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A Detailed Emission Inventory of SO_2 for Denmark

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Data sheet

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Summary

The emissions of SO_2 in Denmark from domestic heating, energy generation, industrial combustion, industrial production, road traffic, large point sources and some maritime vessels have been computed and distributed on a grid with 1x1 km^2 elements. The land based area sources have also been distributed among municipalities.

Emission data from the EEC database Corinair for Denmark have been used for domestic heating, energy generation, industrial combustion, industrial production and road traffic. For freighters and ferries, emissions proposed by the European Monitoring and Evaluation Progam (EMEP) and information from the Danish State Railways (DSB), have been used to calculate the emissions.

The distribution of the emissions from area sources on land over the 1x1 km^2 grid has been performed using statistics on the total number of inhabitants in each municipality, inhabitants in urban areas and the registration of the land use by *Runge and Asman* (1989). For road traffic, the emissions have, for major roads been distributed, using information from the Road Data Laboratory (Vejdatalaboratoriet) on placement of the roads in the country. On minor roads, the emissions have as for other area sources on land, been distributed according to the number of inhabitants.

Further, the distribution of emissions among municipalities has been done using both the grid and the land use registrations.

The total Danish SO_2 emission, is estimated to be 351 Kt SO_2 a^{-1}.

Sammenfatning

Emissionen af SO_2 i Danmark fra boligopvarmning, energiproduktion, industriel forbrænding, industriel produktion, vejtrafik, punktkilder samt nogle skibs- og færgeruter er opgjort og fordelt på et 1x1 km^2 net. Arealkilderne på land, er desuden fordelt på kommuner.

For boligopvarmning, energiproduktion, industriel forbrænding, industriel produktion og vejtrafik er brugt data fra EF-databasen Corinair, for Danmark. For skibs- og færgeruter er brugt emissionsstørrelser, som er foreslået af EMEP (European Monitoring and Evaluation Progam) og information fra DSB, i beregningen af emissionen.

Fordelingen af emissionen fra arealkilder på land, over 1x1 km^2 nettet er foretaget udfra befolkningstallene i de enkelte kommuner totalt og i byområder samt udfra registreringen af arealets anvendelse som opgjort i 'Land-use' registreringen (*Runge og Asman, 1989*). For vejtrafik er emissionen på de større veje fordelt udfra information fra Vejdatalaboratoriet, om vejenes placering i landet. På

de mindre veje er emissionen fordelt, som for de andre arealkilder på land, efter befolkningstætheden.

Udfra opgørelsen af emissionerne på 1x1 km^2 er, ved hjælp af registreringen i 'Land-use' af hvilke kommuner hver enkelt km^2 ligger i, beregnet emissionens fordeling på kommuner.

Den samlede danske SO_2-emission beregnet til 351 Ktons SO_2 $år^{-1}$.

1 Introduction

One of the important components in acidification of the environment is sulphur. To be able to model the dispersion and deposition of sulphur components in Denmark, a detailed emission inventory is necessary. The present report describes the characteristics of such a detailed emission inventory for SO_2.

Corinair

A SO_2 emission inventory for Denmark anno 1985 had already been made by the System Analysis Department of Risø National Laboratory, Roskilde, Denmark, within the framework of the EEC Corinair project. This emission inventory consists of two parts: detailed information on the emissions from large point sources and information on emissions from area sources for each county ("amt" in Danish). The latter information, however, is not detailed enough to be used for modelling gradients over Denmark. It was therefore decided to make a more detailed emission inventory for area sources, partly by using information from the existing inventory on domestic heating, energy generation, road traffic and industrial sources. These emissions were then distributed among municipalities ("kommuner" in Danish) and on a grid with 1x1 km^2 elements applying the land-use database for Denmark, developed at NERI (*Runge and Asman, 1989*). Emissions from maritime vessels were computed separately using data from the Danish State Railways (DSB).

The Grid

The grid used in this inventory is the Universal Transverse Mercator (UTM) grid (*Geodætisk Institut, 1981*). The UTM grid is divided into zones. Most of Denmark is situated in Zone 32, but the eastern part of Zealand and Bornholm are situated in Zone 33. To make the inventory more uniform, the Zone 33 coordinates of Zealand and Bornholm, have been transformed to Zone 32 coordinates. That is, all coordinates in the inventory are given in UTM Zone 32.

Risø National Laboratory computed the emission from domestic heating, energy generation, road traffic and industrial production and combustion.

Erik Runge at NERI performed the computations of emissions from maritime vessels, the distribution of SO_2 emissions among municipalities and grid elements and the construction of the detailed inventory.

The computation of emissions have been done using in principle the same programs as used in *Runge, Asman and Kilde* (1991).

We wish to thank Svend Schrøder from the Road Data Laboratory for making road traffic data available, Bo V. Thomsen from DSB for giving information on the main ferry services and Nicky Brown, NERI for proofreading.

The work done by NERI was supported by the Danish National Agency of Environmental Protection (Miljøstyrelsen) within the framework of the projects "NPo" and at the "Marine Research Programme-90".

2 Emissions from area sources on land

2.1 Introduction

The following categories of SO_2 emissions from area sources have been taken from the Corinair database:

- domestic heating
- energy generation
- industrial combustion
- industrial production
- road traffic.

The difference between emissions from industrial combustion and those from industrial production is that in combustion, the flue gases are not in direct contact with the produced material, whereas in production they are.

2.2 Computation of the gridded emissions

Corinair

In the Corinair database the total emission from domestic heating, energy generation, industrial combustion, industrial production and road traffic, for each county is given. For use in dispersion models, we wanted to have the emissions on a regular grid. Therefore the Corinair data were distributed on a 1x1 km^2 grid.

But as dispersion models using a 1x1 km^2 grid may be considered to be unnecessarily time consuming, the emissions were additionally distributed on a 5x5 km^2 grid.

Land use

Within each county and municipality the emissions were distributed according to the land-use registration of *Runge and Asman* (1989), where for each km^2 it has been registered i.a. how much of the area is urban and how much is farmland.

Distribution

It was assumed that all industry and energy generation is placed in urban areas. The total emission from industry and energy generation was distributed evenly over all areas which have been registered as urban. The emissions from domestic heating were for each municipality, within the urban areas distributed according to the number of inhabitants in urban areas, while in other areas they were distributed evenly according to the total number of inhabitants not living in urban areas. The distribution on the 1x1 km^2 grid was conducted using again the land-use registration.

Road traffic

The emissions from the road traffic have also been distributed on the 1x1 km^2 grid. From the Danish Road Data Laboratory (RDL) ("Vejdatalaboratoriet" in Danish) under the Road Directorate, we have received information on the positions of all Danish state and county roads, i.e. all major roads in Denmark (*S. Schrøder, RDL, pers. comm. 1990*). Each road was divided into smaller pieces. To each piece were attached i.a. the road number, the coordinates of the beginning and ending points and the yearly traffic.

Using questionnaires the RDL has estimated the total traffic per year on all Danish roads. By subtracting the sum of the traffic on main roads from the total traffic, we obtained an estimate of the traffic on minor (mainly municipal) roads in Denmark.

As we for most of the major roads have their placement in the country by their beginning and ending coordinates for each road piece, they have in this way been distributed on the 1x1 km^2 grid net. For road pieces where coordinates of the beginning and ending points were missing, the emissions were distributed evenly over the county in which the road is situated (this was the case for county roads in Ringkøbing amt).

The emissions on minor roads have been distributed over the municipalities according to the number of inhabitants in each municipality (1988 statistics given by the Danish Statistical Office). Within municipalities the emissions have been distributed on the 1x1 km^2 grid, using information in the land-use registration and population data from the Danish Statistical Office. We have, using this distribution key, assumed that all inhabitants in Denmark drive equally much on municipal roads.

Municipalities

Thus all land based SO_2 area emissions were computed and distributed on a 1x1 km^2 grid. The data were stored in a data file named SO2_AREA.dat. The distribution of emissions over municipalities was done using the file SO2_AREA.dat and the land-use registration, the latter in which each km^2 is subordinated to municipalities. The results of this distribution are shown in Table 1.

Figures 1 to 5 show the geographical distribution of the SO_2 emissions for the five different categories; domestic heating, energy generation, industrial combustion, industrial production and traffic. Figure 6 shows the geographical distribution of the total SO_2 emission from area sources in Denmark.

3 Emissions from large point sources on land

3.1 Introduction

Limits

The following categorizing of SO_2 emission point sources has been taken from the Corinair database:

- power stations over 300 MW
- oil refineries
- manufacturing of sulphuric and nitric acid
- iron- and steelworks
- paper mills
- car lacquering works with over 100000 cars a^{-1}.

Of these categories it is mainly major power stations which in Denmark are categorized as point sources. Sources, in Denmark, which are too small to be categorized as a point source are registred in the Corinair database for area sources.

3.2 Locations of the emissions

In the Corinair database the location of a point source is given by its global longitude and latitude. These have been transformed to UTM Zone 32 coordinates.

In Table 2, are listed the total SO_2 emissions from major point sources for the counties in Denmark. In Figure 7 are plotted the major point sources. Note that the diameter of a circle in the figure shows the relative magnitude of the corresponding source or cluster of sources.

4 Emissions from maritime vessels

4.1 Introduction

Categories

The emissions from maritime vessels can be divided into different categories, such as:

- international freighter traffic
- national freighter traffic
- international ferry traffic
- national ferry traffic
- fishing boats
- leisure vessels
- military ships
- other maritime vessels.

In this study only emissions from international freighter traffic and some of the main national ferries were included.

Of importance for the SO_2 emissions are especially for ferries the time used in port and the time used for arrival at and departure from ports, which have not been taken into account in this investigation.

4.2 SO_2 emissions from international freighter traffic

Routes

There are two main routes for international freighter traffic through Danish waters. These are (see Figure 8):

Route T from Skagen, east of the island of Anholt, through the Great Belt (Storebælt), south of Lolland and Falster and into the Baltic Sea (Østersøen). Route D/B which is initially as route T, but from Anholt it goes southeast through the Sound into the Baltic Sea.

North of Skagen and within the Baltic Sea the ships do not follow specific routes but sail in different directions depending on their destinations. For this reason, the SO_2 emissions have been estimated and gridded only for those route sections as shown in Figure 8.

There are other freighter routes in Danish national waters, but these two are the most important.

Emissions

The total emission was calculated using the emissions given by Bremnes (1990). For route T from Skagen to southeast of Lolland, Bremnes gives an emission of 31 tonne SO_2 per nautical mile per year (tonne nmi^{-1} a^{-1}).

Southeast of Lolland a different route passing through the Kiel Canal joins route T, and the emission from the joining point further eastwards is 78 tonne nmi^{-1} a^{-1}. Along route D/B the emission is 19 tonne nmi^{-1} a^{-1}. These emissions must be taken as average emissions for all types of freighters.

4.3 SO_2 emissions from national ferry services

Companies

The ferry services in Denmark are run by different companies, of which the largest are DSB, DFDS and Bornholmstrafikken. Of these, DSB is by far the largest, having 29 ferry routes. We were given information on the 9 most important DSB routes, including their yearly consumption of marine dieseloil and fueloil. The 9 routes are shown in Figure 9.

