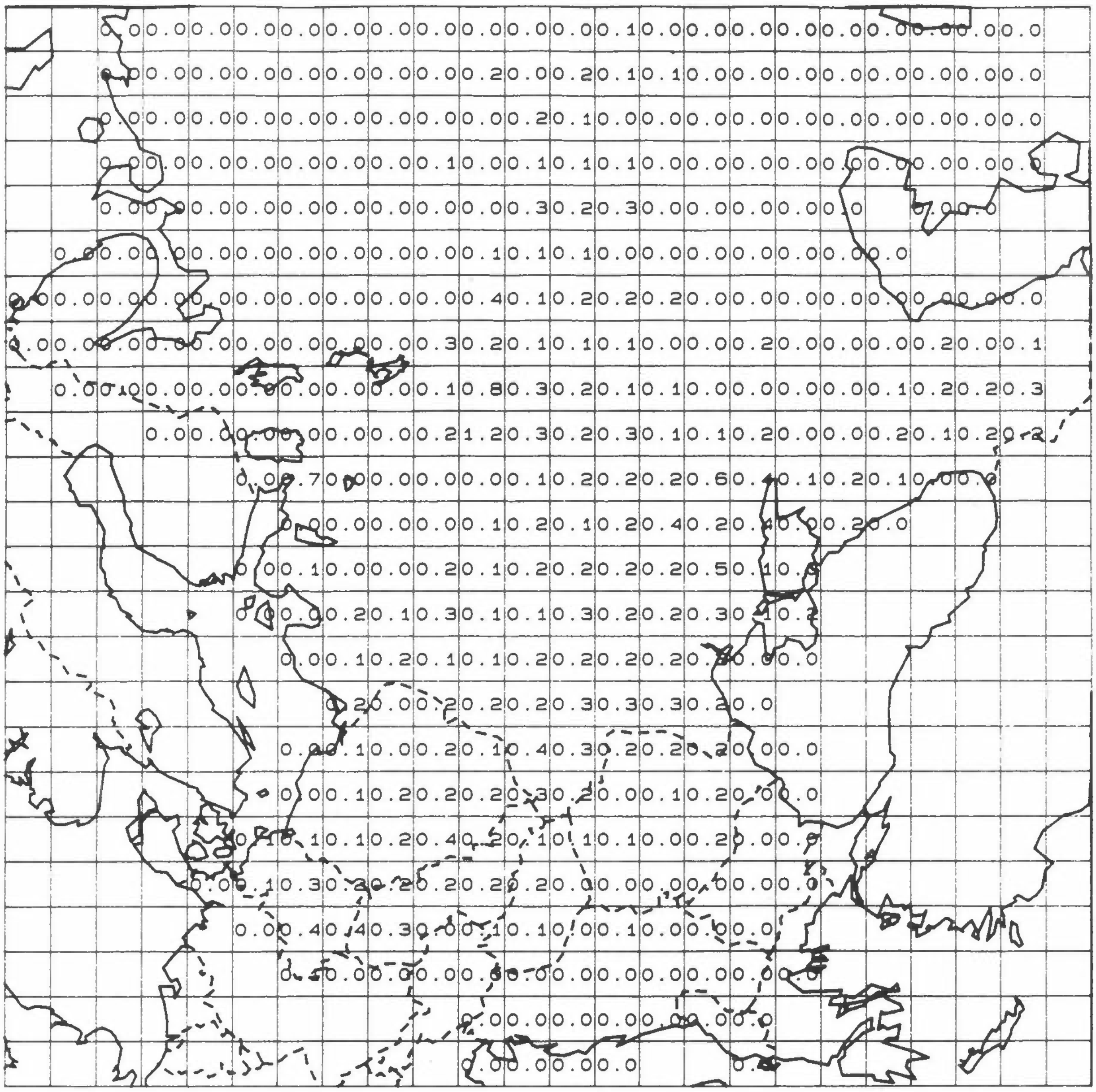

Figure 7: Spatial distribution of formaldehyde emissions in Eastern Europe in 1982 within the EMEP grid of 150 x 150 km. The unit used: 10^3 t.

