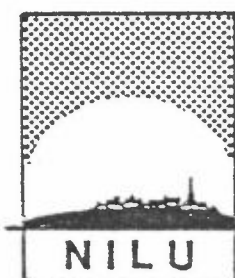


NILU
SUPPLEMENT TIL
TEKNISK RAPPORT NR. 5 /82
REFERENCE: 24781
DATE: DECEMBER 1982

TRACE ELEMENT EMISSIONS
FROM COAL-, AND OIL-POWER
PLANTS IN EUROPE
METHODOLOGY OF CALCULATIONS

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This report should be considered as a supplement to technical report No. 5/82 "The spatial distribution of the trace element emission from conventional thermal power plants in Europe" by Jozef Pacyna.

EMISSION OF TRACE ELEMENTS FROM
COAL- AND OIL-POWER PLANTS IN EUROPE.
METHODOLOGY OF CALCULATIONS

1 INTRODUCTION

The aim of this report is to detail the methodology of trace element emission calculations used in an earlier report [1], where the spatial distribution of the trace element emission from conventional thermal power plants in Europe was described.

2 ELECTRICITY PRODUCTION IN DIFFERENT EUROPEAN COUNTRIES

The electricity production in several types of power plants in Europe is given in Table 1 [1,2,3]. Trace element emissions are calculated chiefly using trace emission factors for power plants that in turn depend upon kind of fuel burned. Therefore, it was just necessary to estimate the distribution of electricity production in different types of conventional thermal power plant. The distribution has been calculated using data on fuel consumption, import-export relations of fuels, and heat values of fuels.

2.1 Consumption of fuels

Consumption of several kinds of fuels used for electricity production in European countries is listed in Table 2.

Table 1: Electricity production in European countries in 1979
(in TWh) [1,2,3].

Country	Total	Hydro	Nuclear	Conv.Ther.	Geothermal
Albania	2.4	1.9	0	0.5	0
Austria	40.6	28.0	0	12.6	0
Belgium	52.3	0.6	11.4	40.3	0
Bulgaria	32.5	3.3	6.2	23.0	0
Czechoslovakia	67.9	4.1	2.2	61.6	0
Denmark	22.3	v.small	0	22.3	0
Finland	39.1	11.2	6.8	21.1	0
France	240.1	73.7	32.3	134.1	0
German Dem.Rep.	99.0	1.3	8.0	89.7	0
German Fed.Rep.	372.2	18.5	42.3	311.4	0
Greece	22.4	3.2	0	19.2	0
Hungary	24.5	0.1	0	24.4	0
Iceland	2.8	2.7	0	0.1	v.small
Ireland	11.0	1.2	0	9.8	0
Italy	181.3	48.2	2.6	128.0	2.5
Luxemburg	1.1	0.1	0	1.0	0
Netherlands	64.5	0	3.5	61.0	0
Norway	86.5	86.4	0	0.1 ^x	0
Poland	117.5	2.5	0	115.0	0
Portugal	16.1	11.2	0	4.9	0
Romania	64.9	10.7	0	54.2	0
Spain	105.8	47.5	6.7	51.6	0
Sweden	95.0	60.8	21.1	13.1	0
Switzerland	46.6	32.7	11.8	2.1	0
Turkey	24.3	10.5	0	13.8	0
USSR	1240.0	180.0	45.0	1015.0	0
United Kingdom	300.0	5.5	38.3	256.2	0
Yugoslavia	55.0	26.6	0	28.4	0

^x at Spitsbergen

Table 2: Fuel consumption in the European conventional power plants in 1979 (in 10⁶ tons) [4].

Country	Hard coal*1	Lignite	Fuel oil
Albania* 2	-	0.2	-
Austria	0.05	2.08	1.19
Belgium	4.60	-	3.80
Bulgaria*3	-	9.44	2.04
Denmark	6.15	-	1.97
Finland	3.36	-	0.96
France	24.17	2.35	12.54
German Fed.Rep.	37.73	115.00	5.59
Greece	-	20.77	1.83
Iceland	-	-	0.01
Ireland	0.03	-	1.67
Italy	2.26	1.35	22.02
Netherlands	1.70	-	4.75
Norway	0.015	-	-
Poland*4	57.53	34.72	-
Portugal	0.22	-	1.05
Spain	7.65	10.05	6.31
Sweden	0.04	-	3.23
Switzerland	0.01	-	0.30
Turkey	1.18	5.75	1.42
United Kingdom	91.28	-	12.04

*1 Hard coal includes both bituminous and subbituminous coals.

*2 According to [5].

*3 According to [6,7]

*4 According to [8,9]

Production of electricity in hard coal-, lignite- and oil-power plants in GDR, Czechoslovakia, Hungary, Romania, the USSR and Yugoslavia has been taken from the literature (see Table 8). In this case it was not necessary to know fuel consumption in the above mentioned countries, because the distribution of electricity production by type of power plant had already been given.

2.2 Import - export relations of fuels

The import-export relations for hard coal are given in Table 3 [3]. The table presents total import of coal to each country. It was assumed that an exporter contributed to the generation of electricity in an importing country in the same percentage that that exporter had contributed to total coal imports for that country. It was an important assumption in computing the average heat value of coal for each country.

However, for some importers mentioned in Table 3 the assumption is made that indigenous coal production is sufficiently large to meet all their needs in power production. Imported coal in these countries, is used for other purposes. These countries are: the German Federal Republic, Norway (Svalbard), Poland, Turkey, the USSR and the United Kingdom.

