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A Detailed Emission Inventory of Sulphur Dioxide for Denmark

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Abstract. The Danish SO_2 emissions from domestic heating, energy generation, industry, road traffic, point sources and maritime vessels have been distributed on a 1 × 1 km^2 grid and on municipalities.

The total SO_2 emission is calculated to 351 Ktonne SO_2 a^{-1}. This report describes the distribution, of the emissions from the different categories on the grid and municipalities.

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Contents

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 1×1 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 1×1 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 Ktonne 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 1×1 km^2 net. Arealkilderne på land, er desuden fordelt på kommuner.

For boligopvarmning, energi produktion, 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 1×1 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 1×1 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.

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 1×1 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 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).

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

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 1×1 km^2 grid.

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

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.

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 1×1 km^2 grid was conducted using again the land-use registration.

The emissions from the road traffic have also been distributed on the 1×1 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 1×1 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 1×1 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.

Thus all land based SO_2 area emissions were computed and distributed on a 1×1 km^2 grid. The data were stored in a data file named SO2AREA.dat. The distribution of emissions over municipalities was done using the file SO2AREA.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

The following categorizing of SO_2 emission point sources have 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 smal 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

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

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.

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 London 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

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.

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 Ktonne 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.

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 Ktonne SO_2 a^{-1}.

In the present survey, the road traffic emission is estimated to be

11 Ktonne SO_2 a^{-1}.

The total SO_2 emission from point and area sources, but not including emissions from maritime vessels, has been calculated by Torp (1983) to be in 1980

417 Ktonne 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 Ktonne 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 Ktonne SO_2 a^{-1}.

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 tonne SO_2 km^{-2} a^{-1}
		Domestic heating	Energy generation	Industrial combustion	Industrial production	Road traffic	Total	
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 tonne SO_2 km^{-2} a^{-1}
		Domestic heating	Energy generation	Industrial combustion	Industrial production	Road traffic	Total	
151	Ballerup	309.1	419.0	574.5	64.7	92.6	1459.9	42.8
153	Brøndby	233.9	317.1	434.7	48.8	112.9	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	Sollerød	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

Continued

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	Allerod	133.3	159.1	271.9	67.5	53.0	684.9	10.2
205	Birkerod	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	Helsingor	349.1	418.1	714.6	177.4	95.2	1754.4	14.4
219	Hillerod	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	Horsholm	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	Stenlose	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	Koge	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	Vallo	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

Continued

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	Gorlev	46.5	27.6	57.2	6.6	14.1	152.0	1.7
311	Hashoj	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	Hong	62.6	37.2	76.9	8.9	18.8	204.3	1.4
321	Jernlose	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	Korsor	160.5	95.4	197.4	22.8	41.8	517.9	6.9
327	Nykobing-Rorvig	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	Skælskor	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	Soro	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	Tollose	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

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	
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	2.6
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	Mon	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	Nykobing 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	Ronnede	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	Storstroms amtskommune	2279.5	1486.9	2270.5	278.1	619.7	6934.8	2.0

Continued

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	
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	Nekso	116.8	39.9	65.9	28.0	16.8	267.3	2.6
407	Ronne	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	Christianso	1.5	0.0	0.0	0.0	0.1	1.6	3.9
040	Bornholms amtskommune	596.9	202.8	335.0	142.3	91.0	1368.1	2.3

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	Rudkobing	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	Sønderso	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	Ærøskobing	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

Continued

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	Hadersiev	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

Continued

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	574.4	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

Continued

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	Norhald	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	Ronde	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

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	Spottrup	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

Continued

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	
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.