Emissions

The SO_2 emissions were calculated on the basis of the oil consumption, and information from DSB, that the sulphur content of the marine dieseloil is less than 1.0% whereas the sulphur content of fueloil varies between 2.3 and 2.9%. The yearly oil consumption was given in m^3. As the density of the fuel used varied between 0.80 and 0.95 tonne m^{-3}, a mean density of 0.85 tonne m^{-3} was used. In the calculations we assume a sulphur content of 1% in marine dieseloil and uses the percent sulphur content in fueloil as given by DSB on the actual routes. We also assume, that all of the sulphur is emitted as SO_2.

For each of the 9 routes the emission was calculated and distributed evenly along the route (thus not taking into account the time the ferries spent in port or navigating in and out of ports).

4.4 Computation of the gridded emissions

The estimated SO_2 emissions from international freighter traffic and main ferry services are shown in Table 3.

The emissions from international freighter traffic as distributed on the UTM grid are shown in Figure 10. The gridded emissions from main ferry services are shown in Figure 11.

5 Total emissions

The total Danish SO_2 emission comprising all major point and area sources over land and sea, as estimated in this survey, adds up to approximately 351 Kt SO_2 a^{-1}.

In Table 4 are listed the total SO_2 emissions from the different source categories in this survey, and in Figure 12 these are visualised in a pie chart.

6 Comparison with other emission estimates and uncertainties in the inventory

6.1 Comparison with other emission estimates

Some SO_2 emission inventories for Denmark have been made for various source categories, prior to the present inventrory, but as there have been no standards within this field of work, comparison between inventories is difficult.

Road traffic

For the total emission from road traffic, *Torp* (1983) has made an inventory for the year 1980 in which this emission is estimated to be 15 Kt SO_2 a^{-1}.

In the present survey, the road traffic emission is estimated to be 11 Kt SO_2 a^{-1}.

Total emission

The total SO_2 emission from point and area sources, but not including emissions from maritime vessels, has been calculated by *Torp* (1983) in 1980 to be 417 Kt SO_2 a^{-1}.

If in the present survey the total emissions from area sources and large point sources are added together, we get an emission in 1985 of 334 Kt SO_2 a^{-1}, which is 25% lower than the figure given by *Torp*.

The difference is partly due to a reduction in energy consumption and partly due to a change from use of oil to use of coal in the power plants. The reduction is not due to a regulation in the sulphur content of the fuel, which was first prescribed by law after 1985.

Another estimate of the total SO_2 emissions in 1985, given by N. Halvorsen (EMEP, Pers. comm., 1990), is 340 Kt SO_2.

It is seen that there is a reasonable agreement between the total emissions given in the different inventories.

6.2 Uncertainties in the inventory

It is estimated that there are uncertainties of the order of 10% in much of the SO_2 emissions data in the Corinair database.

The distribution of area sources over municipalities has in the present study been done according to the number of inhabitants in each municipality. Other distribution keys could have been used, e.g. for traffic or for domestic heating and energy generation. Which would lead to different results. Thus the resulting distribution, as listed in Table 1, should be treated with caution.

The uncertainty in the estimate of the total emission from maritime vessels is very large, mainly because a great number of lesser transport were omitted. The real total emission from maritime vessels could well be twice as high.

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Tables

Note that in several of the tables, the SO_2 emissions are listed with greater accuracy than warranted by the uncertainties in the present investigation.

Table 1. SO_2 emissions for different source categories and emission densities for each municipality and county in Denmark. Only area sources are listed in this table. Point sources are for each county listed in Table 2.

No. Municipality	Emission (tonne SO_2 a^{-1})						Emission density
	Domestic heating	Energy generation	Industrial combustion	Industrial production	Road traffic	Total	tonne SO_2 km^{-2} a^{-1}
101 København	3132.4	1697.8	5823.8	653.8	437.3	11745.1	133.3
147 Frederiksberg	541.6	285.4	1006.9	113.0	69.4	2016.3	229.9
013 København and Frederiksberg	3673.9	1983.1	6830.7	766.8	506.7	13761.4	142.0

No. Municipality	Emission (tonne SO_2 a^{-1})						Emission density
	Domestic heating	Energy generation	Industrial combustion	Industrial production	Road traffic	Total	tonne SO_2 km^{-2} a^{-1}
151 Ballerup	309.1	419.0	74.5	64.7	92.6	1459.9	42.8
153 Brøndby	233.9	317.1	434.7	48.8	12.9	1147.3	55.4
155 Dragør	83.7	113.5	155.6	17.5	16.9	387.2	21.4
157 Gentofte	461.8	594.8	858.4	96.4	120.6	2132.0	83.5
159 Gladsakse	419.8	553.5	780.2	87.6	144.7	1985.8	79.4
161 Glostrup	139.7	189.4	259.7	29.2	62.9	680.8	51.2
163 Herlev	182.0	244.4	338.3	38.0	52.5	855.2	71.0
165 Albertslund	192.6	261.1	357.9	40.2	63.9	915.7	39.7
167 Hvidovre	336.5	443.6	625.5	70.2	95.1	1570.9	72.5
169 Høje Tåstrup	298.1	403.5	553.1	62.1	131.2	1448.0	18.2
171 Ledøje-Smørum	59.6	80.6	110.5	12.4	11.8	274.8	8.8
173 Lyngby-Tårbæk	329.5	446.9	612.5	68.8	100.5	1558.2	40.0
175 Rødovre	246.7	317.6	458.5	51.5	81.5	1155.8	95.4
181 Søllerød	212.5	287.2	396.1	46.2	74.8	1016.8	25.6
183 Ishøj	137.1	185.7	255.1	28.6	62.0	668.5	27.0
185 Tårnby	284.9	358.5	529.5	59.5	57.1	1289.5	20.6
187 Vallensbæk	80.0	108.5	148.7	16.7	41.3	395.2	43.0
189 Værløse	122.4	165.8	227.3	25.5	44.1	585.2	17.2
015 Københavns amtskommune	4130.0	5490.7	7676.2	863.8	1366.4	19527.0	37.1

Table 1 continued

No. Municipality	Emission (tonne SO_2 a^{-1})						Emission density tonne SO_2 km^{-2} a^{-1}
	Domestic heating	Energy generation	Industrial combustion	Industrial production	Road traffic	Total	
201 Allerød	133.3	159.1	271.9	67.5	53.0	684.9	10.2
205 Birkerød	133.5	160.6	271.8	66.0	58.5	690.4	20.6
207 Farum	103.5	123.9	211.7	52.5	38.1	529.7	23.4
208 Fr.borg-Humlebæk	116.1	138.6	236.9	58.8	44.6	594.9	8.3
209 Frederikssund	103.0	123.7	211.0	52.0	29.9	519.6	12.8
211 Frederiksværk	109.8	132.0	225.5	56.0	35.1	558.4	6.2
213 Græsted-Gilleleje	108.9	130.3	222.8	55.3	35.9	553.2	4.1
215 Helsinge	107.9	128.6	219.8	54.6	37.3	548.2	3.8
217 Helsingør	349.1	418.1	714.6	177.4	95.2	1754.4	14.4
219 Hillerød	208.7	250.5	428.2	106.3	77.9	1071.6	8.1
221 Hundested	54.2	64.8	110.7	27.5	13.0	270.3	8.5
223 Hørsholm	146.4	175.4	299.0	73.7	50.3	744.7	23.7
225 Jægerspris	47.7	57.2	97.7	24.3	21.1	247.9	2.6
227 Karlebo	116.9	139.8	239.0	59.3	40.2	595.3	14.9
229 Skibby	36.2	43.1	73.7	18.3	8.1	179.5	2.3
231 Skævinge	31.8	37.1	63.4	15.7	16.3	164.3	2.4
233 Slangerup	47.7	57.3	97.9	24.3	20.3	247.6	5.4
235 Stenløse	79.2	95.1	162.2	40.1	26.0	402.5	6.2
237 Ølstykke	80.2	96.6	164.4	40.2	24.8	406.1	14.0
020 Frederiksborg amtskommune	2114.1	2531.8	4322.3	1069.7	725.6	10763.6	8.0

No. Municipality	Emission (tonne SO_2 a^{-1})						Emission density tonne SO_2 km^{-2} a^{-1}
	Domestic heating	Energy generation	Industrial combustion	Industrial production	Road traffic	Total	
251 Bramsnæs	48.6	64.4	94.7	10.3	35.7	253.7	3.2
253 Greve	284.4	376.4	552.6	60.3	115.6	1389.4	23.1
255 Gundsø	77.6	102.2	151.6	17.9	19.1	368.4	5.8
257 Hvalsø	44.8	58.8	86.8	9.5	21.3	221.1	3.1
259 Køge	225.5	299.5	440.3	48.0	140.8	1154.1	9.3
261 Lejre	52.6	69.3	101.8	11.1	44.1	278.9	3.2
263 Ramsø	54.1	72.1	106.0	11.6	12.1	255.8	3.8
265 Roskilde	306.5	406.5	597.6	65.2	111.0	1486.8	18.4
267 Skovbo	82.3	108.2	159.0	17.4	41.2	408.0	3.1
269 Solrød	119.7	158.1	232.5	25.4	66.7	602.4	15.1
271 Vallø	57.3	74.6	109.8	12.0	18.7	272.4	3.3
025 Roskilde amtskommune	1353.2	1790.0	2632.6	288.7	626.3	6690.9	7.5

Table 1 continued

No. Municipality	Emission (tonne SO_2 a^{-1})						Emission density tonne SO_2 km^{-2} a^{-1}
	Domestic heating	Energy generation	Industrial combustion	Industrial production	Road traffic	Total	
301 Bjergsted	59.2	35.0	72.5	8.4	20.5	195.5	1.4
303 Dianalund	55.5	33.2	68.7	7.9	13.0	178.2	2.7
305 Dragsholm	98.0	58.1	120.2	13.9	29.7	319.8	2.1
307 Fuglebjerg	49.5	29.4	60.4	7.0	19.8	166.1	1.2
309 Gørlev	46.5	27.6	57.2	6.6	14.1	152.0	1.7
311 Hashøj	50.3	29.2	60.3	7.0	22.3	169.0	1.3
313 Haslev	107.5	63.7	131.7	15.2	31.0	349.1	2.6
315 Holbæk	241.8	143.5	296.8	34.2	74.2	790.4	5.0
317 Hvidebæk	42.4	25.1	52.0	6.0	13.8	139.3	1.4
319 Høng	62.6	37.2	76.9	8.9	18.8	204.3	1.4
321 Jernløse	43.0	25.5	52.6	6.1	18.0	145.2	1.4
323 Kalundborg	151.4	89.8	185.7	21.4	23.4	471.6	3.6
325 Korsør	160.5	95.4	197.4	22.8	41.8	517.9	6.9
327 Nykøbing-Rørvig	53.2	31.7	65.6	7.6	10.5	168.6	4.2
329 Ringsted	223.0	132.2	273.5	31.5	88.9	749.2	2.5
331 Skælskør	86.2	51.2	105.9	12.2	22.7	278.1	1.6
333 Slagelse	265.2	157.6	325.9	37.6	75.5	861.7	4.5
335 Sorø	110.9	66.0	136.6	15.7	51.2	380.5	2.6
337 Stenlille	39.5	23.2	48.0	5.5	13.7	129.9	1.4
339 Svinninge	48.8	28.9	59.7	6.9	17.4	161.7	1.9
341 Tornved	68.9	40.9	84.5	9.7	21.3	225.4	2.2
343 Trundholm	81.4	48.3	99.9	11.5	35.1	276.2	1.7
345 Tølløse	71.4	42.7	87.9	10.1	26.7	238.9	1.9
030 Vestsjællands amtskommune	2216.6	1315.4	2719.9	313.5	703.2	7268.5	2.4