Some countries have their own hard coal and imported coal only partially contributes to total power production. These countries are: Belgium, France, Hungary, the Netherlands, Portugal and Spain. The contribution of indigenous coal production to total coal burned in power plants have been taken into account.

Table 3: Movement of hand coal in 1978 [3] (in 10³ tons)

Exporter	Africa South Africa	North USA	America Canada	India	Western Europe				Centralised Planned European Countries			Oceania	Not specified	
					Belgium	France	F.R. Germany	Nether-lands	United Kingd.	Czechoslo-vakia	Poland			USSR
Importer														
Austria	620	960	170			210					640	750	680	
Belgium					70	3870			150			500	280	210
Bulgaria													6200	
Czechoslovakia	870		310	180		930			140		10	2410	3180	50
Denmark												3070	530	
Finland					80	6610	110	890				4090	700	
France	6830	1500				120					600	4750	850	50
German Dem.Rep.									500			1280	3910	20
German Fed.Rep.	1110	950	490		110	300	220				150	2040	120	240
Hungary						60					560	470	330	
Greece	10											130	10	210
Ireland	870	2556				10		170				640		40
Italy	120	820	60		20	2510		40				3250	1070	1320
Netherlands	20	110*1				1480		170			150	640	180	1410
Norway					10	30	60	70				150		
Poland													760	
Portugal		260			10	10	10					140		
Romania		670	230			40					860	450	700	500
Spain	60	740	70			470						1350	130	600
Sweden	340		90			270		30			100	240	470	
Switzerland	20				10	80	10				10			
Turkey		510				120								
USSR		420				260						9880		
United Kingdom	20	180			20	200					630	420	100	1030
Yugoslavia												70	1970	

*1 Import from North America

Comparing data in Tables 2 and 3 it can be seen that some countries import hard coal for other purposes than combustion in power plants. These are the following: Bulgaria, the German Democratic Republic, Czechoslovakia, Greece and Yugoslavia. For the above-mentioned countries it was assumed that only lignite is burned in power plants. This assumption may not always be valid, especially for Czechoslovakia. The lack of suitable data on hard coal combustion in power plants in these countries forced the author to make this assumption. Lignite burned in the European countries comes chiefly from indigenous production.

The movement of crude petroleum within the European countries having oil-fired power plants is presented in Table 4 [10].

Table 4: Movement of crude petroleum in 1981 [10] (in 10³ tons)

Importer	Exporter	Africa				Other American Countr.		Middle East			Far East		Western Centr. Europe		Not specified					
		Algeria	Egypt	Gabon	Libya	Nigeria	North America	Mexico	Trinidad	Venezuela	Iran	Iraq	Kuwait	Qatar		Saudi Arabia	U.A.E.*1	Singapore	Indonesia	
Austria		700	95	760	220					300	330			3180	8			1850	220	
Belgium				110	260			300		280	10	80	120	4600				1100	330	21750
Denmark					500		70					40		1200	140			2770	1150	
Finland								20		500			130	2370				400	7350	
France		4300	260	750	1500	5600	2750	250	2200	1500	2300	1300	2600	46100	7600		30	5200	7670	3100
German fed.Rep.		5900	500	230	10400	5200	100			1500	200	600	300	25500	3600			19000	2500	4100
Greece			420		3200					650	1150			10000			40	1200		1600
Ireland												130		400	50			80		
Italy		3360	6900	200	10500	2400	140	1400	3700	2800	7800	1400	1700	31400	2260		1200	400	6300	5350
Netherlands		320	100	360	700	5000	1000	550		478	110	3250	2300	16000	1100		170	5600	920	800
Portugal							160			640	1400		800	1900	1060			180	1300	120
Spain		1700	500	470	4500	1900	7500	3500		5000	2300	670	1400	14000	2500			170	1100	
Sweden				50	1370		140	120	700	20				7000	750			4300	540	60
Switzerland		600	20	600	350					1500	5800	100		500	1130			100	400	100
Turkey					2600					750	70			1500						
Bulgaria*2				50	350					130	1050								11300	120
Hungary*2																				
Romania*2		390			2080					4000	3950	1150							8780	1370

*1 United Arab Emirates

*2 Data from 1978 [3].
For these countries no significant changes in the movement of crude petroleum in the period of 1978-82 have been observed, since the majority of crude oil burned comes from production in the Eastern European countries (except Romania). In Romania 50 per cent of crude oil comes from indigenous production and 50 per cent was imported mainly from Middle East. Taking into account political relations it is hard to believe that Iran is still the most important oil importer for Romania, so data from this country should be analyzed carefully.

In the case of the USSR, the ratio of indigenous production of crude oil to oil import was 100 to 1 in 1979. Oil burned in the United Kingdom has also indigenous origin. The indigenous production of crude oil in this country is 2.4 times as high as import (1981 - [10]). It was assumed that all 12 million tons of oil burned in power plants in the United Kingdom is of indigenous origin.

2.3 Heat values of fuels

The next step in assessing electricity production by type of power plant in each of the European countries was to calculate the average heat value for fuels burned. Data on fuel consumption (from Table 2), import-export relations (from Tables 3 and 4) and the heat values of fuels from different fields was hard. The heat values of several sorts of hard coal mined from different fields are given in Table 5 and the heat values of lignite in Table 6.

Table 5: Heat values of hard coals from several fields (MJ/kg).

Exporter (Country having field)	Average heat value	Exporter (Country having field)	Average heat value
South Africa [11]	24.4	Netherlands [11]	24.0
USA [12]	25.6	United Kingdom [11]	24.0
Canada [15]	29.8	Czechoslovakia [13]	24.2
Belgium [11]	24.0	Poland [11,8,9]	24.1 (export) 18.9
France [14]	25.4	USSR [17]	25.0
German Fed.Rep. [13,16]	21.2	Oceania [13]	25.0

Table 6: Heat values of lignite from several fields (MJ/kg) [13].