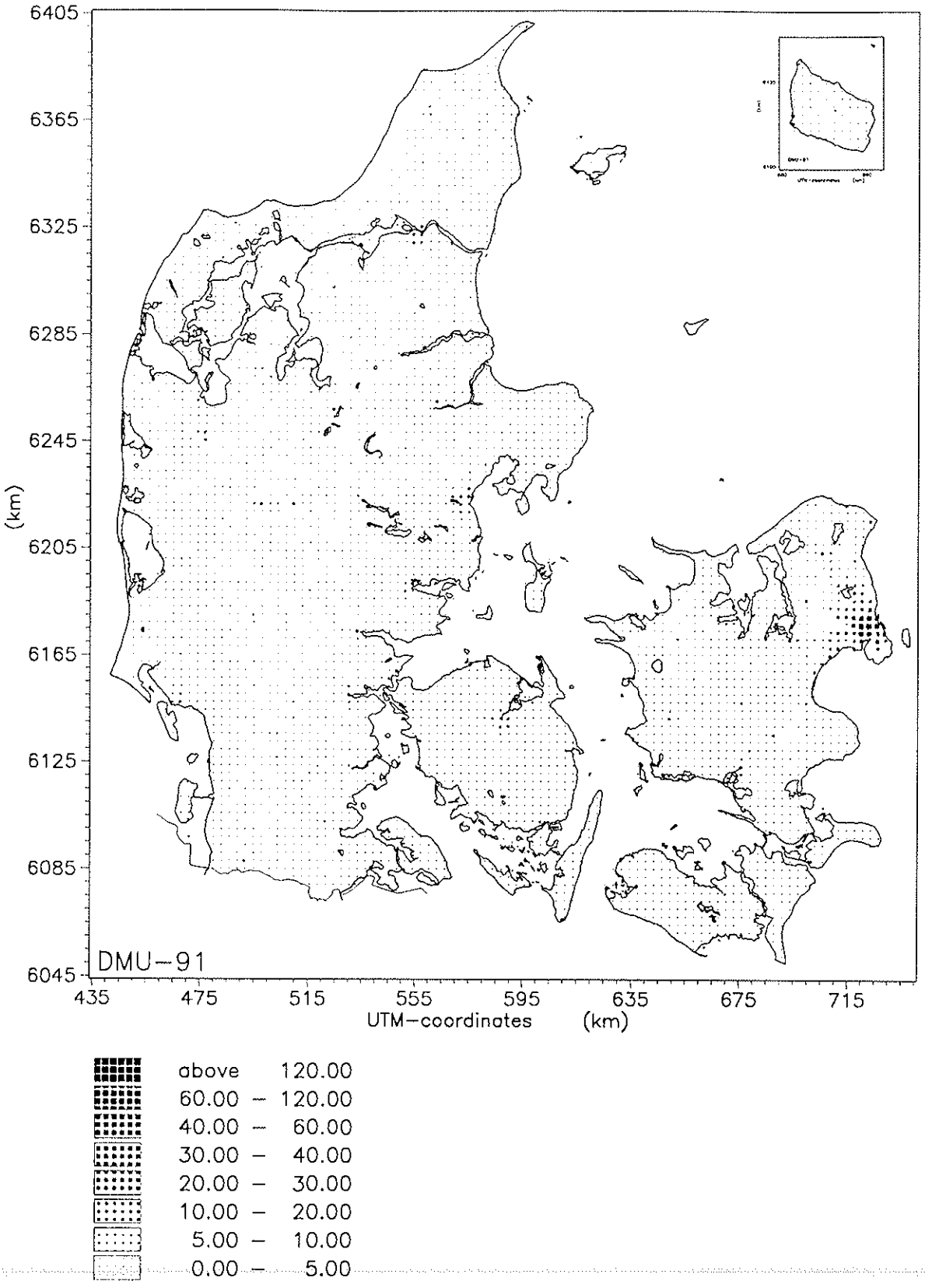


Figure 1. SO_2 emissions density from domestic heating (tonne SO_2 km^{-2} a^{-1}). (Note that the scale is not linear).