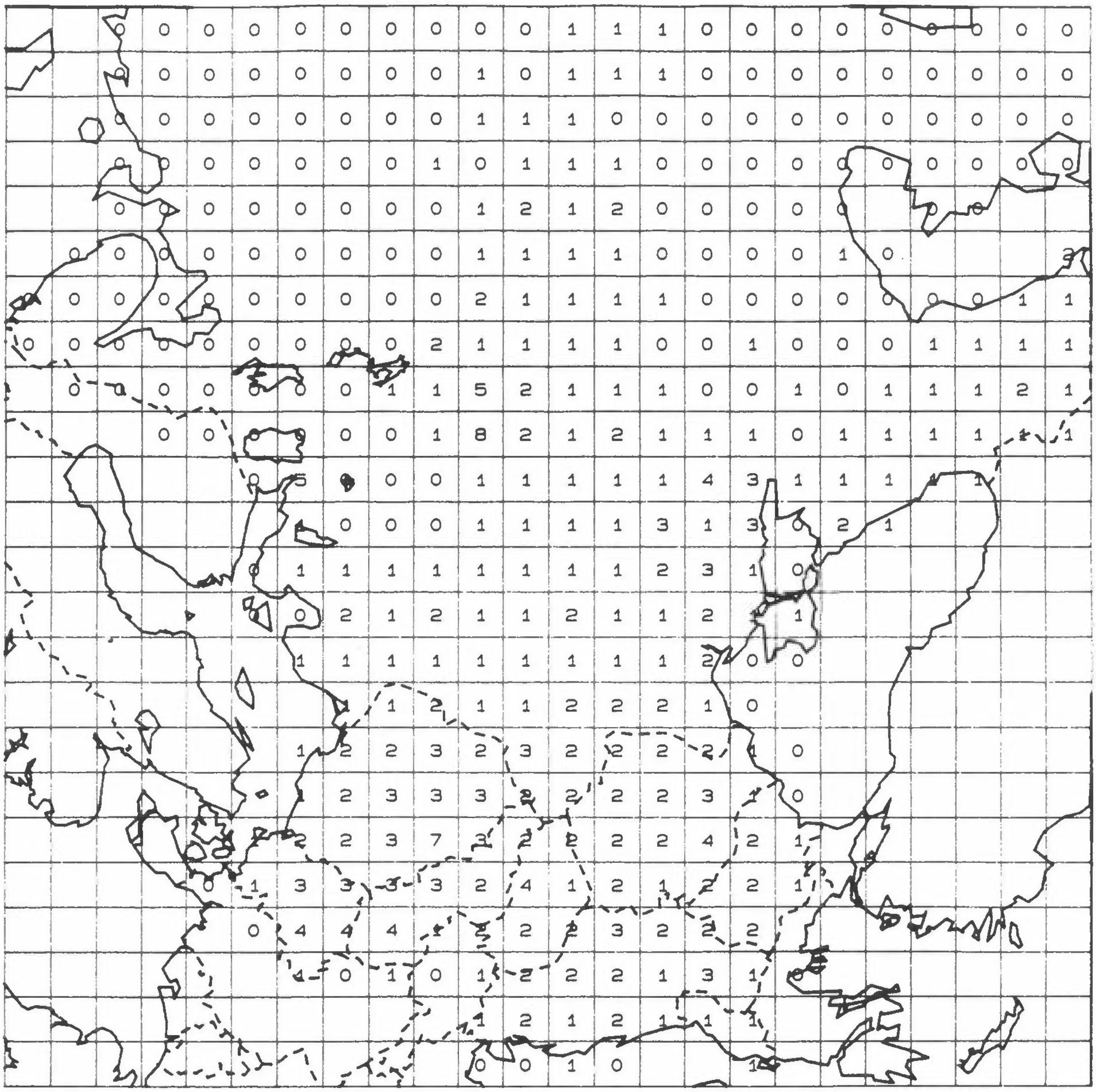

Figure 8: Spatial distribution of ketones and higher aldehydes emissions in Eastern Europe in 1982 within the EMEP grid of 150 x 150 km.
The unit used: 10^3 t.

5 EMISSIONS OF NH_3

There are three major source categories of anthropogenic emissions of NH_3: animal wastes, use of fertilizers, and some industrial activities to produce nitric acid, synthetic ammonia, urea and during chemical wood pulping. The NH_3 emissions from these sources in Europe in the early 1980s were estimated by Buijsman et al. (1987). The authors have also included an extended information on the NH_3 emission factors. The NH_3 emission values calculated by Buijsman et al. (1987) can be used to test the EURAD model. The estimates for Eastern Europe are shown in Table 32. To the author's knowledge there is no other emission survey of NH_3 for Eastern Europe.

Table 32: Anthropogenic emissions of NH_3 from sources in Eastern Europe in the early 1980s[1] (after Buijsman et al (1987)).

Country	Livestock wastes	Fertilizers	Industrial sources[2]	Total
Albania	16	4	1	21
Bulgaria	91	31	4	126
Czechoslovakia	127	39	4	170
GDR	159	42	6	207
Hungary	83	42	4	127
Poland	317	80	7	405
Romania	237	53	11	301
USSR (Europe)	1 046	210		1 256
Yugoslavia	167	29	2	198
Total	2 243	530	39	2 812

1 All data are in 10^3 t NH_3/y.
2 Industrial sources include: ammonia fertilizer and related plants.

According to Buijsman et al. (1987), more than 95% of total anthropogenic emissions of NH_3 are agricultural emissions with the major contribution from animal wastes. The NH_3 emissions from this source were estimated on the basis of livestock statistics and nitrogen production by animals during housing and at grass.

Various parameters were taken into account when estimating the NH_3 emission from fertilizers. They include different emission factors for various kinds of N-fertilizers, soil conditions affecting the NH_3

losses, and drying conditions (temperature, wind speed, humidity). The NH_3 emission factor for Eastern Europe was 5.0% of the N-content consumed in fertilizers.

Fertilizer and NH_3 production plants are the main industrial sources of atmospheric NH_3. Buijsman et al. (1987) used the NH_3 emission factor of 0.8 kg NH_3/t NH_3 produced for NH_3 plants and an average factor of 5.0 kg NH_3/t N-fertilizer produced for fertilizer plants.

The spatial distribution of the NH_3 emissions in Eastern Europe within the EMEP grid of 150 km x 150 km is shown in Figure 9 (after Buijsman et al., 1987).