Place of field	Average heat value	Place of field	Average heat value
Albania	15.5	Hungary	9.2
Austria	15.8	Italy	17.5
Bulgaria	15.5	Poland*	7.8
Czechoslovakia	15.4	Romania	17.4
France	16.3	Spain	17.5
German Dem.Rep.	16.3	Turkey	17.4
German Fed.Rep.	12.2		
Greece	15.5		

* According to [9].

Data from Tables 5 and 6 should be regarded as average values for fields, because the heat value of coal can vary from one area of the field to another.

The average heat value of coal burned in power production in various European countries is listed in Table 7.

Table 7: Average heat values of coal burned in the European power plants (MJ/kg).

Country	Hard coal	Lignite	Country	Hard coal	Lignite
Albania	-	15.5	Italy	24.7	17.5
Austria	24.0	15.8	Netherlands	24.3	-
Belgium	24.1	-	Norway*	29.3	-
Bulgaria	-	15.5	Poland	18.9	7.8
Denmark	24.2	-	Portugal	25.1	-
Finland	24.0	-	Spain	25.1	17.5
France	22.8	16.3	Sweden	24.9	-
German Fed. Republic	21.3	12.2	Switzerland	24.0	-
Greece	-	15.5	Turkey	25.1	17.4
Ireland	24.0	-	United Kingdom	24.0	-

*according to [18]

Similar to Table 2, it was not necessary to know the heat value of coal burned in the GDR, Czechoslovakia, Hungary, Romania, the USSR and Yugoslavia because the distribution of electricity production in other types of power plants was already given in the literature.

The heat value of oils burned in the European power plants vary insignificantly and a value of 41.8 MJ/kg was assumed as an average.

2.4 Distribution of electricity production by type of power plant in European countries

The distribution of electricity production by type of power plant in the different European countries has been assessed using:

- consumption of several sorts of fuels (Table 2)
- average heat values of coals burned (Table 7)
- assumption that efficiency of power plant is the same for hard coal-, lignite- and oil-power plants.

Table 8: *Distribution of electricity production by type of conventional thermal power plants in 1979. ($\cdot 10^9$ MJ/year).*

Country	Total	Type of power plant		
		Hard-coal fired	Lignite-fired	Oil-fired
Albania* ¹	119	0	1.9	0
Austria	40.6	0.6	15.9	24.1
Belgium	123.8	44.3	0	79.5
Bulgaria* ²	82.8	0	53.8	29.0
Czechoslovakia* ¹	221.6	0	221.6	0
Denmark	80.3	52.3	0	28.0
Finland	73.9	49.4	0	24.5
France	465.4	234.6	7.0	223.8
German Dem.Rep.* ¹	322.9	0	322.9	0
German Fed.Rep.	920.3	304.7	534.8	80.8
Greece	69.2	0	55.8	13.4
Hungary* ³	87.7	8.4	49.2	30.1
Iceland* ¹	0.2	0	0	0.2
Ireland	32.7	0.4	0	32.3
Italy	428.3	24.4	10.3	393.6
Netherlands	142.6	24.5	0	118.1
Norway* ¹	0.5	0.5	0	0
Poland	414.0	331.2	82.8	0
Portugal	17.6	1.9	0	15.7
Romania* ⁴	97.6	0	29.3	68.3
Spain	184.0	55.9	51.2	76.9
Sweden	47.1	0.3	0	46.8
Switzerland	7.2	0.1	0	7.1
Turkey	49.6	7.7	26.3	15.6
USSR* ⁵	2183.9	767.6	319.5	1096.8
United Kingdom	914.0	747.7	0	166.3
Yugoslavia* ¹	102.3	0	102.3	0

- *¹ For these countries it was found that all electricity was produced in one type of power plant.
- *² according to [7]
- *³ according to [19]
- *⁴ according to [7]
- *⁵ according to [20,21]

3 TRACE ELEMENT EMISSION FACTORS FROM POWER PLANTS IN VARIOUS EUROPEAN COUNTRIES

Trace element emissions from power plants have been calculated using emission factors. These factors have been calculated for all countries separately. Calculations were made based of emission factors for coal with 10 per cent ash and for oil with 1 per cent of sulphur as well as specific ash content in coal and sulphur content in oil burned in various countries.

3.1 "Universal" emission factors

The term "universal" emission factor includes:

- factors calculated for several types of coal with 10 per cent ash burned in different kinds of boilers equipped with 99 per cent efficient electrostatic precipitators,
- factors calculated for a power plant burning oil with 1 per cent of sulphur.

The methodology of universal emission factors calculations has been presented in earlier reports [22,23].

To calculate the trace element emission factors for power plants in the European countries it was necessary to know the ash content in coal and the sulphur content in oil burned in these countries.

It was found that a majority of power plants in Europe are equipped with electrostatic precipitators working at an efficiency of 99 per cent [14,24].

3.2 Ash contents in coals burned in the European power plants

The ash content of hard coal mined in several mines in the world is presented below (Table 9).

Table 9: The ash content of hard coal from several fields (in %).

Exporter (Country having field)	Average ash content	Exporter (Country having field)	Average ash content
South Africa [11]	14.4	Netherlands [11]	12.4
USA [12]	7.7	United Kingdom	12.5
Canada [15]	9.4	Czechoslovakia [13]	12.8
Belgium [26]	32.5	Poland [11] [9]	14.1 export 20.0
France [14]	13.2	USSR [17]	20
German Fed.Rep. [25]	8.0	Oceania [13]	15.5

Data for lignites are listed in Table 10.