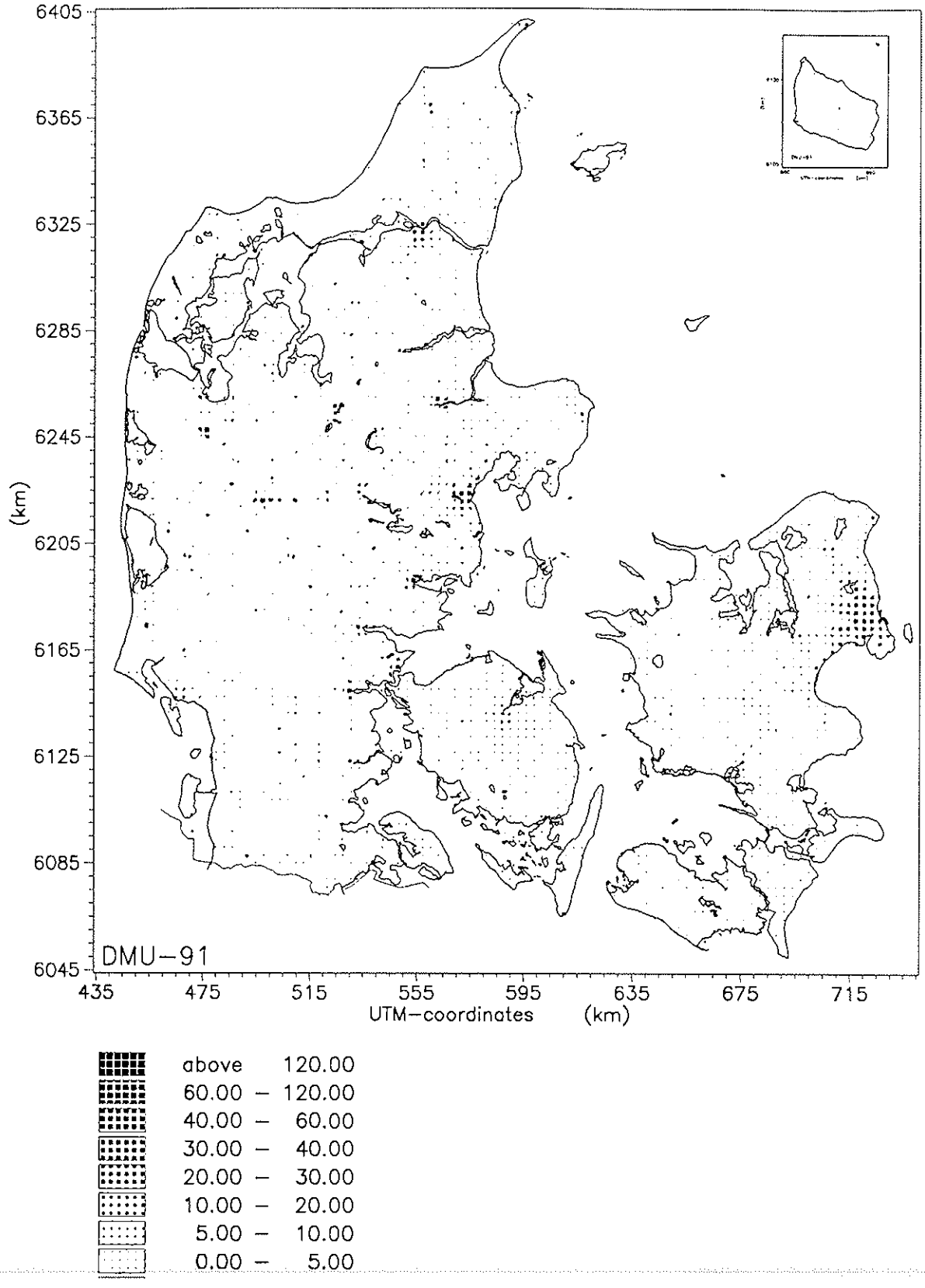


Figure 2. SO_2 emissions density from energy generation (tonne SO_2 km^{-2} a^{-1}). (Note that the scale is not linear).