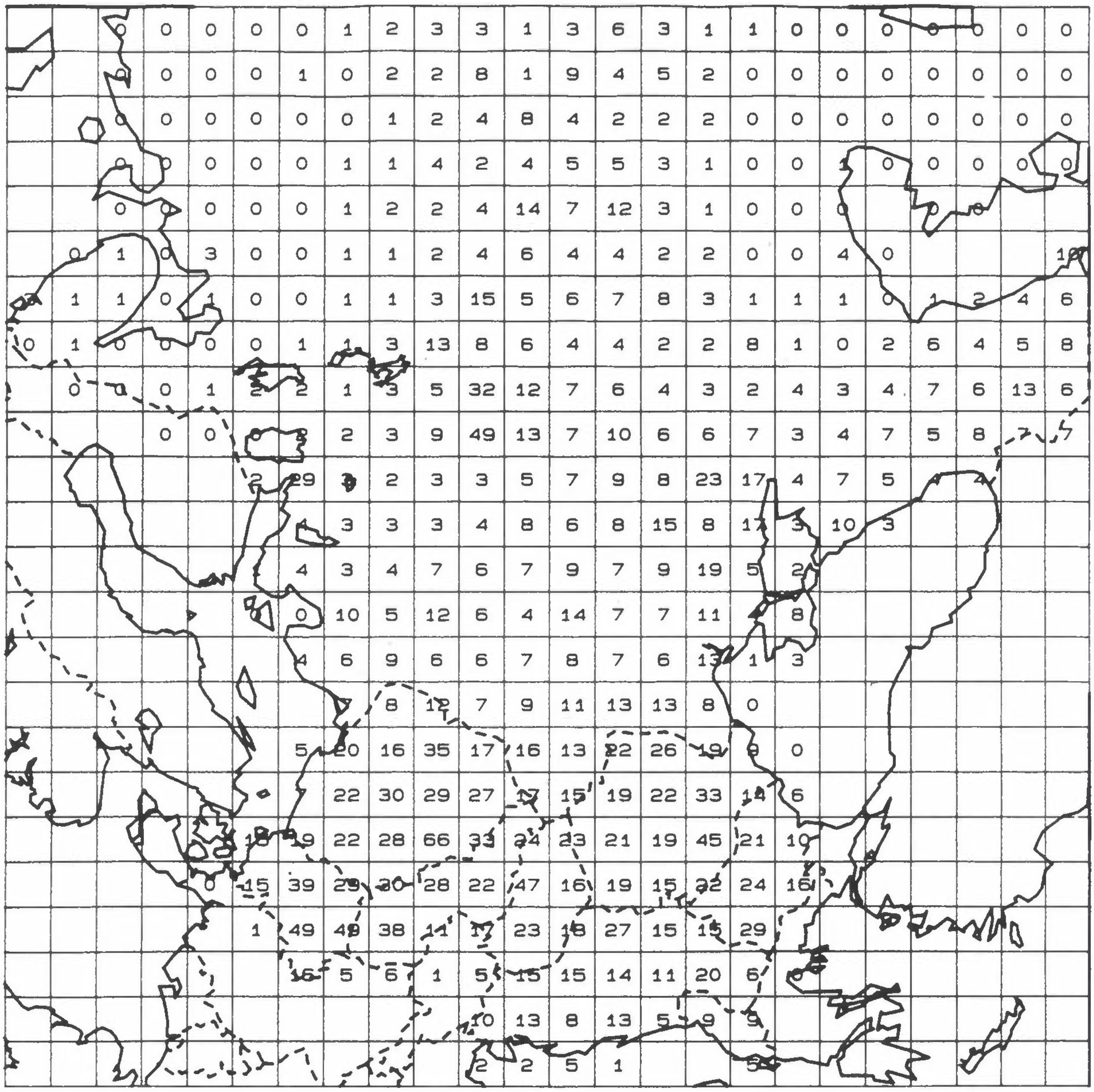

Figure 9: Spatial distribution of NH_3 emissions in Eastern Europe in 1982 within the EMEP grid of 150 x 150 km.
The unit used: 10^3 t.

6 EMISSIONS OF N_2O

The major anthropogenic sources of N_2O include coal combustion and nitrogen fertilizer application. The measurements of the N_2O/CO_2 ratios in stack gases from large oil- and coal-fired power plants were used to calculate the N_2O emission factor by Weiss and Craigh (1976) and Pierotti and Rasmussen (1976). A factor of ca. 1.8 kg N_2O/t can be suggested on the basis of these measurements. It should be mentioned, however, that the N_2O emission factors for oil- and coal combustion have attracted several discussions (e.g. Lyon et al., 1989). It has been suggested that these factors may be lower than reported here. This suggestion stems from the discovery of an artifact in common sampling procedure for N_2O. There is an urgent need for accurate measurements of N_2O emissions from stationary combustion systems.

The emission of N_2O from soil after application of fertilizers is often considered as a natural source. The following N_2O emission factors can be suggested on the basis of the handbook of emission factors from the Dutch Ministry of Health and Environmental Protection (1980):

a) for unfertilized soil: 0.1 g N_2O/ha·h
b) for soil fertilized with artificial fertilizer additioned 0.2 g N_2O/ha·h
c) for soil fertilized with organic fertilizer additioned 0.16 g N_2O/ ha·h
d) for freshly fertilized soil: $0.1+0.2+0.16 \lesseqqgtr 0.5$ g N_2O/ha·h.

The N_2O emissions from coal and oil combustion in electric- and heat-power plants are presented in Table 33. Combustion of fossil fuels seems to emit slightly more N_2O than the application of nitrogen fertilizers.

The total N_2O emissions from Table 33 were then spatially distributed within the EMEP grid of 150 km x 150 km. Since combustion processes emit more N_2O than application of fertilizers, it was assumed here, that the spatial distribution of NOx emissions from stationary sources in Europe presented by Pacyna (1988) can be used as a basis for the spatial distribution of N_2O emissions. The above assumption was necessary due to a lack of information on the spatial distribution of fertilized soils in Eastern Europe. The spatial distribution of N_2O emissions is presented in Figure 10.

Table 33: Emissions of N_2O from major anthropogenic sources in Eastern Europe in 1982 (in t).