Table 10: The ash contents in lignites from several fields (13).

Place of field	Average ash content	Place of field	Average ash content
Albania	17.7	Hungary	15.0
Austria	7.4	Italy	17.7
Bulgaria	15.0	Poland*	24.0
Czechoslovakia	16.0	Romania	17.7
France	11.5	Spain	17.7
German Dem.Rep.	17.2	Turkey	17.7
German Fed.Rep.	10.4	USSR	20.0
Greece	12.8	Yugoslavia	17.7

*according to [9]

All values presented in Tables 9 and 10 should be regarded as average values because the ash contents in coal can vary from one area of a field to another. The averages in Tables 9 and 10 were calculated using information obtained in the literature.

Using data on fuel consumption (Table 2), import-export relations (Table 3) and ash content of coal (Tables 9 and 10), the average ash content of coal burned in the European countries as calculated. The results are given in Table 11.

Table 11: Average ash content of coal burned in countries in Europe in 1979 (in %).

Country	Hard coal	Lignite	Country	Hard coal	Lignite
Albania	-	17.7	Italy	11.5	17.7
Austria	12.4	7.4	Netherlands	13.4	
Belgium	32.5* ²	-	Norway* ¹	11.0	
Bulgaria	-	15	Poland	20.0	24.0
Czechoslovakia	-	16	Portugal	15.0	
Denmark	13.2	-	Romania	-	17.7
Finland	12.4		Spain	15.0	17.7
France	10.8	11.5	Sweden	10.6	-
German Dem.Rep.	-	17.2	Switzerland	12.5	-
German Fed.Rep.	8.0	10.4	Turkey	15.0	17.7
Greece	-	12.8	USSR	20.0	20.0
Hungary	15.0	15.0	United Kingdom	12.5	-
Ireland	12.5	-	Yugoslavia	-	17.7

*¹ According to [18]

*² According to [26]

3.3 Sulphur content of oil burned in the European power plants

The average sulphur content of crude oil from several fields in the world are presented in Table 12 [27]. The values should be considered as averages of all the fields.

Table 12: Average sulphur content of crude oil (in %) [27].

Exporter (Country having field)	Average sulphur content	Exporter (Country having field)	Average sulphur content
1) Africa:		4) Middle East	
Algeria	0.1	Iran	1.6
Egypt	1.7	Iraq	1.9
Gabon	0.1	Kuwait	2.5
Libya	0.2	Qatar	1.3
Nigeria	0.15	Saudi Arabia	2.8
2) North America* ¹	0.08	Unit.Arab.Emir.	1.7
3) Other American countries		5) Far East	
Mexico* ²	1.0	Singapore	0.1
Trinidad* ¹	0.4	Indonesia	0.1
Venezuela	2.0	6) Western Europe	0.2
		7) Eastern Europe	1.4

*¹ according to [28]

*² assumption by the author

Using data on consumption of oil in power plants (Table 2), import-export relations (Table 4) and average sulphur content of crude oil from several fields, the average sulphur content of crude oil burned in power plants in several countries has been calculated. The results are presented in Table 13.

Table 13: Average sulphur content of crude oil burned in countries in Europe in 1981 (in %).

Country	Average sulphur content	Country	Average sulphur content	Country	Average sulphur content
Austria	2.1	Greece	2.1	Romania	1.6
Belgium	2.1	Hungary	1.4	Spain	1.1
Bulgaria	1.4	Iceland	0.5	Sweden	2.1
Denmark	2.8	Ireland	1.5	Switzerland	0.2
Finland	2.1	Italy	1.5	Turkey	0.8
France	2.1	Netherlands	2.1	USSR	1.4
German Fed.Rep.	1.4	Portugal	1.2	United Kingdom	0.5

3.4 Emission factors of trace elements for power plants in the particular European countries

Knowing 1) the trace element emission factors for coal- and oil-powered plants burning fuel with 10 per cent ash content in coal and 1 per cent sulphur content in crude oil (called "universal emission factors" and presented in a previous report [1]) and 2) the average ash content of coal and the average sulphur content of crude oil burned in European countries, the trace element emission factors for power plants in these countries can be calculated. For coal power plants, calculations are obtained by multiplying the universal emission factors by the ratio of the ash content in the coal burned in that particular country to the assumed 10 per cent ash content. The results for hard coal are presented in Table 14.

Table 14: Trace element emission factors for hard coal power plants in European countries (in µg/MJ).