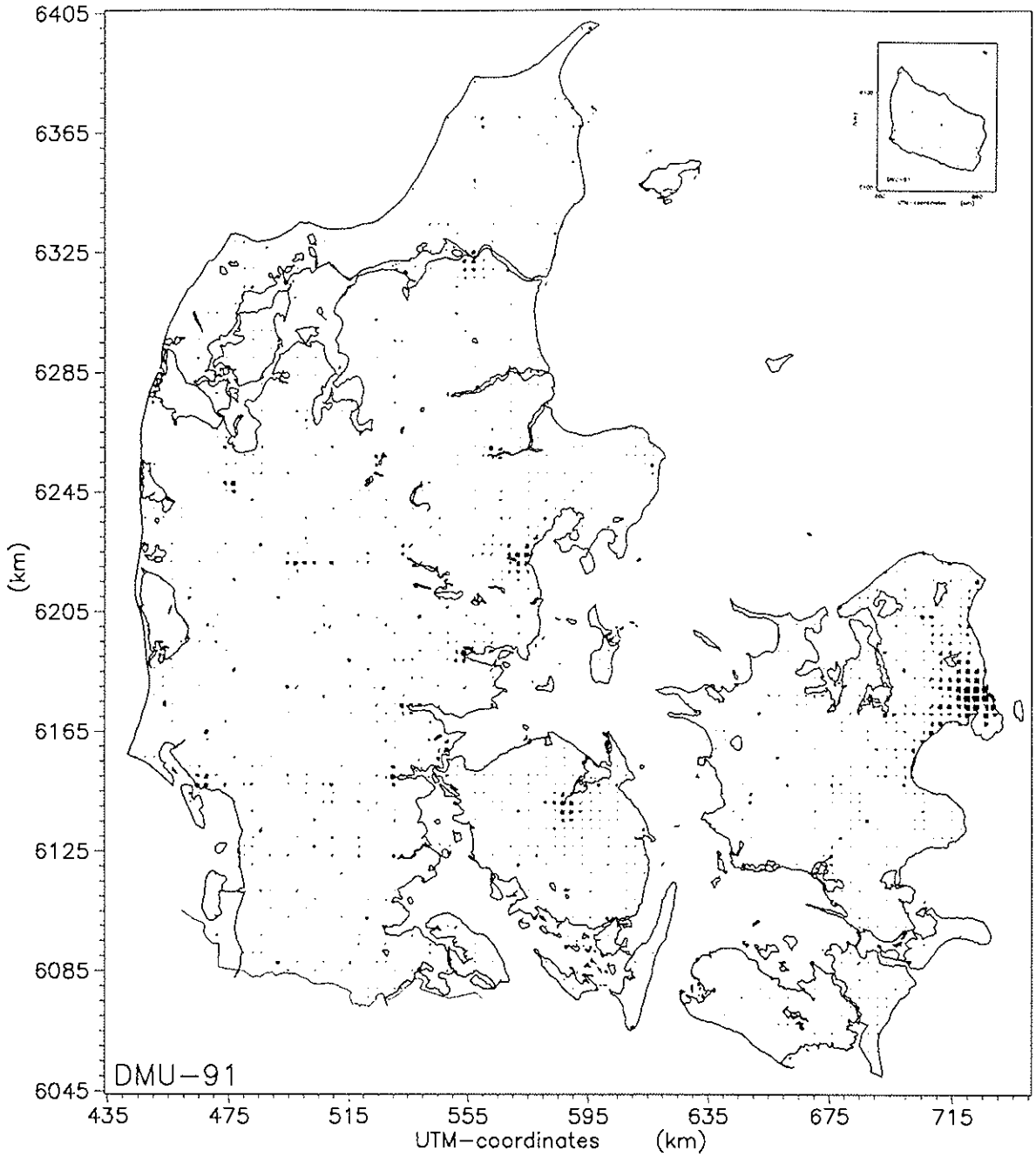


Figure 3. SO_2 emissions density from industrial combustion (tonne SO_2 km^{-2} a^{-1}). (Note that the scale is not linear).