Table 1 continued

No.	Municipality	Emission (tonne SO_2 a^{-1}) Domestic heating	Energy generation	Industrial combustion	Industrial production	Road traffic	Total	Emission density tonne SO_2 km^{-2} a^{-1}
351	Fakse	100.4	66.0	100.7	12.3	21.1	300.5	2.1
353	Fladså	63.8	41.8	63.8	7.8	32.3	209.5	1.6
355	Holeby	40.8	26.6	40.7	5.0	7.7	120.8	1.0
357	Holmegård	58.1	37.8	57.7	7.1	12.5	173.2	1.6
359	Højreby	39.2	25.6	39.1	4.8	14.8	123.6	1.0
361	Langebæk	53.0	34.6	52.8	6.5	15.3	162.1	1.6
363	Maribo	102.3	66.6	101.8	12.5	33.3	316.5	2.1
365	Møn	99.2	64.7	98.8	12.1	25.7	300.6	1.3
367	Nakskov	143.8	93.8	143.3	17.6	15.6	414.1	12.7
369	Nykøbing Falster	222.7	145.4	222.1	27.2	46.8	664.2	5.0
371	Nysted	51.1	33.0	50.4	6.2	12.2	152.9	1.1
373	Næstved	400.2	261.0	398.5	48.8	79.3	1187.8	5.9
375	Nr. Alslev	85.9	56.1	85.6	10.5	43.0	281.2	1.6
377	Præstø	61.7	40.2	61.3	7.5	23.9	194.6	1.8
379	Ravnsborg	58.4	38.0	58.1	7.1	10.0	171.6	0.9
381	Rudbjerg	34.3	22.3	34.0	4.2	6.6	101.3	0.7
383	Rødby	63.7	41.4	63.3	7.8	17.2	193.3	1.6
385	Rønnede	57.0	37.2	56.7	7.0	48.1	205.9	1.7
387	Sakskøbing	82.5	53.9	82.2	10.1	36.3	264.9	1.5
389	Stevns	93.2	61.0	93.1	11.4	15.3	274.1	1.7
391	Stubbekøbing	61.4	39.8	60.8	7.5	13.3	182.7	1.2
393	Suså	70.5	45.9	70.2	8.6	18.6	213.8	1.5
395	Sydfalster	59.3	38.9	59.4	7.3	16.1	181.0	1.6
397	Vordingborg	177.0	115.3	176.1	21.6	54.6	544.6	3.1
035	Storstrøms amtskommune	2279.5	1486.9	2270.5	278.1	619.7	6934.8	2.0

No.	Municipality	Emission (tonne SO_2 a^{-1}) Domestic heating	Energy generation	Industrial combustion	Industrial production	Road traffic	Total	Emission density tonne SO_2 km^{-2} a^{-1}
401	Allinge-Gudhjem	105.7	36.0	59.5	25.3	16.5	243.0	1.6
403	Hasle	87.0	29.5	48.7	20.7	15.1	201.0	1.8
405	Neksø	116.8	39.9	65.9	28.0	16.8	267.3	2.6
407	Rønne	196.2	67.1	110.9	47.1	21.4	442.7	15.3
409	Åkirkeby	89.7	30.4	50.1	21.3	21.1	212.6	1.1
411	Christiansø	1.5	0.0	0.0	0.0	0.1	1.6	3.9
40	Bornholms amtskommune	596.9	202.8	335.0	142.3	91.0	1368.1	2.3

Table 1 continued

No. Municipality	Emission (tonne SO_2 a^{-1})						Emission density tonne SO_2 km^{-2} a^{-1}
	Domestic heating	Energy generation	Industrial combustion	Industrial production	Road traffic	Total	
421 Assens	53.1	52.1	122.7	9.1	21.0	258.0	1.9
423 Bogense	30.3	29.7	69.9	5.2	11.4	146.4	1.4
425 Broby	31.7	31.1	73.2	5.4	13.5	155.0	1.6
427 Egebjerg	42.4	41.7	98.2	7.3	22.2	211.8	1.7
429 Ejby	48.6	47.7	112.4	8.4	43.4	260.5	1.6
431 Fåborg	86.0	84.2	198.5	14.8	36.9	420.5	1.9
433 Glamsbjerg	28.7	28.1	66.3	4.9	14.0	142.1	1.6
435 Gudme	30.1	29.5	69.4	5.2	10.7	144.8	1.2
437 Hårby	24.5	24.0	56.6	4.2	9.4	118.8	1.5
439 Kerteminde	51.1	49.9	117.6	8.7	20.6	247.9	1.7
441 Langeskov	29.4	29.0	68.2	5.1	19.3	151.0	3.5
443 Marstal	18.0	17.7	41.8	3.1	3.8	84.5	5.0
445 Middelfart	91.0	89.5	210.8	15.7	46.6	453.5	6.3
447 Munkebo	28.6	28.3	66.6	5.0	9.8	138.2	7.2
449 Nyborg	90.6	88.9	209.4	15.6	40.0	444.5	5.3
451 Nr. Åby	26.2	25.6	60.3	4.5	25.7	142.3	2.2
461 Odense	859.7	844.0	1988.5	148.0	322.5	4162.7	13.7
471 Otterup	54.6	53.5	126.2	9.4	20.0	263.6	1.6
473 Ringe	54.6	53.8	126.8	9.4	32.5	277.2	1.8
475 Rudkøbing	34.0	33.5	79.0	5.9	11.3	163.7	2.6
477 Ryslinge	34.8	34.1	80.3	6.0	18.7	173.8	2.1
479 Svendborg	201.0	197.2	464.7	34.6	58.3	955.7	5.5
481 Sydlangeland	23.8	23.3	54.9	4.1	11.0	117.2	1.0
483 Søndersø	55.0	53.8	126.8	9.4	22.4	267.5	1.5
485 Tommerup	36.2	35.5	83.6	6.2	16.9	178.5	2.4
487 Tranekær	19.2	18.7	44.1	3.3	9.8	95.1	0.9
489 Ullerslev	23.7	23.4	55.2	4.1	15.0	121.4	2.2
491 Vissenbjerg	29.2	28.7	67.7	5.0	37.9	168.6	3.6
493 Ærøskøbing	22.0	21.5	50.6	3.8	8.0	105.9	1.4
495 Ørbæk	32.6	31.8	74.8	5.6	18.5	163.3	1.2
497 Årslev	45.1	43.9	103.4	7.7	18.5	218.6	2.9
499 Årup	25.8	25.3	59.5	4.4	21.2	136.2	1.7
042 Fyns amtskommune	2261.8	2218.9	5228.1	389.1	990.9	11088.9	3.2

Table 1 continued

No. Municipality	Emission (tonne SO_2 a^{-1})						Emission density tonne SO_2 km^{-2} a^{-1}
	Domestic heating	Energy generation	Industrial combustion	Industrial production	Road traffic	Total	
501 Augustenborg	43.3	63.3	76.9	8.4	13.8	205.8	3.9
503 Bov	69.0	100.4	121.9	13.4	58.5	363.2	2.5
505 Bredebro	26.2	38.0	46.2	5.1	10.0	125.5	0.8
507 Broager	40.6	59.1	71.7	7.9	14.7	194.1	4.5
509 Christiansfeld	59.5	86.8	105.3	11.5	43.5	306.6	1.5
511 Gram	34.2	49.6	60.3	6.6	14.4	165.1	1.3
513 Gråsten	45.7	66.6	80.8	8.9	18.7	220.6	3.9
515 Haderslev	200.0	291.3	353.6	38.8	66.4	950.0	3.5
517 Højer	20.1	29.3	35.6	3.9	7.7	96.5	0.9
519 Lundtoft	40.9	59.6	72.3	7.9	33.8	214.6	1.6
521 Løgumkloster	46.2	67.1	81.4	8.9	19.7	223.2	1.1
523 Nordborg	98.3	143.0	173.6	19.0	25.6	459.6	3.7
525 Nr. Rangstrup	66.2	96.2	116.8	12.8	33.9	325.9	1.1
527 Rødding	72.3	105.3	127.9	14.0	33.0	352.6	1.3
529 Rødekro	73.0	106.2	128.9	14.1	52.2	374.4	1.9
531 Skærbæk	51.1	74.4	90.3	9.9	28.5	254.3	0.7
533 Sundeved	35.1	50.8	61.7	6.8	17.1	171.5	2.5
535 Sydals	44.4	64.4	78.2	8.6	13.3	208.9	2.2
537 Sønderborg	184.1	268.0	325.3	35.7	46.4	859.5	15.8
539 Tinglev	69.2	100.5	122.0	13.4	29.3	334.4	1.0
541 Tønder	83.4	121.5	147.5	16.2	35.3	404.0	2.2
543 Vojens	112.1	162.7	197.6	21.7	63.9	558.0	1.9
545 Åbenrå	141.4	206.0	250.0	27.4	63.9	688.7	5.4
050 Sønderjyllands amtskommune	1656.5	2410.2	2925.8	320.8	743.6	8056.7	2.1

No. Municipality	Emission (tonne SO_2 a^{-1})						Emission density tonne SO_2 km^{-2} a^{-1}
	Domestic heating	Energy generation	Industrial combustion	Industrial production	Road traffic	Total	
551 Billund	35.0	42.0	97.6	9.1	15.9	199.6	1.3
553 Blåbjerg	30.4	36.5	84.8	7.9	19.4	179.1	0.7
555 Blåvandshuk	18.1	22.1	51.3	4.8	11.2	107.4	0.5
557 Bramming	59.4	71.5	166.1	15.4	28.0	340.4	2.0
559 Brørup	28.7	34.5	80.2	7.5	15.2	166.1	1.6
561 Esbjerg	376.5	453.4	1053.5	98.0	126.6	2108.1	9.6
563 Fanø	14.8	17.9	41.5	3.9	2.8	80.8	1.5
565 Grindsted	79.4	95.4	221.7	20.6	46.0	463.2	1.2
567 Helle	38.6	46.2	107.3	10.0	22.6	224.7	0.8
569 Holsted	31.7	38.1	88.4	8.2	20.5	186.9	1.0
571 Ribe	83.2	100.1	232.5	21.6	49.0	486.4	1.4
573 Varde	87.2	105.0	244.1	22.7	47.0	506.0	2.0
575 Vejen	74.3	90.5	208.1	19.4	44.3	436.6	1.8
577 Ølgod	51.9	62.6	145.5	13.5	22.9	296.4	1.2
055 Ribe amtskommune	1009.3	1215.6	2822.7	262.6	471.4	5781.6	1.8

Table 1 continued

No. Municipality	Emission (tonne SO_2 a^{-1})						Emission density tonne SO_2 km^{-2} a^{-1}
	Domestic heating	Energy generation	Industrial combustion	Industrial production	Road traffic	Total	
601 Brædstrup	52.9	114.8	140.8	18.2	22.1	348.9	1.7
603 Børkop	66.7	144.7	177.5	22.9	39.9	451.8	4.4
605 Egtved	88.2	190.6	233.8	30.2	46.4	589.2	1.8
607 Fredericia	288.4	624.1	765.4	99.0	91.6	1868.4	13.9
609 Gedved	60.1	130.7	160.3	20.7	27.8	399.7	2.6
611 Give	85.5	184.6	226.3	29.3	40.6	566.3	1.4
613 Hedensted	90.7	196.4	240.9	31.1	37.4	596.5	4.3
615 Horsens	343.4	742.9	911.1	117.8	97.3	2212.6	11.7
617 Jelling	30.8	67.4	82.7	10.7	9.8	201.4	2.3
619 Juelsminde	92.1	199.6	244.8	31.6	32.4	600.5	2.5
621 Kolding	358.0	774.4	949.8	122.8	143.4	2348.4	9.8
623 Lunderskov	30.1	64.6	79.9	10.3	12.4	197.4	2.1
625 Nr. Snede	45.9	99.3	121.7	15.7	36.4	319.0	1.3
627 Tørring-Uldum	72.7	156.7	192.1	24.8	50.3	496.6	2.6
629 Vamdrup	42.8	92.4	113.3	14.6	18.5	281.6	2.8
631 Vejle	318.3	690.0	846.2	109.4	122.0	2086.0	14.5
060 Vejle amtskommune	2066.8	4473.2	5486.7	709.3	828.3	13564.2	4.5