Country	As	Be	Cd	Co	Cr	Cu	Hg	Mn	Mo	Ni	Pb	Sb	Se	V	Zn	Zr
Austria	22.5	2.3	7.2	35.9	120	89.4	0.5	99.6	27.2	137	77.9	13.3	10.4	83.1	112	85.6
Belgium	62.4	6.5	19.8	99.5	334	278	1.3	276	75.4	381	216	36.7	28.9	230	311	237
Denmark	21.1	2.1	6.8	33.5	112	83.3	0.5	92.7	25.3	128	72.6	12.3	9.7	77.4	105	79.6
Finland	23.8	2.5	7.6	38.0	127	94.5	0.5	105	28.8	145	82.8	14.0	11.0	87.8	119	90.4
France	20.7	2.2	6.6	33.0	111	82.3	0.4	91.7	25.0	126	71.7	12.2	9.6	76.4	103	78.7
German Fed.Rep.	15.4	1.6	4.9	24.5	82.2	61.0	0.3	67.9	18.6	93.6	53.1	9.0	7.1	56.6	76.6	58.3
Hungary	43.0	4.5	13.2	81.1	218	172	0.9	186	56.0	274	155	25.6	20.0	152	217	150
Ireland	21.6	2.3	6.9	34.4	116	85.7	0.5	95.5	26.1	132	74.7	12.7	10.0	80.0	108	82
Italy	22.1	2.3	7.0	35.2	118	87.7	0.5	97.7	26.7	135	76.4	13.0	10.2	81.4	110	83.8
Netherlands	21.3	2.1	6.8	33.9	114	84.4	0.5	93.8	25.6	129	73.5	12.5	9.8	78.3	106	80.6
Norway	19.0	1.9	6.1	30.4	102	75.5	0.5	84.0	22.9	116	65.8	11.2	8.8	70.1	94.8	72.1
Poland	57.2	6.0	17.6	108	290	228	1.2	247	74.4	365	207	34.0	26.6	20.3	288	199
Portugal	24.5	2.5	7.9	39.0	131	97.0	0.6	108	29.5	149	84.5	14.3	11.3	90.1	122	92.6
Spain	23.9	2.4	7.7	38.0	127	94.4	0.6	105	28.7	145	82.2	13.9	11.0	87.7	118	90.2
Sweden	18.5	1.9	6.0	29.5	98.8	73.4	0.5	81.7	22.3	113	63.9	10.9	8.5	68.1	92.1	70.1
Switzerland	26.0	2.8	8.5	42.8	144	107	0.6	119	32.5	164	93.0	15.8	12.5	99.1	134	102
Turkey	35.6	3.8	11.0	66.9	180	142	0.7	154	46.3	227	128	22.6	16.6	126	179	124
USSR	57.2	6.0	17.6	108	290	228	1.2	247	74.4	365	207	34.0	26.6	203	288	199
United Kingdom	24.0	2.5	7.6	38.3	128	92.5	0.5	106	29.0	146	83.0	14.1	11.1	88.5	120	91.1

The highest values for trace element emission factors for hard coal were obtained for Belgium. In this case it was assumed, that only indigenous coal is burned in Belgian power plants and that import of coal to this country is used for other purposes. The Belgian hard coal contains very high amounts of ash (more than 30 per cent) [26]. Therefore, these values must be interpreted with caution.

When calculating emission factors for hard coal, the kind of hard coal burned in particular countries and type of boilers used should be considered. On the basis of thoroughly studied literature [11,18,29,30,31] and export-import relations for coal, it was found that bituminous coals are mainly burned in Denmark, the Netherlands, Norway, Portugal, Spain, Sweden and Turkey. Subbituminous coal is fired in larger amounts than bituminous coal in the following countries: Austria, Belgium, Finland, France, the German Federal Republic, Hungary, Ireland, Italy, Poland, Switzerland, the USSR and the United Kingdom [26,32,33,34,35,19,9,20,21].

The higher trace emission factors for Hungary, Poland, the USSR and Turkey are also due to type of boilers used. In these countries cyclone boilers are more commonly used than pulverized ones.

The trace element emission factors for lignite power plants in European countries are given in Table 15.

Table 15: Trace element emission factors for lignite-power plants in European countries (in $\mu\text{g}/\text{MJ}$).

Country	As	Be	Cd	Co	Cr	Cu	Hg	Mn	Mo	Ni	Pb	Sb	Se	V	Zn	Zr
Albania	46.7	4.7	14.9	74.7	250	186	1.0	207	56.3	285	162	27.5	21.7	172	233	174
Austria	19.8	2.0	6.3	31.6	106	78.6	0.5	87.6	23.9	121	68.5	11.6	9.2	73.0	98.7	73.7
Bulgaria	59.7	6.1	18.4	112	302	238	1.3	257	77.5	380	215	35.4	27.7	212	300	208
Czechoslovakia	63.7	6.6	19.7	120	322	253	1.4	275	82.7	405	230	37.8	29.6	226	320	222
France	26.8	3.1	9.7	48.9	164	121	0.7	135	36.9	187	106	18.0	14.2	113	153	114
German Dem.Rep.	68.5	7.1	21.2	129	347	272	1.5	295	88.9	436	247	40.6	31.8	243	341	238
German Fed.Rep.	27.8	2.8	8.8	44.3	148	110	0.6	123	33.5	169	96.0	16.3	12.9	102	138	103
Greece	34.2	3.5	10.9	54.6	183	136	0.8	151	41.2	208	118	20.1	15.9	126	170	127
Hungary	59.7	6.1	18.5	112	302	238	1.3	257	77.6	380	216	35.4	27.8	212	300	208
Italy	47.2	4.8	15.0	75.2	252	187	1.1	208	56.9	287	163	27.7	21.9	174	235	175
Poland	95.5	9.8	29.5	180	484	380	2.2	412	124	608	345	56.6	44.4	338	480	333
Romania	70.4	7.2	21.7	132	356	280	1.6	303	91.4	448	254	41.7	32.7	249	354	245
Spain	47.2	4.8	15.0	75.3	252	187	1.1	209	57.0	288	163	27.8	21.9	174	235	176
Turkey	70.4	7.2	21.8	132	356	280	1.6	303	91.4	448	254	41.7	32.7	249	354	245
USSR	79.5	8.2	24.6	150	403	317	1.8	343	103	507	287	47.2	37.0	282	400	277
Yugoslavia	70.4	7.2	21.8	132	356	280	1.6	303	91.4	448	254	41.7	32.7	249	354	245

The lignite from the south-eastern European fields has higher ash content than that from other parts of Europe. This partly explains the high emission factors for Romania, Turkey and Yugoslavia. The high emission factors calculated for the eastern European countries are due to the use of cyclone boilers and the high ash content of lignite.