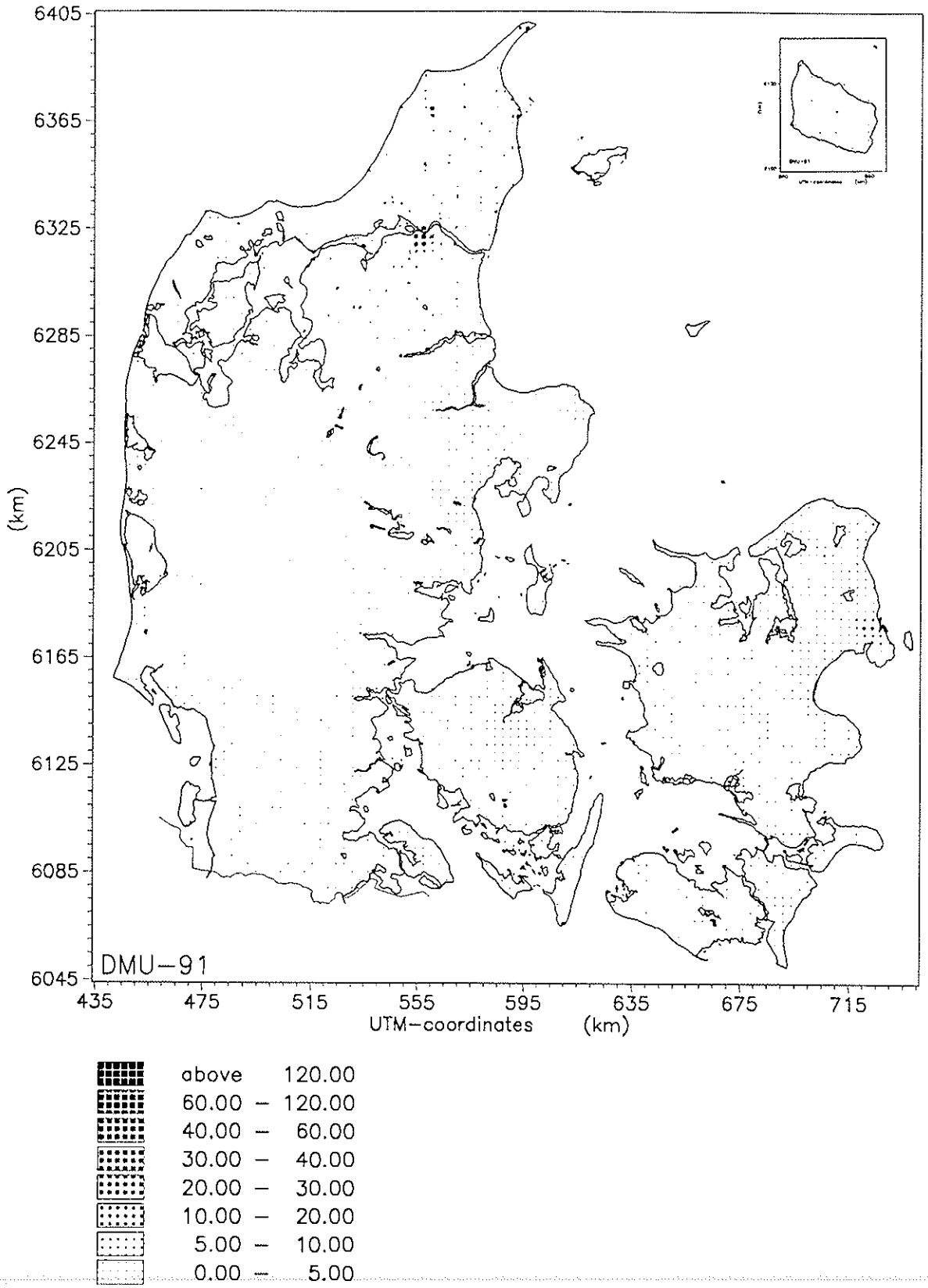


Figure 4. SO_2 emissions density from industrial production (tonne SO_2 km^{-2} a^{-1}). (Note that the scale is not linear).