No. Municipality	Emission (tonne SO_2 a^{-1})						Emission density tonne SO_2 km^{-2} a^{-1}
	Domestic heating	Energy generation	Industrial combustion	Industrial production	Road traffic	Total	
651 Avlum-Haderup	41.9	146.1	105.1	8.3	21.2	322.6	1.3
653 Brande	53.3	188.6	135.6	10.6	19.4	407.5	2.2
655 Egvad	60.2	212.6	152.8	12.0	32.8	470.3	1.3
657 Herning	352.1	1244.8	894.6	70.1	142.2	2703.7	5.0
659 Holmsland	33.3	117.4	84.4	6.6	22.5	264.1	2.8
661 Holstebro	239.7	847.5	609.0	47.7	78.3	1822.2	5.2
663 Ikast	137.0	484.2	348.0	27.3	59.0	1055.5	3.6
665 Lemvig	120.3	425.3	305.6	24.0	36.3	911.4	2.0
667 Ringkøbing	106.4	376.8	270.8	21.2	40.9	816.2	2.0
669 Skjern	78.9	279.1	200.6	15.7	27.3	601.6	1.8
671 Struer	119.3	422.0	303.3	23.8	34.4	902.8	5.2
673 Thyborøn-Harboør	33.1	117.1	84.1	6.6	10.0	250.9	6.0
675 Thyholm	24.4	85.0	61.3	4.9	11.4	187.0	2.5
677 Trehøje	57.8	204.1	146.7	11.5	18.1	438.2	1.5
679 Ulfborg-Vemb	44.4	156.9	112.7	8.8	15.4	338.3	1.5
681 Videbæk	74.9	264.9	190.4	14.9	29.2	274.4	2.0
683 Vinderup	51.2	179.9	129.4	10.2	26.4	397.1	1.8
685 Åskov	42.6	150.6	108.2	8.5	20.9	330.8	1.4
065 Ringkøbing amtskommune	1670.9	5902.8	4242.5	332.9	645.7	12794.8	2.6

Table 1 continued

No. Municipality	Emission (tonne SO_2 a^{-1})						Emission density tonne SO_2 km^{-2} a^{-1}
	Domestic heating	Energy generation	Industrial combustion	Industrial production	Road traffic	Total	
701 Ebeltoft	63.4	155.5	140.2	14.4	31.9	405.2	1.5
703 Galten	48.7	118.8	107.1	11.0	19.4	305.0	4.2
705 Gjern	36.1	88.1	79.4	8.1	21.4	233.2	1.6
707 Grenå	92.4	226.4	204.1	20.9	29.1	572.9	2.9
709 Hadsten	53.8	131.3	118.4	12.1	34.4	349.9	2.5
711 Hammel	49.2	120.5	108.6	11.1	29.4	318.8	2.2
713 Hinnerup	49.3	120.8	108.9	11.2	17.4	307.6	4.0
715 Hørning	37.0	90.9	82.0	8.4	24.1	242.4	3.6
717 Langå	41.3	100.7	90.6	9.4	17.7	259.7	2.0
719 Mariager	40.4	99.2	89.4	9.2	17.9	256.1	1.3
721 Midtdjurs	37.4	91.4	82.4	8.4	17.1	236.7	1.3
723 Nørhald	43.4	106.2	95.8	9.8	18.7	273.9	1.4
725 Nr. Djurs	38.2	93.8	84.6	8.7	15.8	241.1	1.0
727 Odder	91.3	223.6	201.6	20.7	32.9	570.1	2.5
729 Purhus	44.5	108.0	97.3	10.1	22.9	282.8	1.7
731 Randers	304.5	747.1	673.5	69.0	119.9	1914.1	12.5
733 Rosenholm	47.0	115.3	104.0	10.7	32.0	309.0	2.2
735 Rougsø	40.2	98.5	88.8	9.1	13.3	250.0	1.1
737 Ry	48.2	118.3	106.7	10.9	26.6	310.8	2.0
739 Rønde	29.5	72.5	65.3	6.7	25.7	199.7	2.0
741 Samsø	22.1	54.1	48.8	5.0	6.6	136.6	1.2
743 Silkeborg	238.9	586.6	528.8	54.2	86.1	1494.6	5.9
745 Skanderborg	98.3	240.5	216.8	22.2	68.4	646.3	4.5
747 Sønderhald	40.6	99.5	89.7	9.2	30.8	269.8	2.0
749 Them	31.5	75.8	68.3	7.0	25.1	207.8	1.0
751 Århus	1286.2	3153.6	2843.2	291.3	412.4	7986.7	17.0
070 Århus amtskommune	2953.5	7237.1	6524.4	668.8	1197.1	18580.9	4.1

Table 1 continued

No. Municipality	Emission (tonne SO_2 a^{-1})						Emission density tonne SO_2 km^{-2} a^{-1}
	Domestic heating	Energy generation	Industrial combustion	Industrial production	Road traffic	Total	
761 Bjerringbro	102.6	175.2	144.6	24.5	30.5	477.4	2.3
763 Fjends	64.2	110.1	90.7	15.3	21.3	301.6	1.2
765 Hanstholm	47.5	80.6	66.5	11.3	12.6	218.5	1.0
767 Hvorslev	51.0	87.3	72.3	12.1	11.1	233.8	1.8
769 Karup	53.4	91.7	75.5	12.7	20.1	253.3	1.6
771 Kjellerup	105.6	180.5	149.0	25.3	47.2	507.7	2.0
773 Morsø	190.2	323.9	267.3	45.3	42.5	869.2	2.4
775 Møldrup	58.3	98.7	81.5	15.4	25.3	279.2	1.3
777 Sallingsund	49.7	84.8	69.9	11.9	16.4	232.7	2.3
779 Skive	212.4	361.8	298.5	50.6	53.3	976.6	4.2
781 Spøttrup	62.5	106.5	87.9	14.9	19.1	290.9	1.5
783 Sundsøre	54.7	93.2	76.9	13.1	11.6	249.5	1.5
785 Sydthy	97.9	167.6	138.1	23.3	27.5	454.3	1.4
787 Thisted	235.1	400.8	330.8	56.1	72.8	1095.6	1.9
789 Tjele	65.3	111.0	91.6	15.5	31.3	314.8	1.2
791 Viborg	312.7	533.1	439.9	74.6	91.2	1451.5	4.6
793 Ålestrup	59.5	101.8	84.0	15.6	21.3	282.3	1.6
076 Viborg amtskommune	1822.7	3108.8	2564.9	437.6	554.9	8488.9	2.1

Table 1 continued

No.	Municipality	Emission (tonne SO_2 a^{-1}) Domestic heating	Energy generation	Industrial combustion	Industrial production	Road traffic	Total	Emission density tonne SO_2 km^{-2} a^{-1}
801	Arden	50.4	94.1	80.5	140.4	30.5	395.9	1.7
803	Brovst	53.2	99.5	85.1	148.5	18.0	404.3	1.8
805	Brønderslev	125.6	234.4	200.5	349.8	43.7	954.0	3.0
807	Dronninglund	94.5	176.6	151.0	263.5	45.8	731.4	2.3
809	Farsø	49.5	92.4	79.1	138.0	19.0	378.0	1.9
811	Fjerritslev	51.4	95.9	82.0	143.1	23.2	395.6	1.3
813	Frederikshavn	220.2	411.4	351.9	614.0	61.9	1659.4	9.3
815	Hadsund	64.9	121.2	103.7	181.0	24.2	495.0	2.9
817	Hals	66.3	123.7	105.8	184.7	18.9	499.4	2.6
819	Hirtshals	90.1	168.2	143.8	251.0	29.5	682.5	3.5
821	Hjørring	213.0	398.6	340.9	594.9	68.3	1615.7	5.2
823	Hobro	86.8	162.6	139.1	239.8	42.5	670.9	4.1
825	Læsø	15.9	29.7	25.4	44.3	4.8	119.9	1.1
827	Løgstør	66.3	124.2	106.2	185.4	22.2	504.3	2.3
829	Løkken-Vrå	54.9	102.7	87.8	153.2	19.3	417.8	2.3
831	Nibe	46.2	86.1	73.7	128.5	13.9	348.4	1.9
833	Nørager	34.3	64.0	54.7	94.1	21.2	268.3	1.6
835	Pandrup	64.4	120.5	103.1	179.8	25.7	493.4	2.6
837	Sejlflod	56.1	104.2	89.1	155.5	15.1	419.9	2.0
839	Sindal	59.6	111.4	95.3	166.2	22.6	455.0	1.9
841	Skagen	86.0	160.8	137.6	240.0	27.2	651.7	4.6
843	Skørping	58.9	110.3	94.3	164.6	21.7	449.8	1.9
845	Støvring	74.1	138.3	118.3	206.4	40.6	577.8	2.6
847	Sæby	112.2	209.8	179.5	313.2	48.5	863.2	2.7
849	Åbybro	68.4	127.4	109.0	190.2	26.9	521.9	3.1
851	Ålborg	956.6	1788.9	1530.2	2670.1	287.8	7233.6	12.9
861	Års	77.3	144.4	123.5	215.5	25.2	585.9	2.6
080	Nordjyllands amtskommune	2997.0	5601.1	4791.0	8355.8	1048.1	22793.0	3.7

Table 2. SO_2 emissions from large point sources for the counties in Denmark.

No.	Municipality	Emission in tonne SO_2 a^{-1}
015	Københavns amtskommune	16071.
020	Frederiksborg amtskommune	4028.
030	Vestsjællands amtskommune	47795.
035	Storstrøms amtskommune	1711.
042	Fyns amtskommune	39952.
050	Sønderjyllands amtskommune	19702.
055	Ribe amtskommune	15399.
060	Vejle amtskommune	9184.
070	Århus amtskommune	3963.
080	Nordjyllands amtskommune	8253.
Total		166058.

Table 3. Estimated SO_2 emissions from maritime vessels.

	Tonne SO_2 a^{-1}
International freighter traffic	15157.
Main national ferry services	2316.
Total	17473.

Table 4. Total Danish SO_2 emissions.

Source	Tonne SO_2 a-1	%
Domestic heating	32803.	9.35
Energy generation	46969.	13.38
Industrial combustion	61373.	17.49
Industrial production	15200.	4.33
Road traffic	11119.	3.17
Maritime vessels	17473.	4.98
Large point sources	166058.	47.31
Total	350995.	100.01

The difference between the summary of 'road traffic' in the Table 1 and the figure given here in Table 4, arise from rounding off and from the gridding of the emissions from roads. Where some km^2 with emissions, do not exist in the land-use registration and therefore cannot be assigned to a municipality. This is e.g. caused by the fact that there is traffic on bridges between islands and these bridges are in the land-use survey registered as sea.