The trace element emission factors for oil power plants in European countries can be obtained from the "universal" trace element emission factors using the following equation [36]:

$$C_p = 1.25 \cdot S + 0.38 \quad (1)$$

where:

C_p = the particulate emission factor, kg of dust/ 10^3 liters
 S = the percentage by weight of sulphur in the crude oil in %

Similarly:

$$Ef_x = (1.25 \cdot S + 0.38)Ef_{(u)} \quad (2)$$

where:

Ef_x = the trace element emission factor calculated for oil with "x" per cent of sulphur
 Ef_u = the "universal" trace element emission factor calculated for oil with 1 per cent of sulphur

The results of calculations are given in Table 16.

Table 16: Trace element emission factors for oil-power plants in European countries (in $\mu\text{g}/\text{MJ}$).

Country	As	Cd	Co	Cr	Cu	Mn	Mo	Ni*	Pb	Se	V*	Zn
Austria	44.8	21.3	238	79.6	319	74.8	51.6	1.87	231	34.0	6.80	163
Belgium	45.1	21.4	239	80.1	321	75.3	52.0	1.89	232	34.2	6.84	164
Bulgaria	31.9	15.1	169	56.7	227	53.3	36.8	1.34	164	24.2	4.84	116
Denmark	58.1	27.6	308	103	414	96.9	66.9	2.43	299	44.0	8.80	211
Finland	44.9	21.3	238	79.7	320	74.9	51.7	1.88	231	34.0	6.80	163
France	44.8	21.3	238	79.6	319	74.8	51.6	1.87	231	34.0	6.80	163
German Fed.Rep.	32.4	15.4	172	57.6	231	54.1	37.4	1.36	167	24.6	4.92	118
Greece	44.7	21.2	237	79.4	319	74.8	51.5	1.87	230	33.9	6.78	163
Hungary	32.0	15.2	170	56.7	228	53.3	36.8	1.34	164	24.2	4.84	116
Iceland	17.2	8.2	90.6	30.3	122	28.5	19.6	0.71	88.0	12.9	2.59	72.1
Ireland	15.4	7.3	81.7	27.3	110	25.7	17.7	0.64	79.4	11.7	2.34	56.0
Italy	33.7	16.0	179	59.7	240	56.2	38.8	1.41	173	25.5	5.10	112
Netherlands	44.9	21.3	238	79.7	320	74.9	51.7	1.88	231	34.0	6.80	163
Portugal	28.0	13.3	148	50.0	199	46.7	32.2	1.17	144	21.2	4.24	102
Romania	35.6	16.9	189	63.2	254	59.4	41.0	1.49	184	27.0	5.40	129
Spain	26.4	12.5	140	46.8	188	44.0	30.4	1.10	136	20.0	3.99	95.8
Sweden	44.9	21.3	238	79.7	320	74.9	51.7	1.88	231	34.0	6.80	163
Switzerland	8.8	4.2	46.8	15.7	62.9	14.7	10.2	0.40	45.5	6.70	1.34	32.1
Turkey	20.2	9.6	107	35.9	144	33.7	23.3	0.85	104	15.3	3.06	73.5
USSR	32.0	15.2	170	56.7	227	53.3	36.8	1.34	164	24.2	4.84	116
United Kingdom	15.4	7.3	81.7	27.3	110	25.7	17.7	0.64	79.4	11.7	2.34	56.0

*in mg/MJ

4 EMISSION OF TRACE ELEMENTS

Trace element emissions from conventional thermal power plants in the European countries have been calculated using the trace element emission factors for hard coal-, lignite- and oil-power stations (Tables 14, 15 and 16) and the data on electricity production from several types of power plants in individual countries (Table 7).

The results are presented in Tables 17, 18 and 19 for hard coal-, lignite-, and oil-power plants, respectively.

It must be added though, that a large number of power plants in Europe burn not only monovalent but also bivalent and trivalent fuel. For example, power plants can fire combinations of hard coal and lignite or hard coal, lignite, and oil. The contribution of particular fuels to trace element emissions has been calculated based on consumption of these fuels and their heat values. The detailed data on this matter have been taken from several issues of the monthly bulletin "Electrical Energy" and [14].

Table 17: Emission of trace elements from hard coal-power plants in Europe in 1979 (in t/year).