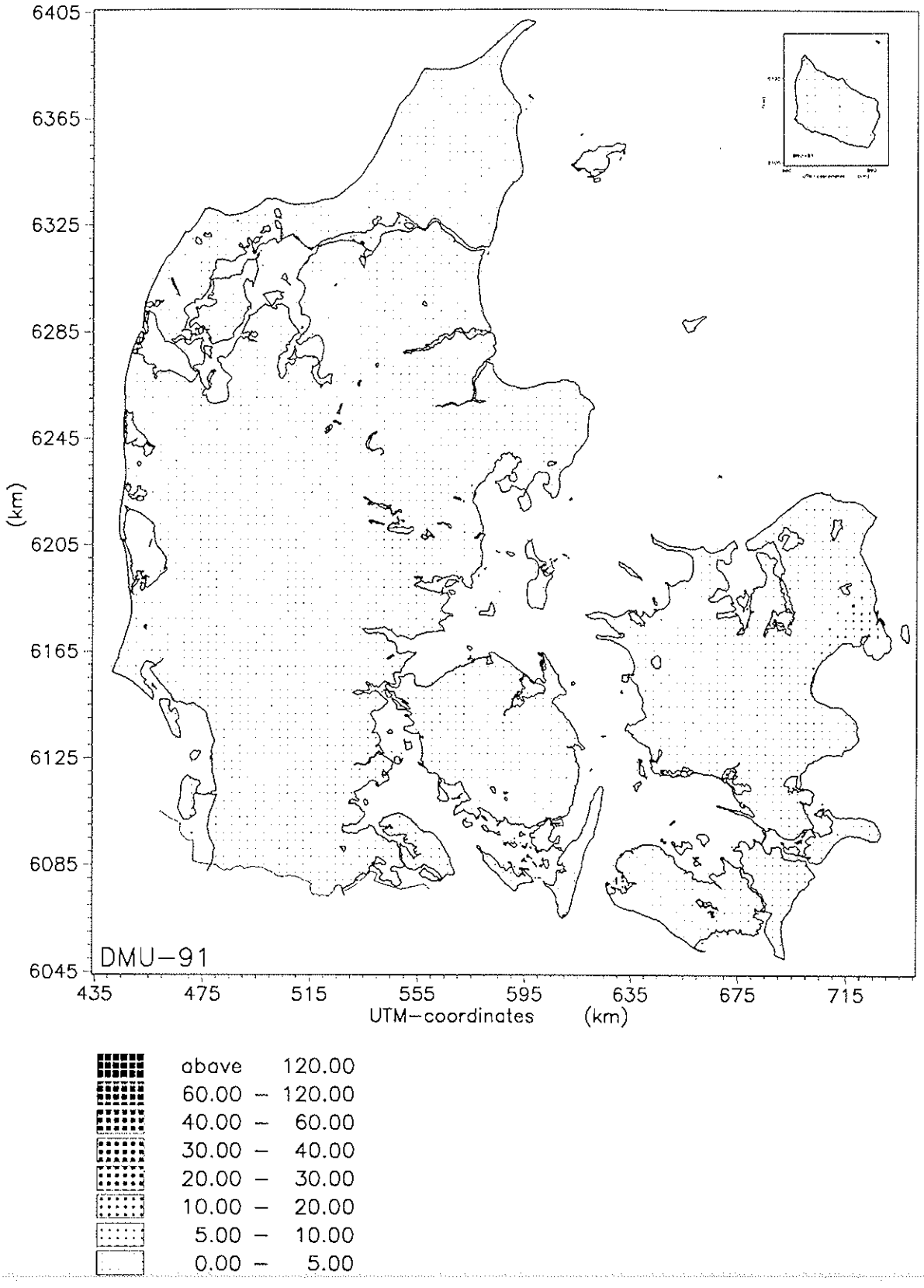


Figure 5. SO_2 emissions density from road traffic (tonne SO_2 km^{-2} a^{-1}). (Note that the scale is not linear).