Figures

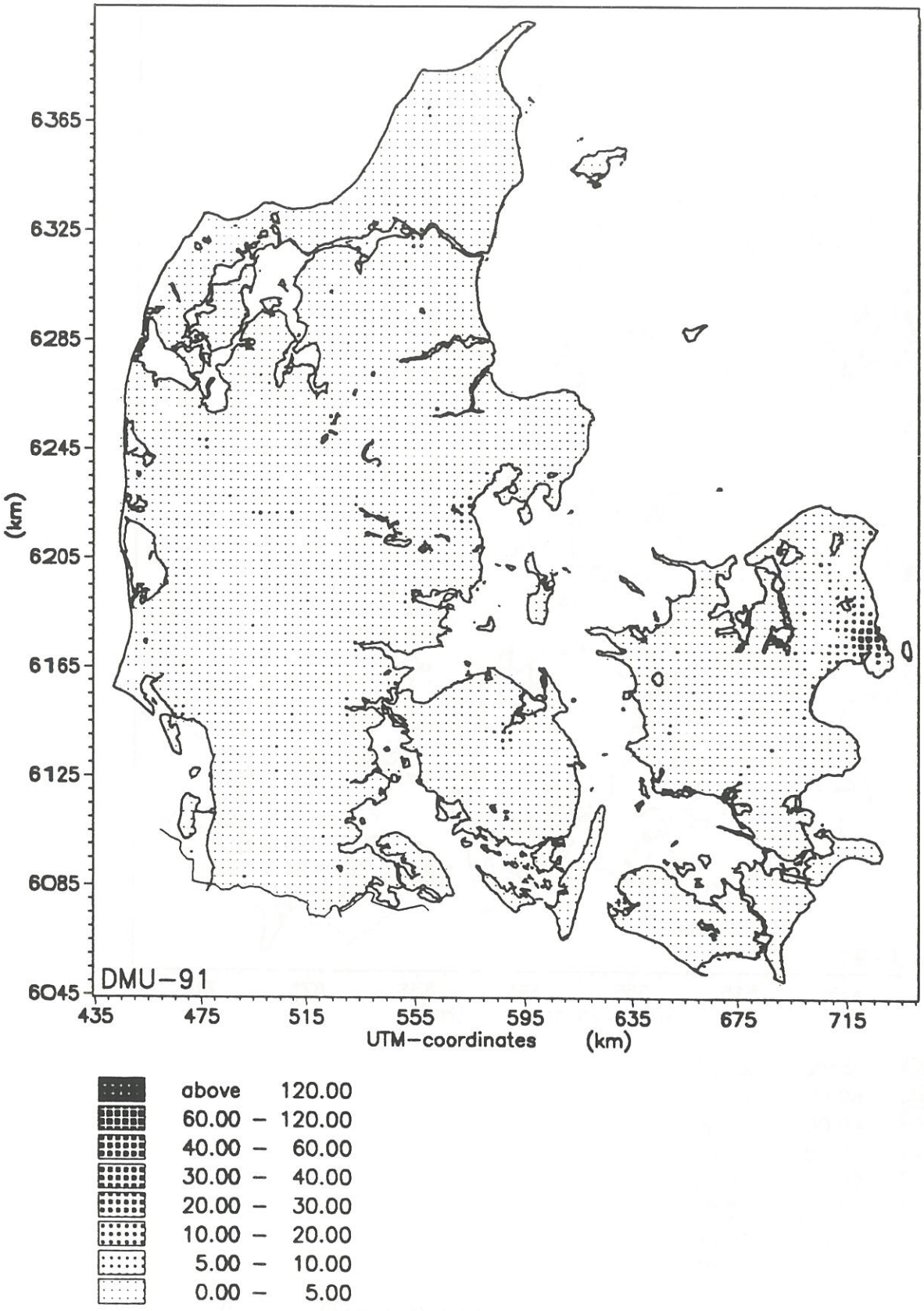


Figure 1. SO_2 emissions density from domestic heating (tonne SO_2 km^{-2} a^{-1}). (Note that the scale is not linear).

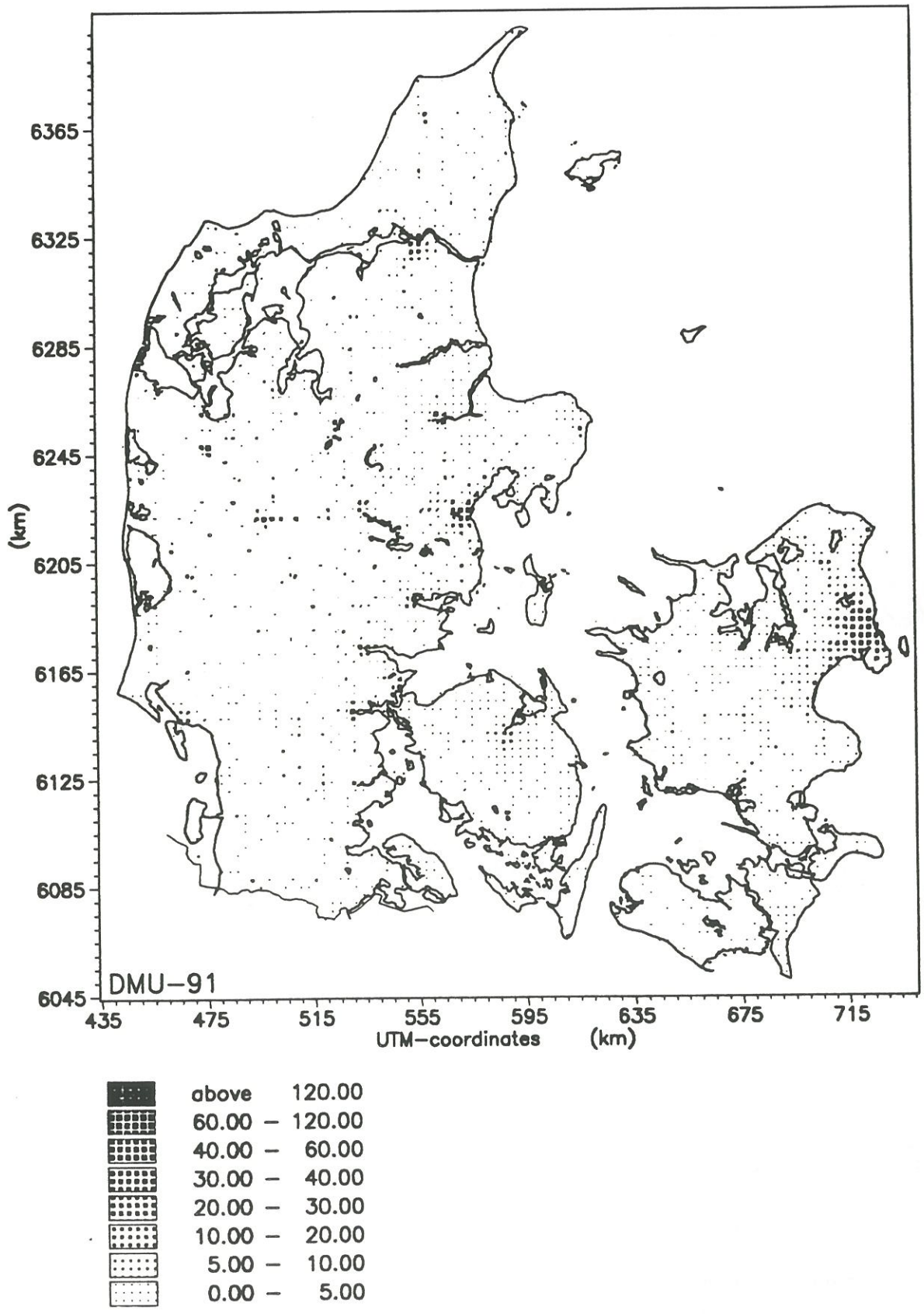


Figure 2. SO_2 emissions density from energy generation (tonne SO_2 km^{-2} a^{-1}). (Note that the scale is not linear).

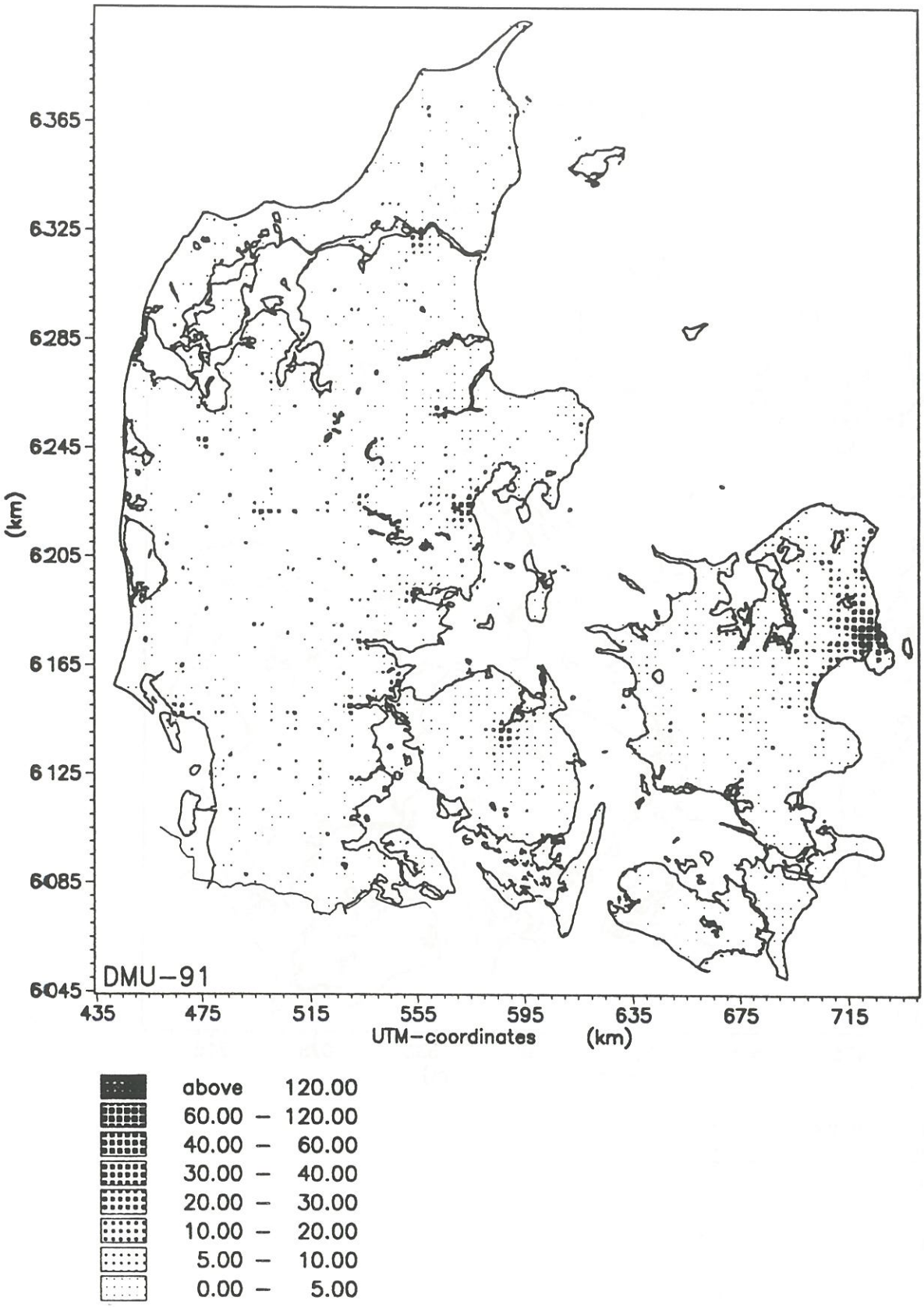


Figure 3. SO_2 emissions density from industrial combustion (tonne SO_2 km^{-2} a^{-1}). (Note that the scale is not linear).