Country	Coal and oil combustion in electric- and heat plants[1]		Nitrogen fertilizer application[2]		Total emission
	Coal	Oil	Area, 10^6 ha	Emission	
Albania	510		1.5	6 570	7 080
Bulgaria	36 790	4 240	4.2	18 400	59 430
Czechoslovakia	91 010	2 670	4.2	18 400	112 080
GDR	232 960		3.9	17 080	250 040
Hungary	20 670	1 900	3.9	17 080	39 650
Poland	163 470		12.0	52 560	216 030
Romania	60 790	18 130	8.8	38 540	117 460
USSR (Europe)	563 500	310 690	208.7	914 110	1 788 300
Yugoslavia	51 580		9.1	39 860	91 440
Total	1 221 280	337 630	256.3	1 122 600	2 681 510

1 An emission factor of 1.8 kg N_2O/t was used.
2 An emission factor of 0.5 g N_2O/ha·h was used.

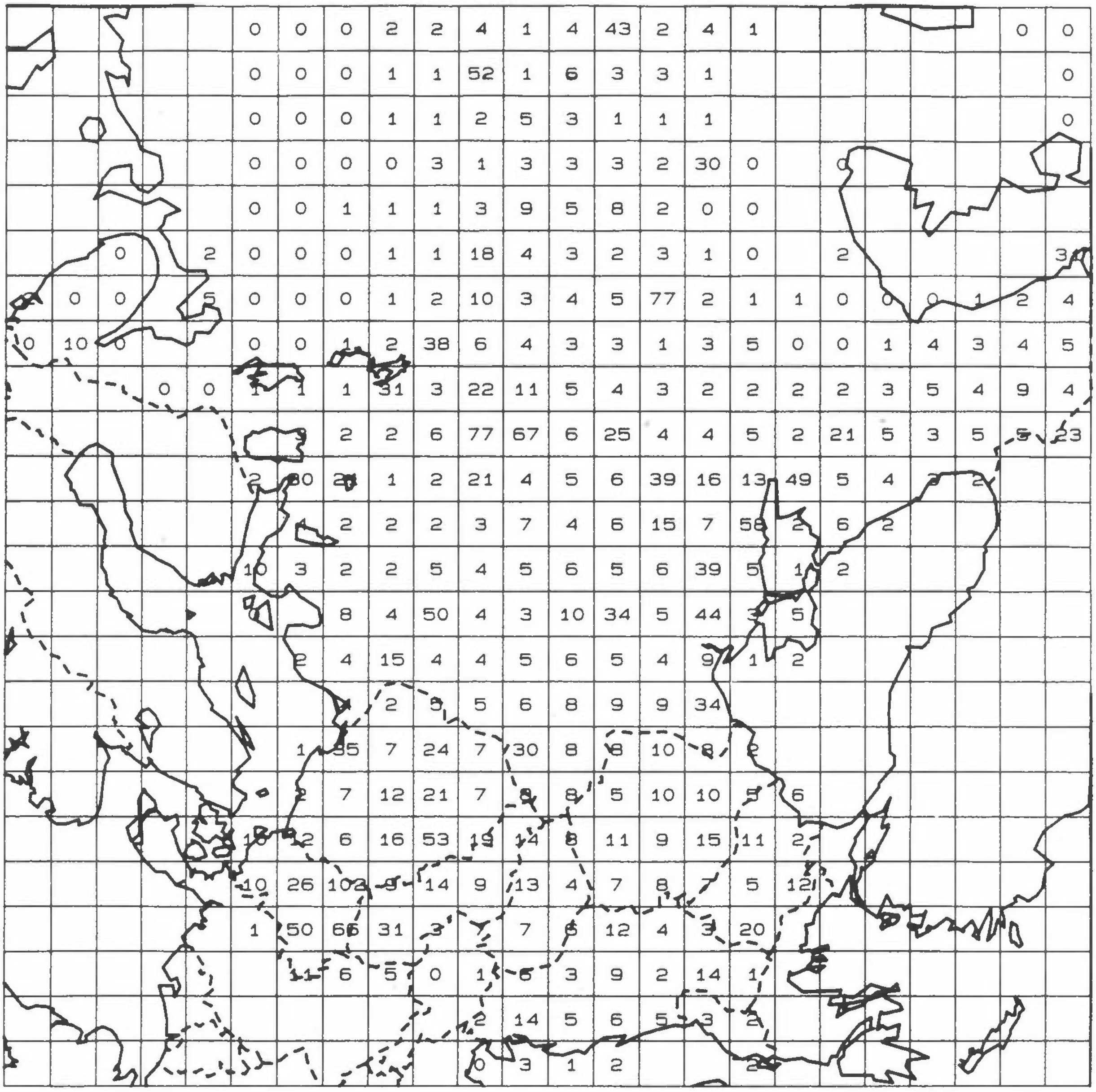

Figure 10: Spatial distribution of N_2O emissions in Eastern Europe in 1982 within the EMEP grid of 150 x 150 km.
The unit used: 10^3 t.

7 EMISSIONS OF CO

CO is a product of incomplete combustion in stationary and mobile sources. It is assumed that complete combustion of fuels takes place in large utility boilers and industrial power plants, resulting in no emission of CO. There is, however, CO emission from smaller industrial and residential boilers. To obtain the information on the CO emissions from these boilers, an extended literature review has been performed using the following data basis: SFT (1987), Bakkum and Veldt (1986), CBS (1984), OECD (1984), KHM (1983) and Gram (1984). As a result, the CO emission factors were selected and used together with the statistical data to calculate CO emissions from combustion of various fuels in industrial and residential boilers in Eastern Europe in 1982. The estimates are shown in Table 34.

Table 34: CO emissions from combustion of various fuels in industrial and residential boilers in Eastern Europe in 1982 (in t)[1].