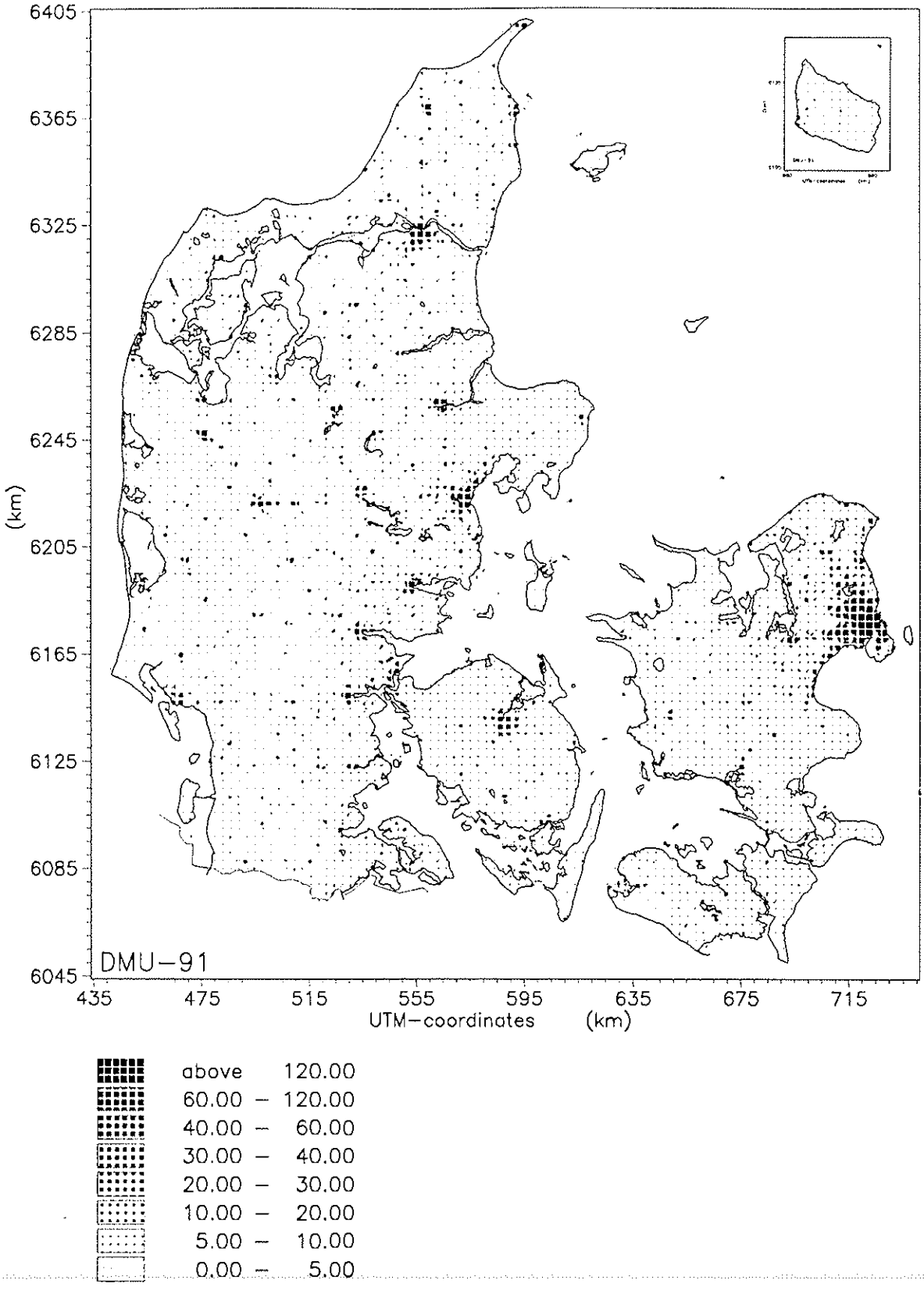


Figure 6. Total SO_2 emissions density from area sources (tonne SO_2 km^{-2} a^{-1}). (Note that the scale is not linear).