Country	As	Be	Cd	Co	Cr	Cu	Hg*	Mn	Mo	Ni	Pb	Sb	Se	V	Zn	Zr
Austria	0.01	v.s.	v.s.	0.02	0.07	0.05	0.3	0.06	0.02	0.08	0.05	0.01	0.01	0.05	0.07	0.05
Belgium	2.8	0.3	0.9	4.4	14.8	10.9	58	12.2	3.3	16.8	9.6	1.6	1.3	10.2	13.8	10.5
Denmark	1.1	0.1	0.4	1.7	5.9	4.4	28	4.8	1.3	6.7	3.8	0.6	0.5	4.1	5.5	4.2
Finland	1.2	0.1	0.4	1.9	6.3	4.7	24	5.2	1.4	7.2	4.1	0.7	0.5	4.3	5.9	4.5
France	4.9	0.5	1.5	7.7	26.0	19.3	101	21.5	5.9	29.6	16.8	2.9	2.3	17.9	24.2	18.5
German Fed.Rep	4.7	0.5	1.5	7.5	25.0	18.6	97	20.7	5.7	28.5	16.2	2.7	2.2	17.3	23.3	17.8
Hungary	0.4	0.04	0.1	0.7	1.8	1.4	8	1.6	0.5	2.3	1.3	0.2	0.2	1.3	1.8	1.3
Ireland	0.01	v.s.	v.s.	0.01	0.05	0.03	v.s.	0.04	0.01	0.05	0.03	0.01	0.01	0.03	0.04	0.03
Italy	0.5	0.1	0.2	0.9	2.9	2.1	11	2.4	0.6	3.3	1.9	0.3	0.2	0.2	2.7	2.0
Netherlands	0.5	0.1	0.2	0.8	2.8	2.1	13	2.3	0.6	3.2	1.8	0.3	0.2	2.0	2.6	2.0
Norway*	10	1	3	15	51	38	v.s.	42	11	58	33	6	4	35	47	36
Poland	18.9	2.0	5.8	35.7	96.0	75.5	400	81.8	24.6	121	68.4	11.3	8.8	67.2	95.3	66.0
Portugal	0.05	v.s.	0.01	0.07	0.2	0.2	1	0.2	0.06	0.3	0.2	0.03	0.02	0.2	0.2	0.2
Spain	1.3	0.1	0.4	2.1	7.1	5.3	34	5.9	1.6	8.1	4.6	0.8	0.6	4.9	6.6	5.0
Sweden*	6	1	2	9	30	22	v.s.	24	7	34	19	3	3	20	28	21
Switzerland*	3	v.s.	1	4	14	11	v.s.	12	3	16	9	2	1	10	13	10
Turkey	0.3	0.03	0.1	0.5	1.4	1.1	6	1.2	0.4	1.7	1.0	0.2	0.1	1.0	1.4	1.0
USSR	43.9	4.6	13.5	82.7	233	175	921	190	57.1	280	159	26.0	20.0	156	221	153
United Kingdom	17.9	1.9	5.7	28.6	96.0	71.2	374	79.3	21.7	109	62.0	10.6	8.3	66.2	89.4	68.1

* in kg/year

v.s. very small

Table 18: Emission of trace elements from lignite-power plants in Europe in 1979 (in t/year).

Country	As	Be	Cd	Co	Cr	Cu	Hg*	Mn	Mo	Ni	Pb	Sb	Se	V	Zn	Zr
Albania	0.09	0.01	0.03	0.14	0.47	0.35	2	0.39	0.11	0.54	0.31	0.05	0.04	0.33	0.44	0.33
Austria	0.3	0.03	0.1	0.5	1.7	1.3	7	1.4	0.38	1.9	1.1	0.18	0.15	1.2	1.6	1.2
Bulgaria	3.2	0.3	1.0	6.0	16.2	12.8	73	13.8	4.2	20.5	11.6	1.9	1.5	11.4	16.1	11.2
Czechoslovakia	14.1	1.5	4.4	26.6	71.4	56.2	320	60.8	18.3	90.0	51.0	8.4	6.6	50.0	71.0	49.1
France	0.2	0.02	0.07	0.3	1.1	0.8	5	0.9	0.3	1.3	0.7	0.1	0.1	0.8	1.1	0.8
German Dem.Rep.	22.1	2.3	6.8	41.6	112	88.0	500	95.3	28.7	141	78.0	13.1	10.3	78.3	110	77.0
German Fed.Rep.	14.8	1.5	4.7	23.7	79.4	58.9	333	65.6	17.9	90.4	51.3	8.7	6.9	5.5	74.0	55.2
Greece	1.9	0.2	0.6	3.0	10.2	7.6	43	8.4	2.3	11.6	6.6	1.1	0.9	7.0	9.5	7.1
Hungary	2.9	0.3	0.9	5.5	14.9	11.7	66	0.2	3.8	18.7	10.6	1.7	1.4	10.4	14.8	10.2
Italy	0.5	0.05	0.1	0.8	2.6	1.9	11	2.1	0.6	3.0	1.7	0.3	0.2	1.8	2.4	1.8
Poland	7.9	0.8	2.4	14.9	40.0	31.5	178	34.1	10.3	50.0	28.5	4.7	3.7	28.0	39.7	27.5
Romania	2.1	0.2	0.6	3.9	10.4	8.2	47	8.9	2.7	13.1	7.4	1.2	1.0	7.3	10.4	7.2
Spain	2.4	0.2	0.8	3.9	12.9	9.6	54	10.7	2.9	14.7	8.4	1.4	1.1	8.9	12.0	9.0
Turkey	1.9	0.2	0.6	3.5	9.4	7.4	42	8.0	2.4	11.8	6.7	1.1	0.5	6.6	9.3	6.4
USSR	25.4	2.6	7.9	47.9	129	101	575	110	33.0	162	91.8	15.1	11.8	90.1	128	88.6
Yugoslavia	7.2	0.7	2.2	13.6	36.5	28.7	163	31.1	9.4	45.9	26.0	4.3	3.3	25.5	36.2	25.1

*in kg/year.

Table 19: Emission of trace elements from oil-power plants in Europe in 1979 (t/year).