Country	Fuel oil boilers[2]	Paraffin boilers[3]	Fuel wood[4]	Total
Albania	230	330	46 980	47 540
Bulgaria	1 270	940	50 750	52 960
Czechoslovakia	2 030	1 470	51 620	55 880
GDR	3 770	70	22 040	25 880
Hungary	460	920	84 680	86 060
Poland	1 020	970	78 300	80 290
Romania		3 860	133 690	137 550
USSR (Europe)	14 040	143 970	2 440 060	2 598 070
Yugoslavia	2 510	270	116 000	118 780
Total	25 330	152 800	3 024 120	3 202 250

1 Statistical data are given in Tables 7 and 17.
2 An emission factor of 10 g/GJ was used and the heat value of oil was assumed to be 41.9 GJ/t.
3 An emission factor of 100 g/GJ was used as an average value of the industrial boiler factor of 50 g/GJ and the residential boiler factor of 150 g/GJ.
4 An emission factor of 2 900 g/GJ was used as an average value of the industrial boiler factor of 500 g/GJ and the residential boiler factor of 5 300 g/GJ.

CO is also emitted during the production of iron and steel. On the basis of the OECD (1983) emission survey, a set of emission factors can be suggested for Eastern Europe. These factors are presented in Table 35. Using these factors and statistical data, the CO emissions were calculated (Table 36).

Table 35: CO emission factors for iron and steel production in Eastern Europe.

Process	Unit	Emission factor
1. Sintering	kg/t sinter	30
2. Coke oven	kg/t coke	1
3. Iron production	kg/t pig iron	10
4. Foudry emissions		
- cupola	kg/t metal	90
- electric arc furnace	kg/t metal	5

Table 36: CO emissions from iron and steel production in Eastern Europe in 1982 (in t).

Country	Sintering		Coke production		Pig iron		Cupola		Electric arc furnace		Total
	Production 10^3 t	Emission	Production 10^3 t	Emission	Production 10^3 t	Emission	Production 10^3 t	Emission	Production 10^3 t	Emission	
Albania	n.d.		15	20	n.d.						20
Bulgaria	n.d.		1 274	1 270	1 562	15 620	4	360	871	4 360	21 610
Czechoslovakia	n.d.		10 606	10 610	9 525	95 250	456	41 040	2 998	14 990	161 890
GDR	n.d.		1 226	1 230	2 149	21 490	401	36 090	2 244	11 220	70 030
Hungary	n.d.		947	950	2 201	22 010	116	10 440	437	2 190	35 590
Poland	8 523	255 690	17 728	17 730	5 523	55 230	802	72 180	2 175	10 880	411 710
Romania	n.d.		3 513	3 510	8 637	86 370	656	59 040	2 702	13 510	162 430
USSR (Europe)	n.d		86 000	86 000	106 700	1 067 000	n.d.		16 481	82 410	1 235 410
Yugoslavia	n.d.		3 440	3 440	2 702	27 020	248	22 320	1 044	5 220	58 000
Total	8 523	255 690	124 789	124 760	138 999	1 389 990	2 683	241 470	28 952	144 780	2 156 690

n.d. = no data available.

Based on the OECD project (OECD, 1983) it can be concluded that mobile sources emit the largest amounts of CO in Western Europe. Based on the available literature (e.g. OECD, 1983; SFT, 1987) a set of emission factors was selected and the factors are given in Table 37.

Table 37: CO emission factors for mobile sources in Eastern Europe (in kg/t fuel used unless indicated).

Source	Emission factor
1. Road traffic	
a) automobiles	
- gasoline-powered	250
- diesel oil-powered	22
b) heavy-duty vehicles	
- gasoline-powered	280
- diesel oil powered	36
c) motorcycles	380
d) tractors	48
2. Inland shipping	15.0
3. Trail	15.0

In the next step, statistics on the use of gasoline and diesel-oil in various types of vehicles were used together with the factors from Table 37 to calculate CO emissions. The estimates of the CO emissions from gasoline-powered vehilces are shown in Table 38, and the CO emissions from diesel-oil-powered vehicles are in Table 39. The CO emissions from gasoline vehicles outweight far the CO emissions from diesel vehicles, which is not surprising when considering the chemical composition of both fuels and then their behaviour during combustion in the engines.

Table 38: CO emissions from gasoline-powered vehicles in Eastern Europe in 1982[1] (in t).

Country	Passenger cars	Heavy duty vehicles	Motorcycles	Total
Albania	59 250[2]		4 940	64 190
Bulgaria	202 500	252 000	34 200	488 700
Czechoslovakia	403 000		32 680	435 680
GDR	419 500	362 320	69 920	851 740
Hungary	265 000	35 000	25 460	325 460
Poland	401 500	316 400	90 440	808 340
Romania	647 250[2]		51 680	698 930
USSR (Europe)	3 596 250	14 193 200	1 301 500	19 090 950
Yugoslavia	521 500	61 040	46 360	628 900
Total	6 515 750	15 219 960	1 657 180	23 392 890

1 Statistic data presented in Table 22.
2 Including emissions from heavy duty vehicles using gasoline.

Table 39: CO emissions from diesel-powered engines in Eastern Europe in 1982[1] (in t).

Country	Passenger car	Heavy duty vehicle	Rail	Shipping	Agriculture	Total
Albania	290	3 460			6 240	9 990
Bulgaria	1 100	35 400	3 260	450	24 000	64 210
Czechoslovakia	2 200	58 210	14 430	780	37 630	113 250
GDR	0	30 890	10 580	330	31 200	73 000
Hungary	1 560	35 570	4 670	1 580	37 440	80 820
Poland	4 090	72 360	7 290	420	63 070	147 230
Romania	2 970	80 390	15 870	570	77 380	177 180
USSR (Europe)	54 800	217 510	100 170[3]		712 320	1 084 800
Yugoslavia	3 410	70 270	4 430	710	45 120	123 940
Total	70 420	604 060	160 700	4 840	1 034 400	1 874 420

1 Statistical data presented in Table 23.
2 Including rail + agriculture + shipping.
3 Including rail + shipping.

Table 40 summarizes the estimates of CO emissions from major anthropogenic sources in Eastern Europe in 1982. As much as 82% of the estimated total emissions come from mobile sources. Thus, in order to spatially distribute the CO emissions from anthropogenic sources in Eastern Europe, population data were used. This distribution within the EMEP grid of 150 x 150 km is given in Figure 11.