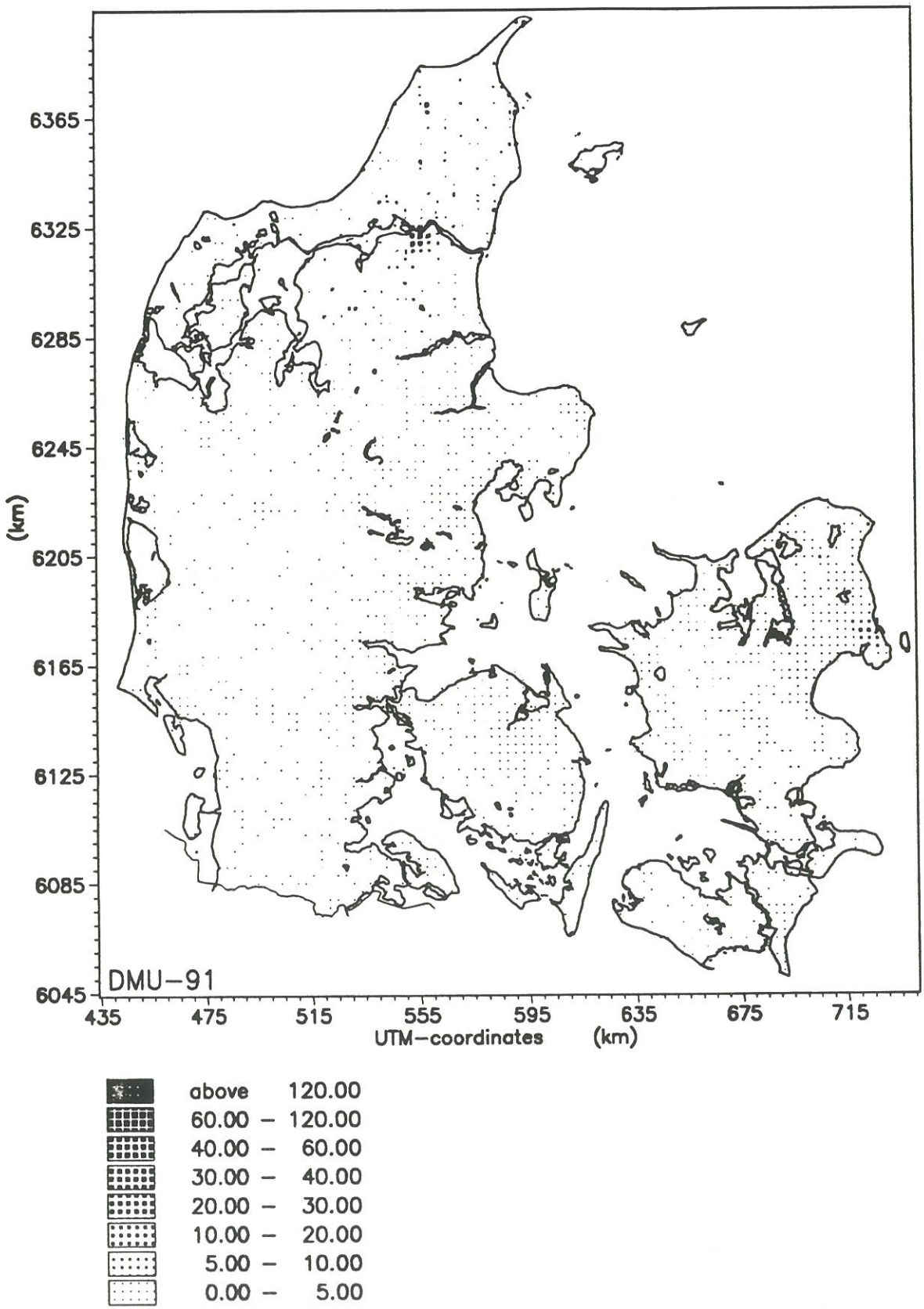


Figure 4. SO_2 emissions density from industrial production (tonne SO_2 km^2 a^{-1}). (Note that the scale is not linear).

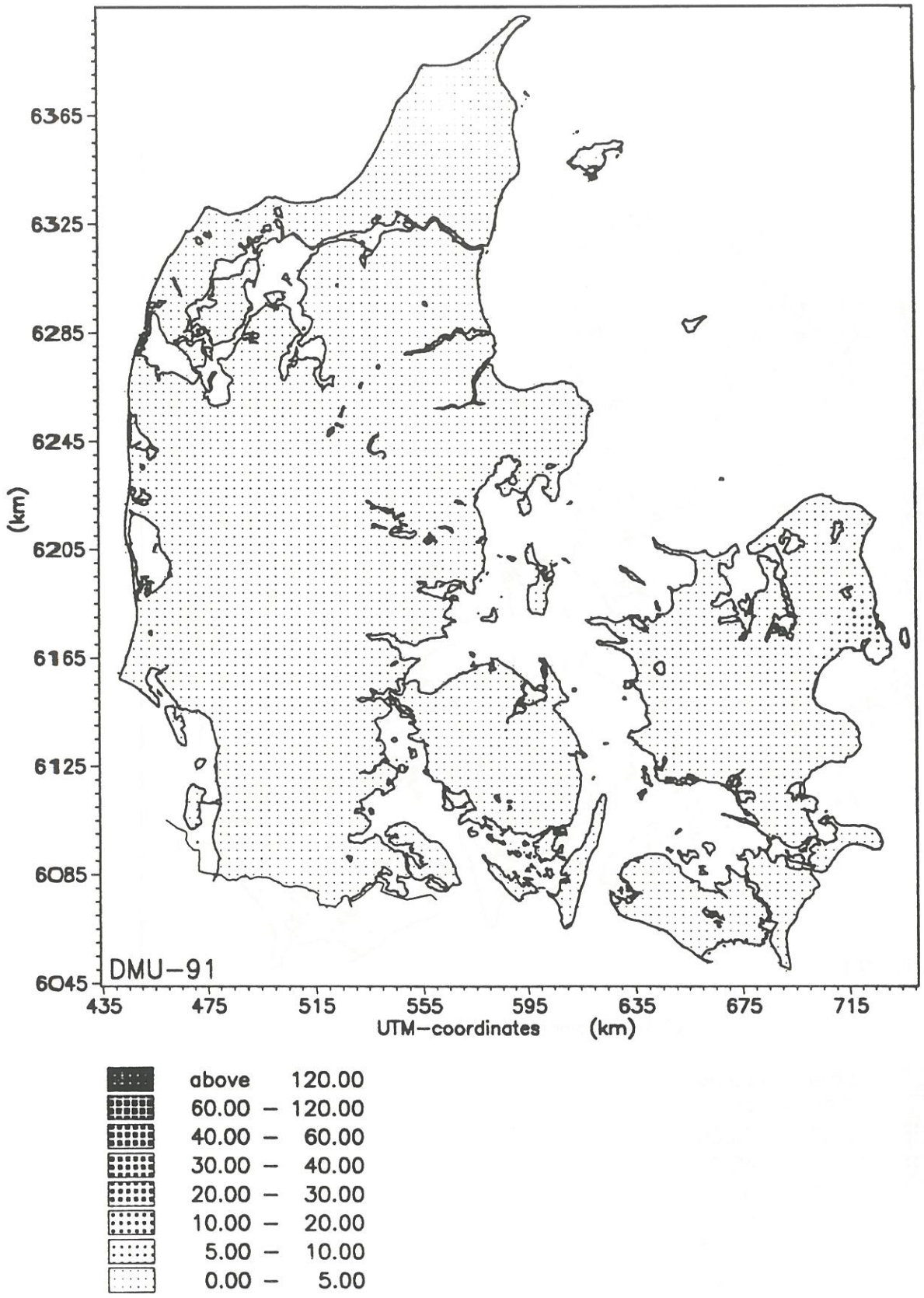


Figure 5. SO_2 emissions density from road traffic (tonne SO_2 km^{-2} a^{-1}). (Note that the scale is not linear).

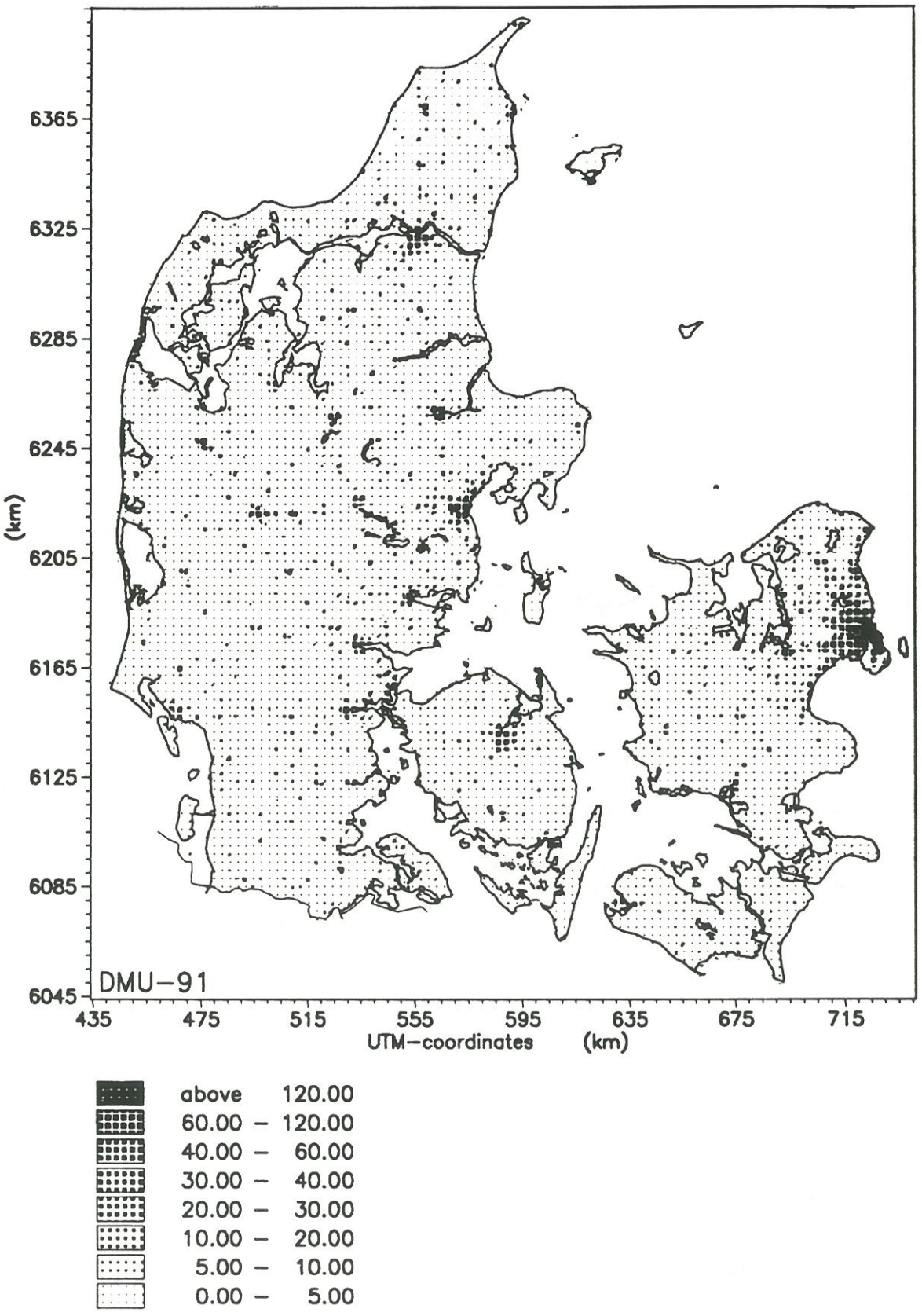


Figure 6. Total SO_2 emissions density from area sources (tonne SO_2 km^{-2} a^{-1}). (Note that the scale is not linear).