Country	As	Cd	Co	Cr	Cu	Mn	Mo	Ni	Pb	Se	V	Zn
Austria	1.1	0.51	5.7	1.9	7.7	1.8	1.2	45	5.6	0.82	164	3.9
Belgium	3.6	1.7	19.0	6.3	25.5	6.0	4.1	150	18.5	2.7	544	13.0
Bulgaria	0.9	0.4	4.9	1.6	6.6	1.5	1.1	39	4.8	0.7	140	3.4
Denmark	1.6	0.8	8.6	2.9	11.6	2.8	1.9	68	8.4	1.2	247	5.9
Finland	1.1	0.5	5.8	1.9	7.8	1.8	1.3	46	5.7	0.8	167	4.0
France	2.0	0.9	10.4	3.5	14.0	3.3	2.3	82	10.1	1.5	298	7.1
German Fed.Rep.	2.6	1.2	13.9	4.7	18.7	4.4	3.0	109	13.5	2.0	397	9.5
Greece	0.6	0.3	3.2	1.1	4.3	1.0	0.7	25	3.1	0.5	91	2.2
Hungary	1.0	0.5	5.1	1.7	6.9	1.6	1.1	40	5.0	0.7	146	3.5
Iceland*	3	2	18	6	24	5	4	143	18	3	518	14
Ireland	0.5	0.2	2.6	0.9	3.5	0.8	0.6	21	2.6	0.4	75	1.8
Italy	13.3	6.3	70.3	23.6	94.4	22.1	15.3	554	68.3	10.0	2008	48.2
Netherlands	5.3	2.5	28.1	9.4	37.7	8.8	6.1	222	27.3	4.0	803	19.3
Portugal	0.4	0.2	2.3	0.8	3.1	0.7	0.5	18	2.3	0.3	67	1.6
Romania	2.4	1.2	12.9	4.3	17.3	4.1	2.8	102	12.5	1.8	369	8.8
Spain	2.0	1.0	10.7	3.6	14.4	3.4	2.3	85	10.4	1.5	307	7.4
Sweden	2.1	1.0	11.1	3.7	14.9	3.5	2.4	88	10.8	1.6	318	7.6
Switzerland	0.1	0.03	0.3	0.1	0.5	0.1	0.1	2.6	0.3	0.05	9.5	0.2
Turkey	0.3	0.1	1.7	0.6	2.2	0.5	0.4	13.2	1.6	0.2	48	1.1
USSR	35.1	16.6	186	62.2	250	58.5	40.4	1470	181	26.6	5300	127
United Kingdom	2.6	1.2	13.6	4.5	18.2	4.3	2.9	107	13.2	1.9	388	9.3

*in kg/year.

5 SPATIAL DISTRIBUTION

The spatial distribution of trace element emissions, presented in Figs 1-16 in the previous report [1] were either based on location and capacity of the conventional thermal power plants or inferred subjectively by the author, using any available information such as SO₂ emission, population density, energy consumption density, location of industrial areas, etc. The EMEP grid system with length of 150 km was used.

The location of power plants in eight countries was available from [41]. Details are given in Table 20.

Table 20: Power plants considered for spatial distribution of trace element emissions [41].

Country	Number of power plants considered	Power plant with the lowest output capacity, MW	Power plant with the highest output capacity, MW
Belgium	24	Angleur-100	Rulen-997
Denmark	18	Svanemölle-vaerket-131	Kyndbyvaerket-934
France	45	Harnes-110	Porcheville B-2340
German Fed.Rep.	124	Gelsenkirchen/Horst-104	Frimmersdorf-2376
Ireland	6	Great Island-121	Poolberg-268
Italy	59	Codrongianos-102	La Spezia-1821
Netherland	34	Merwedekanaal-100	Amer-1717
United Kingdom	144	Hastings-110	Longannet-2304

The location of 97 units in Greece was taken partly from [40] and partly assessed on the basis of SO₂ emissions in this country [37]. The spatial distribution of trace element emissions from the Swiss power plants was available from [42] and the same information for Spain from [31].

The location of major power stations in Poland was taken from [9]. The coal power plant in Spitzbergen was taken into account when calculating the Norwegian trace element emissions.

The spatial distribution of trace element emissions from the Swedish power plants was based on data from the large project on coal, health and environment relations [30] and yearly reports on heavy metals in the Swedish environment [43].

Data from [49] were used to estimate trace element emissions from Czechoslovakian power plants. The location of major power plants in Hungary was taken from [19].

Data for the two smallest countries, Iceland and Albania were assessed using population density and energy consumption density. The population figures come from The Times Atlas of the World [45].

The spatial distribution of the trace element emissions for Austria, Bulgaria, Finland, the German Democratic Republic, Portugal, Romania, Turkey, the USSR and Yugoslavia have been calculated based on SO₂ emissions in Europe [37,38] and emissions of nitrogen oxides from fossil fuel combustion [39].

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NORSK INSTITUTT FOR LUFTFORSKNING

(NORGES TEKNISK-NATURVITENSKAPELIGE FORSKNINGSRÅD)
POSTBOKS 130, 2001 LILLESTRØM
ELVEGT. 52.

TLF. (02) 71 41 70

RAPPORTTYPE Teknisk rapport	RAPPORT NR. TR 5/82 (supplement)	ISBN--82-7247-
DATO JANUARY 1983	ANSV.SIGN. B. Ottar	ANT. SIDER 36
TITTEL Trace element emissions from coal- and oil- power plants in Europe. Methodology of calculations		PROSJEKTLEDER K.E.Grønskei
FORFATTER(E) Jozef M. Pacyna		NILU PROSJEKT NR. 24781
		TILGJENGELIGHET** A
		OPPDRAKSGIVERS REF.
OPPDRAKSGIVER NTNF		
3 STIKKORD (å maks. 20 anslag) Emission	Trace metal	Power station
REFERAT (maks. 300 anslag, 5-10 linjer)		
TITLE		
ABSTRACT (max. 300 characters, 5-10 lines. The aim of this supplement is to detail the methodology of trace element emission calculations used in the report TR 5/82 where the spatial distribution of the trace element from conventional thermal power plants in Europe was described.		

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