Table 40: CO emissions from anthropogenic sources in Europe in 1982 (in t).

Country	Stationary combustion	Iron & steel production	Mobile sources	Total
Albania	47 540	20	74 180	121 740
Bulgaria	52 960	21 610	552 910	627 480
Czechoslovakia	55 120	161 890	548 930	765 940
GDR	25 880	70 030	924 740	1 020 650
Hungary	86 060	35 590	406 280	527 930
Poland	80 290	411 710	955 570	1 447 570
Romania	137 550	162 430	876 110	1 176 090
USSR (Europe)	2 598 070	1 235 410	20 175 750	24 009 230
Yugoslavia	118 780	58 000	752 840	929 620
Total	3 202 250	2 156 690	25 267 310	30 626 250

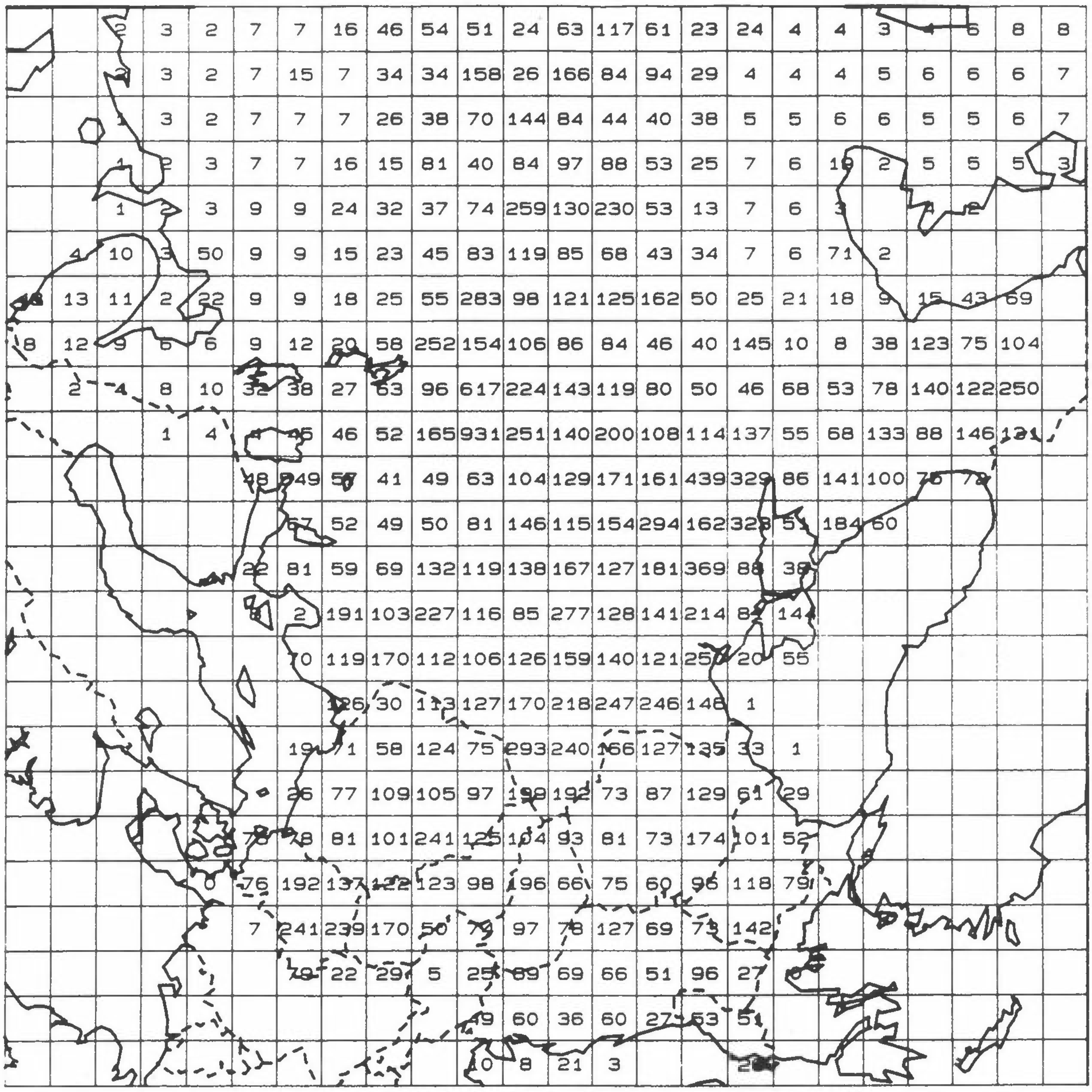

Figure 11: Spatial distribution of CO emissions in Eastern Europe in 1982 within the EMEP grid of 150 km x 150 km.
The unit used: 10^3 t.

8 EMISSIONS OF CH_4

Only very limited information is available to calculate the CH_4 emissions in Eastern Europe. Reviewing the VOC profiles for combustion processes, it was concluded that the following assumption can be made for CH_4:

a) For natural gas combustion, the CH_4 emissions are 3 times higher than the non-methane VOC emissions.
b) For liquid fuel combustion, the CH_4 emissions are 5 times lower than the non-methane VOC emissions.
c) For wood combustion, the CH_4 emissions are 4 times lower than the non-methane VOC emissions.