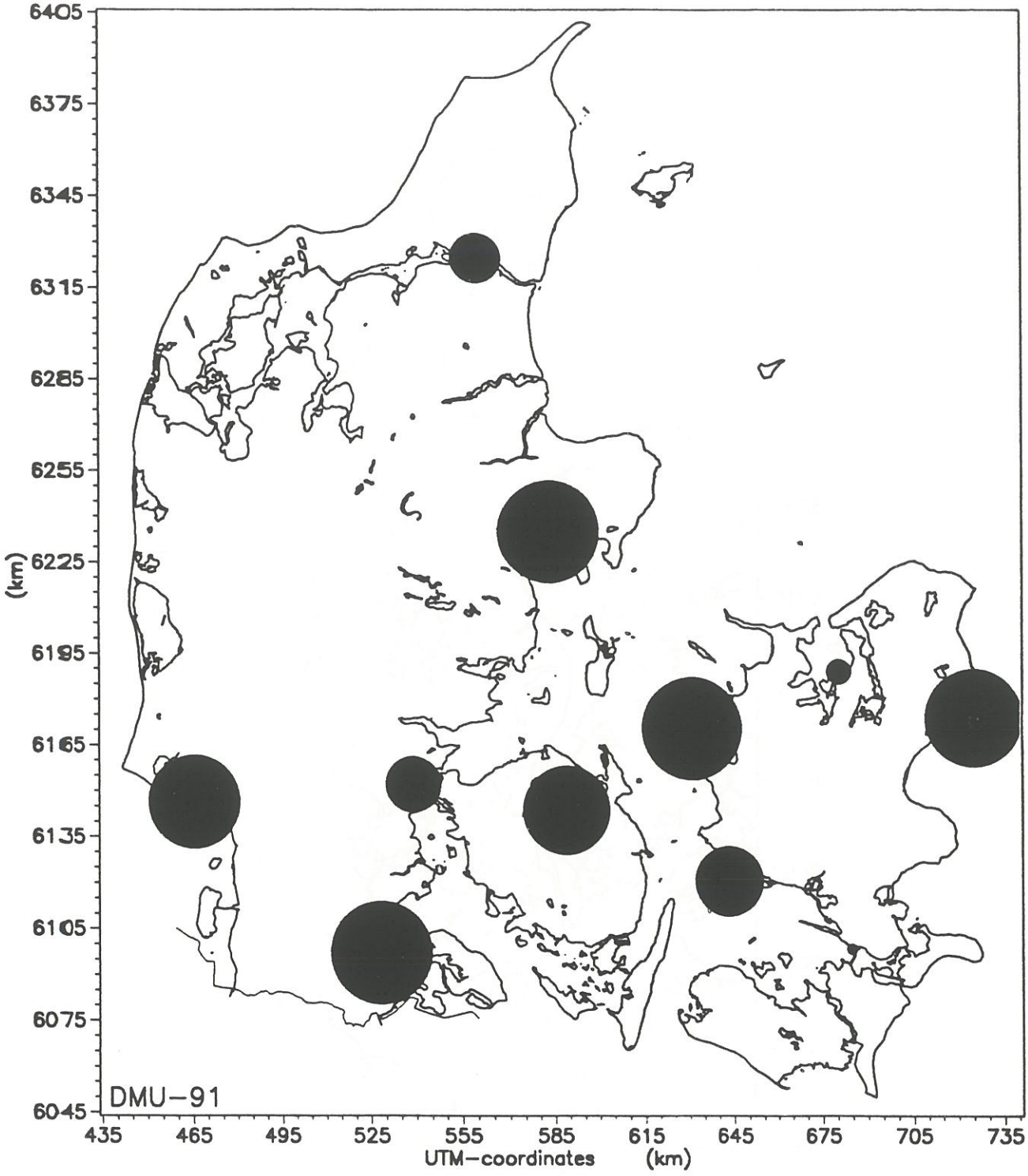


Figure 7. SO_2 emissions from major Danish point sources. The diameter of a circle shows the relative magnitude of the source. Sources near each other have been clustered for clarity.

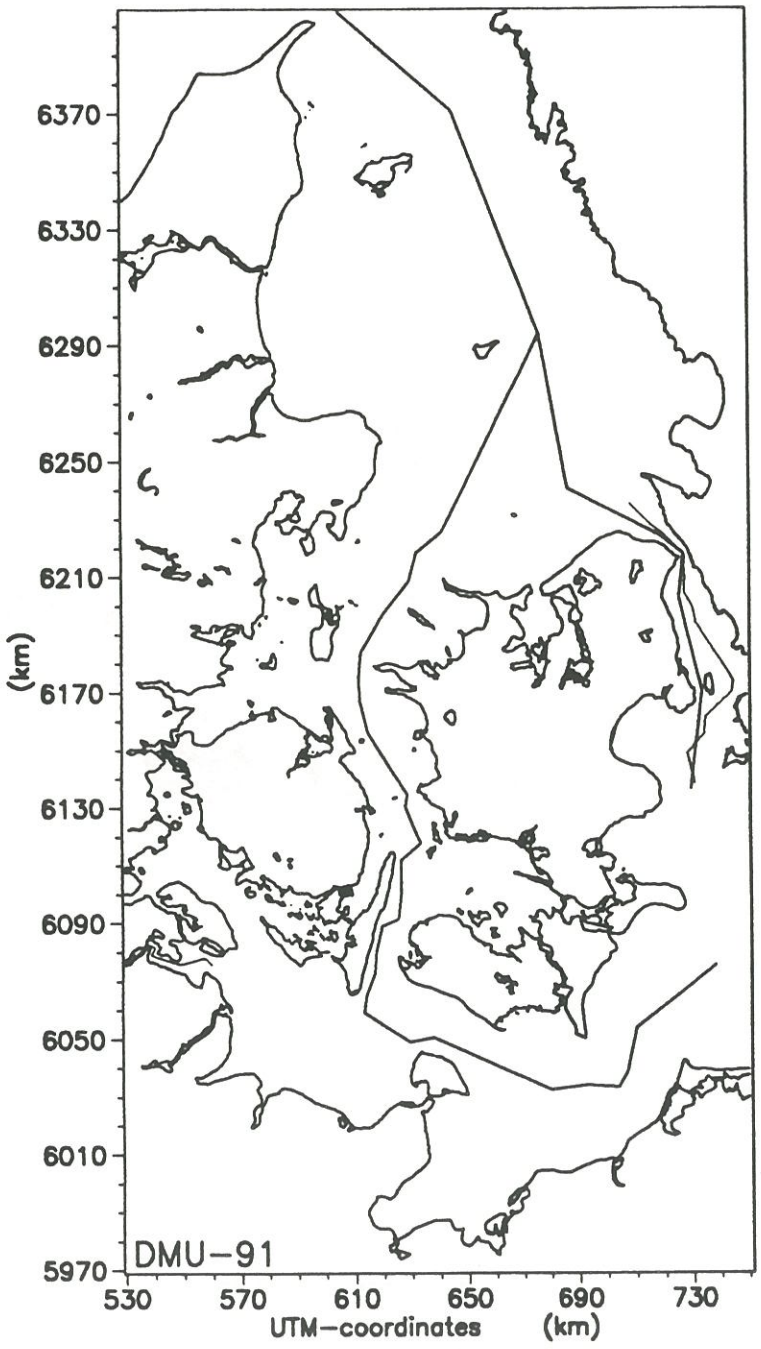
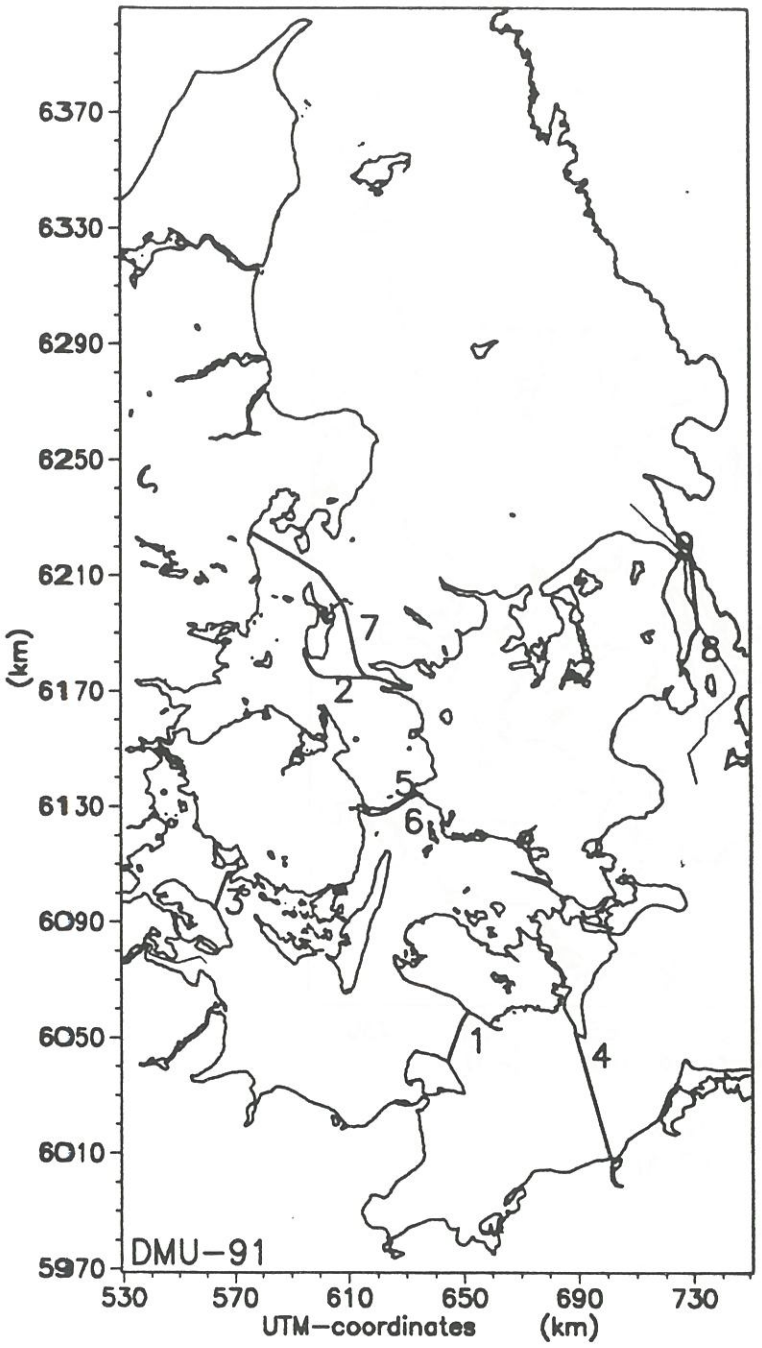


Figure 8. Main freighter routes through Danish waters.