Considering the above assumptions, the CH_4 emissions were calculated for combustion of natural gas, liquid fuels and wood. The estimates are given in Table 41.

Table 41: CH_4 emissions from combustion processes in Eastern Europe in 1982[1] (in t).

Country	Natural gas	Liquid fuels	Wood	Total
Albania		50	410	460
Bulgaria	2 490	380	440	3 310
Czechoslovakia	17 730	480	450	18 660
GDR	25 080	750	190	26 020
Hungary	5 130	140	730	6 000
Poland	36 630	200	680	37 510
Romania	16 320	120	1 150	17 590
USSR (Europe)	292 830	8 670	21 040	322 540
Yugoslavia	7 890	500	1 000	9 390
Total	404 100	11 290	26 090	441 480

1 This is only a very rough estimate, based on the VOC emissions from combustion procesess. It was assumed, that the CH_4 emissions are 3 times as high as the non-methane VOC emissions for natural gas combustion. For liquid fuels and wood, the CH_4 emissions are lower than the non-methane VOCs by a factor of 5 and 4, respectively.

The other sources of CH_4 include: incineration processes, open burning in open drums or baskets and in large-scale open dumps or pits, and asphalt roofing manufacturing. There is no reliable information available to present the CH_4 emission factors for these sources. However, it is believed that the CH_4 emissions from the above sources in Eastern Europe are not significant.

CH_4 is also emitted from mobile sources but in low quantities. For example, the weight percentage content of CH_4 in gasoline-, diesel-, and LPG-exhausts is 4.5, 2 and 3, respectively, thus insignificant.

CH_4 is also formed as a result of fermentation taking place in the rumenreticulum of ruminants in the amount of 1 to 9 g CH_4/ruminant/h. Finally, there are natural CH_4 emissions from various types of vegetation. Very often they are at the level of 3 to 15 g/ha·h with an average of 8 g/ha·h.

A lack of statistics for the last two source categories made it impossible to assess the CH_4 emissions from fermentation and from natural sources. This certainly influence the quality of CH_4 emission survey in this work.

In order to distribute spatially the CH_4 emissions calculated in Table 41, the distribution of NOx from stationary sources in Eastern Europe by Pacyna (1988) was used. The results are presented in Figure 12.

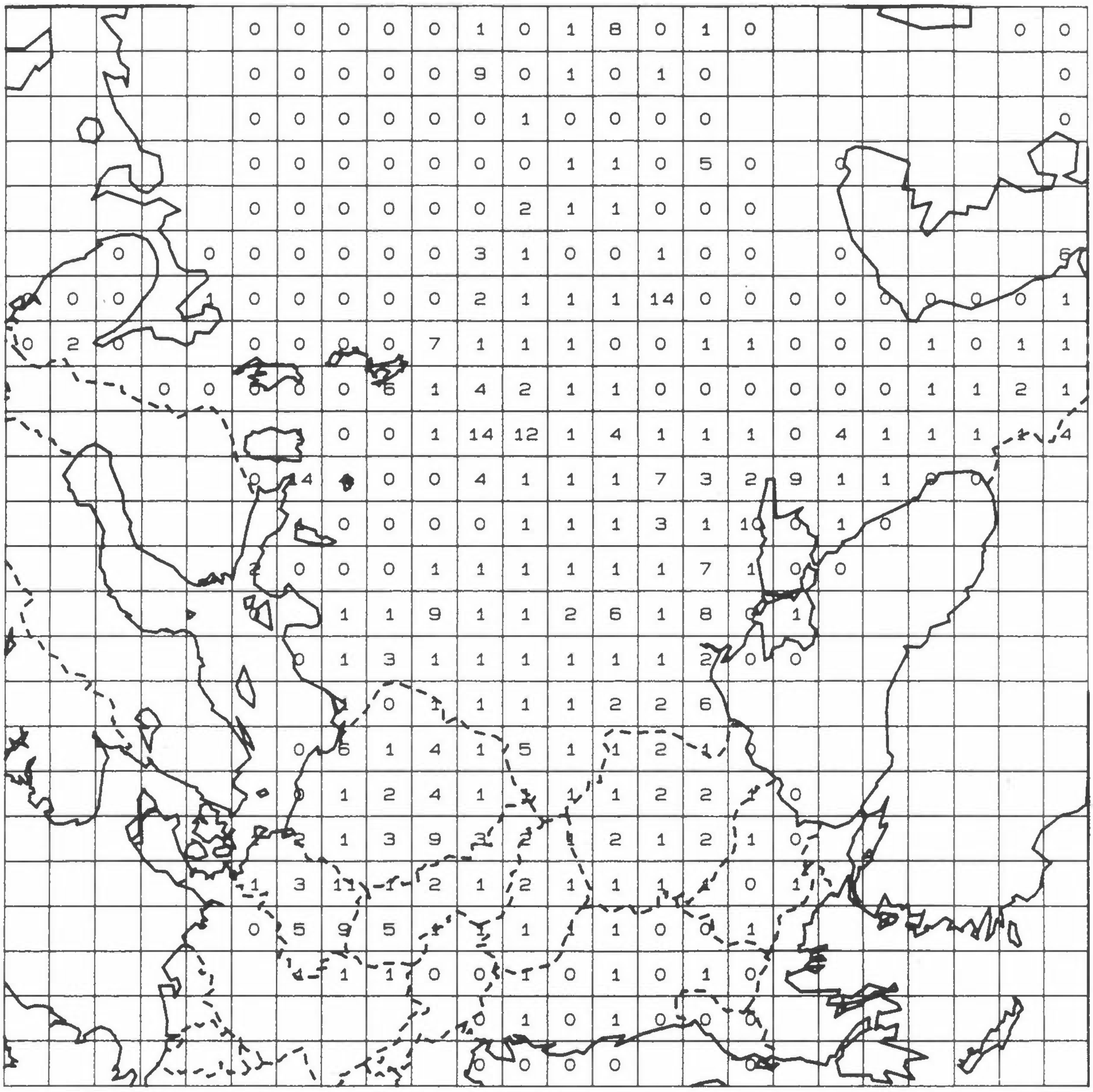

Figure 12: Spatial distribution of CH_4 emissions in Eastern Europe in 1982 within the EMEP grid of 150 km x 150 km.
The unit used: 10^3 t.

9 FINAL REMARKS

Anthropogenic emissions of compounds considered in this work are summarized in Table 42. The largest emissions were calculated for CO and then SO_2, NOx, and VOC. Two major source categories generating the majority of the compounds considered here were: combustion of fossil fuels and mobile sources. In most of the Eastern European countries electricity and heat is produced from combustion of coal and oil, known as polluting sources of energy. The consumption of diesel-oil was ca. 50% higher than the consumption of gasoline.

Table 42: Anthropogenic emissions of major gases in Eastern Europe in 1982 (in 10^3 t).

Country	SO_2 [1] as S	NOx as NO_2	VOC (non-methane)	NH_3 [2]	CH_4	CO	N_2O
Albania	25	28.0	32.8	21.0	0.5	121.7	7.1
Bulgaria	570	278.3	167.2	126.0	3.3	627.5	59.4
Czechoslovakia	1 575	556.9	258.7	170.0	18.7	765.9	112.1
GDR	2 500	857.1	353.6	207.0	26.0	1 020.7	250.0
Hungary	774	268.5	165.6	127.0	6.0	527.9	39.7
Poland	2 150	1.276.1	493.8	405.0	37.5	1 447.6	216.0
Romania	100	737.8	385.7	301.0	17.6	1 176.1	117.5
USSR (Europe	6 100	7 969.0	5 822.7	1 256.0	322.5	24 009.2	1 788.3
Yugoslavia	657	440.4	290.7	198.0	9.4	929.6	91.4
Total	14 451	12 412.1	7 970.8	2 812.0	441.5	30 626.2	2 681.5

1 after Eliassen et al. (1988).
2 after Buijsman et al (1987).

Concerning the accuracy of the above survey, the emission estimates for combustion of fossil fuels to produce electricity and heat, and for mobile sources are considered by the author as the most reliable due to broad information available on the technology used in the East European power plants, car park, and the statistical data for these source categories. The information on the emissions from solvent use and natural sources is less precised, mostly due to lack of statistical data.

Among the compounds, the emissions of SO_2 and NOx are estimated most accurately. Then the accuracy decreases in the following order: VOC>

NH_3>CO>N_2O>CH_4. The estimates for CH_4 should be considered with caution. The VOC profiles were selected as to the best knowledge of the author.

It should be noted, that in some cases emission factors used in this work, were based on the data from Western Europe. This may have some influence on the quality of the emission estimates for Eastern Europe, but it is difficult to assess to what extent they are inaccurate.

Finally, this set of emission data has been prepared for testing the EURAD model. An extensive work should be done to prepare a final version of emission estimates for model calculations in the second phase of EUMAC, as suggested by the Working Group 4 of EUMAC on Emissions.

The spatial distributions of emissions have been prepared in the EMEP grid of 150 km x 150 km. The testing of EURAD may require the grid of 50 km x 50 km. For this part of work within EUMAC (test phase) it is suggested here to divide an emission estimate for a given grid of 150 km x 150 km, into 9 equal 50 km x 50 km grids. For the final calculations, however, it is suggested to the Working Group 4 of EUMAC, to consider population data in the 50 km x 50 km grid, as a basis to distribute the area source emissions.

It will also be necessary to consider temporal variations of emissions. This work provides information on a yearly basis only.

10 ACKNOWLEDGEMENT

This work was supported by a research grant from the University of Cologne, Federal Republic of Germany.

The author thanks Prof. Adolf Ebel, the EUMAC Co-ordinator, and Director Harald Dovland of NILU for help and comments when preparing this survey.

The author thanks Mr. A. Kibsgaard for producing the emission maps.

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POSTBOKS 64, N-2001 LILLESTRØM

RAPPORTTYPE OPPDRAGSRAPPORT	RAPPORTNR. OR 48/89	ISBN-82-425-0057-6	
DATO SEPTEMBER 1989	ANSV. SIGN. [signature]	ANT. SIDER 54	PRIS NOK 90,-
TITTEL Emissions of major air pollutants emitted in Eastern Europe		PROSJEKTLEDER J.M. Pacyna	
		NILU PROSJEKT NR. O-8861	
FORFATTER(E) J.M. Pacyna		TILGJENGELIGHET A	
		OPPDRAGSGIVERS REF.	

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3 STIKKORD (à maks. 20 anslag)

Emission	Air pollutant	EUMAC

REFERAT (maks. 300 anslag, 7 linjer)

TITLE Emissions of major air pollutants emitted in Eastern Europe

ABSTRACT (max. 300 characters, 7 lines)
The report presents the estimates of the 1982 emissions of SO_2, NOx, VOC, NH_3, CH_4, CO and N_2O from sources in Eastern Europe. The estimates will be used to test the EURAD model in the EUMAC project of EUROTRAC. The SO_2 emission data were accepted from Eliassen et al. (1988) and the NH_3 emissions from Buijsman et al. (1987).

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