1) Rødby - Puttgarden
2) Kalundborg - Samsø
3) Bøjden - Fynshavn
4) Gedser - Warnemünde
5) Korsør - Nyborg
6) Halskov - Knudshoved
7) Kalundborg - Århus
8) Frihavnen - Helsingborg
9) Helsingør - Helsingborg

Figure 9. Main ferry services run by DSB.

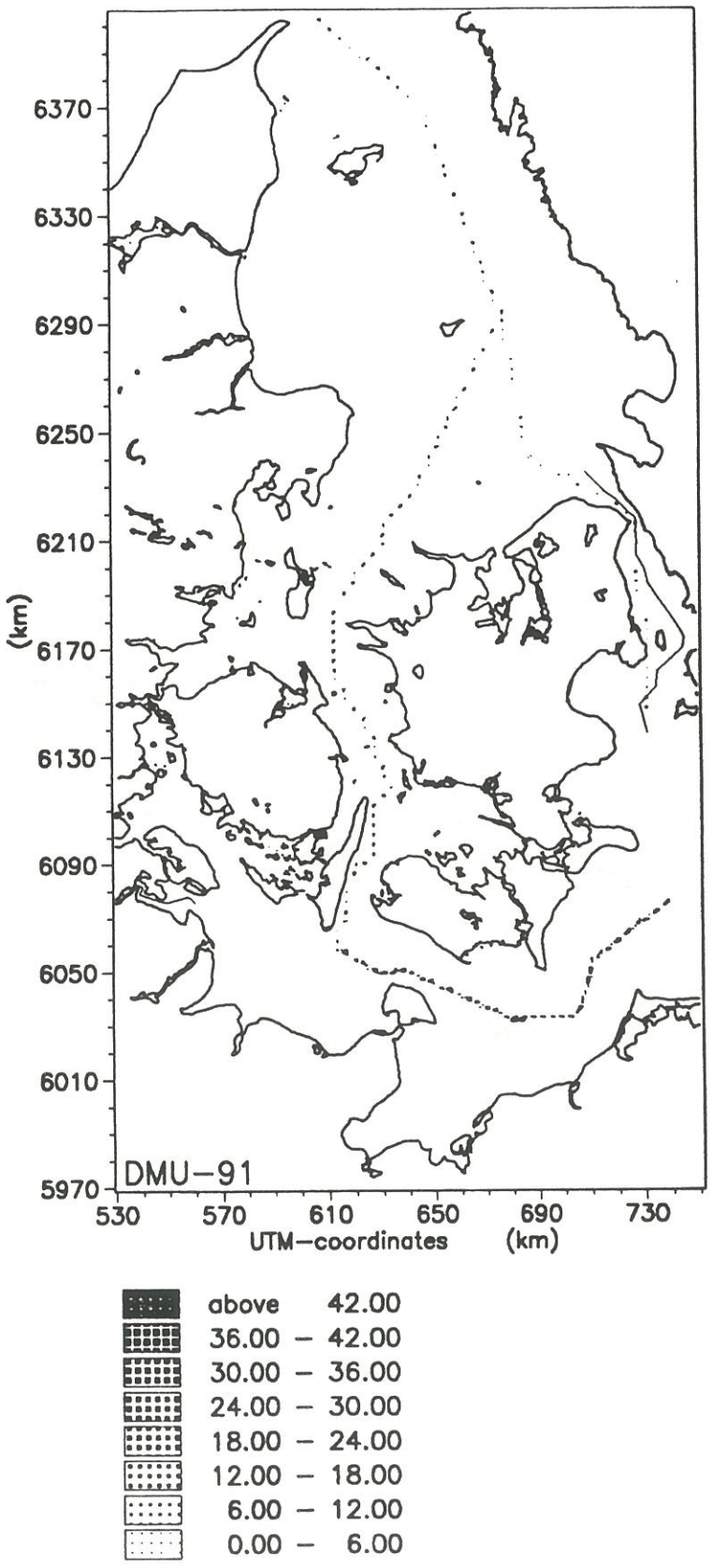


Figure 10. SO_2 emissions density from international freight traffic (tonne SO_2 km^{-2} a^{-1}). (Note that the scale is not linear).

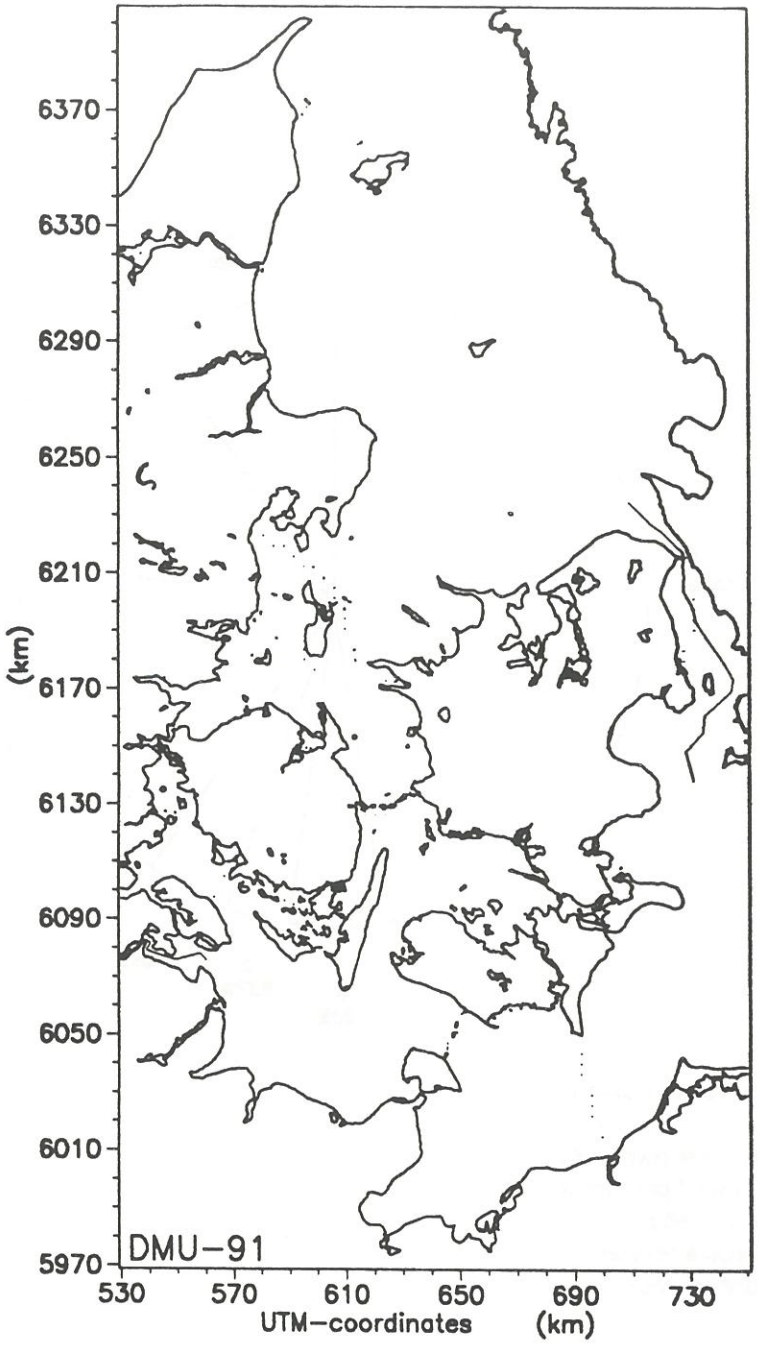


Figure 11. SO_2 emissions density from main ferry services (tonne SO_2 km^{-2} a^{-1}). (Note that the scale is not linear).

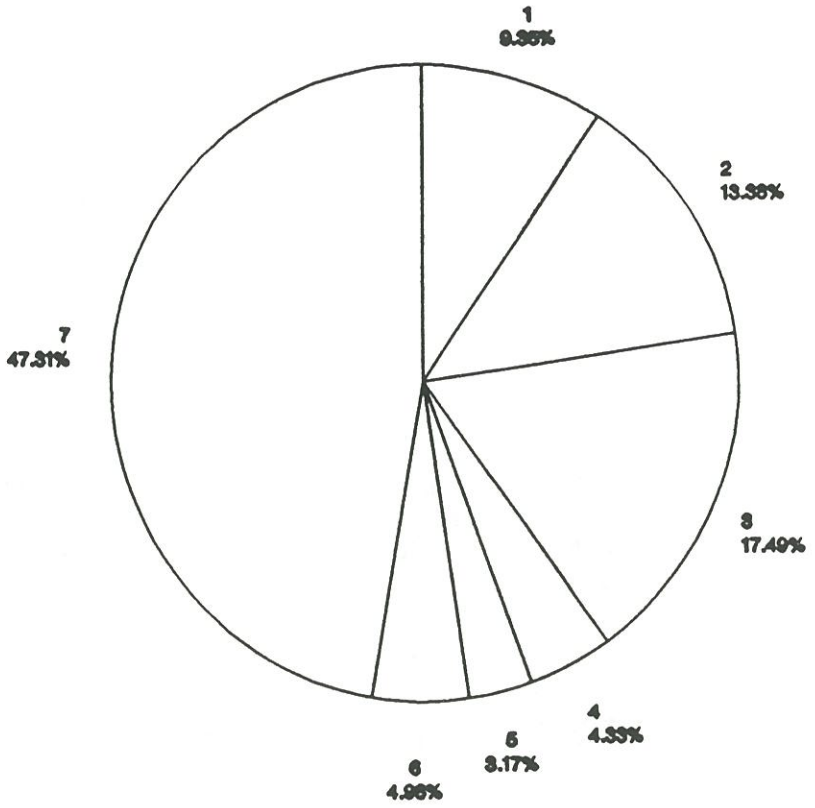


Figure 12. Relative contributions of the different source categories to the total SO_2 emission.

Appendix A

Format of output files

In the following the format of the output files are given as read and written by fortran.

The file, SO2-AREA, with emissions from area sources has the format:
i3, i5, 6 (lx, f10.5)

with the collums:
X and Y coordinate (UTM zone 32), Emission (tonne SO_2 a^{-1}) from: domestic heating, energy generation, combustion in industry, industrial production, road traffic and total emission.

The file, SO2-POINT, with emissions from point sources has the format: a20, 1x, i2, i7, i8, 2i4, i8, i6

with the collumns:
Name of point source
X and Y coordinate (global longitude and latitude)
Height (m) of chimney
Temperature (°C) of flue gas
Volume (1000 m^3 a^{-1})
Emission (tonne SO_2 a^{-1}).

The files, SO2-FREIGHTER and SO2-FERRY, with emissions from freighter and ferry traffic have the format:

i4, i5, f15.4
with the collumns:

X and Y coordinates (UTM zone 32)
Emission (tonne SO_2 a-1).

National Environmental Research Institute

The National Environmental Research Institute - NERI - is a research institute of the Ministry of the Environment. Neri's tasks are primarily to do research, collect data and give advice on problems related to the environment and nature.

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Publications:

NERI publishes professional reports, technical instructions, reprints of scientific and professional articles, a magazine of game biology and the Annual Report.

Included in the annual report is a review of the publications from the year in question. The annual reports and an up-to-date review of the year's publications are available on application to NERI.