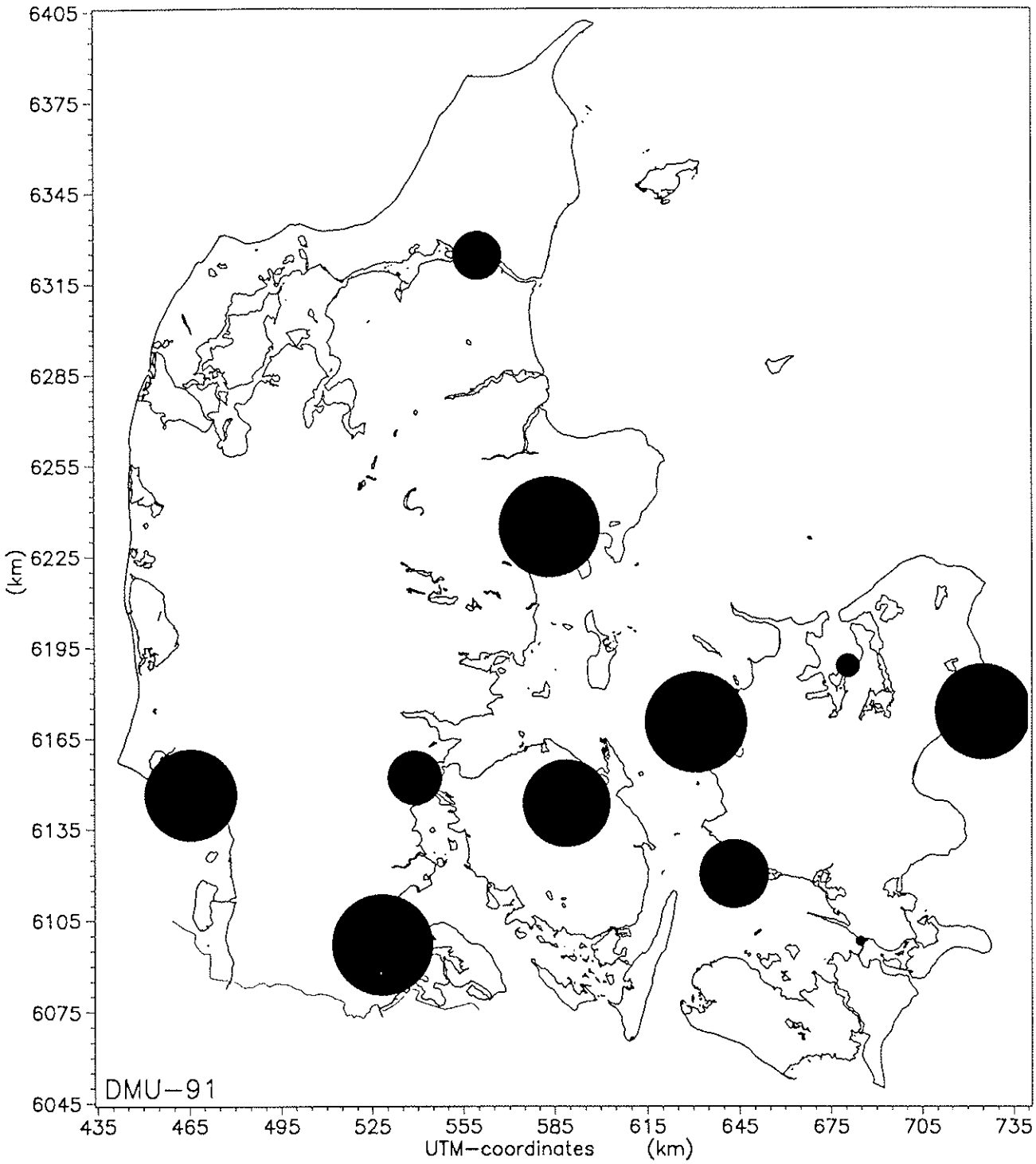


Figure 7. SO_2 emissions from major Danish point sources. The diameter of a circle shows the relative magnitude of the source. Sources near each other have been clustered for clarity.

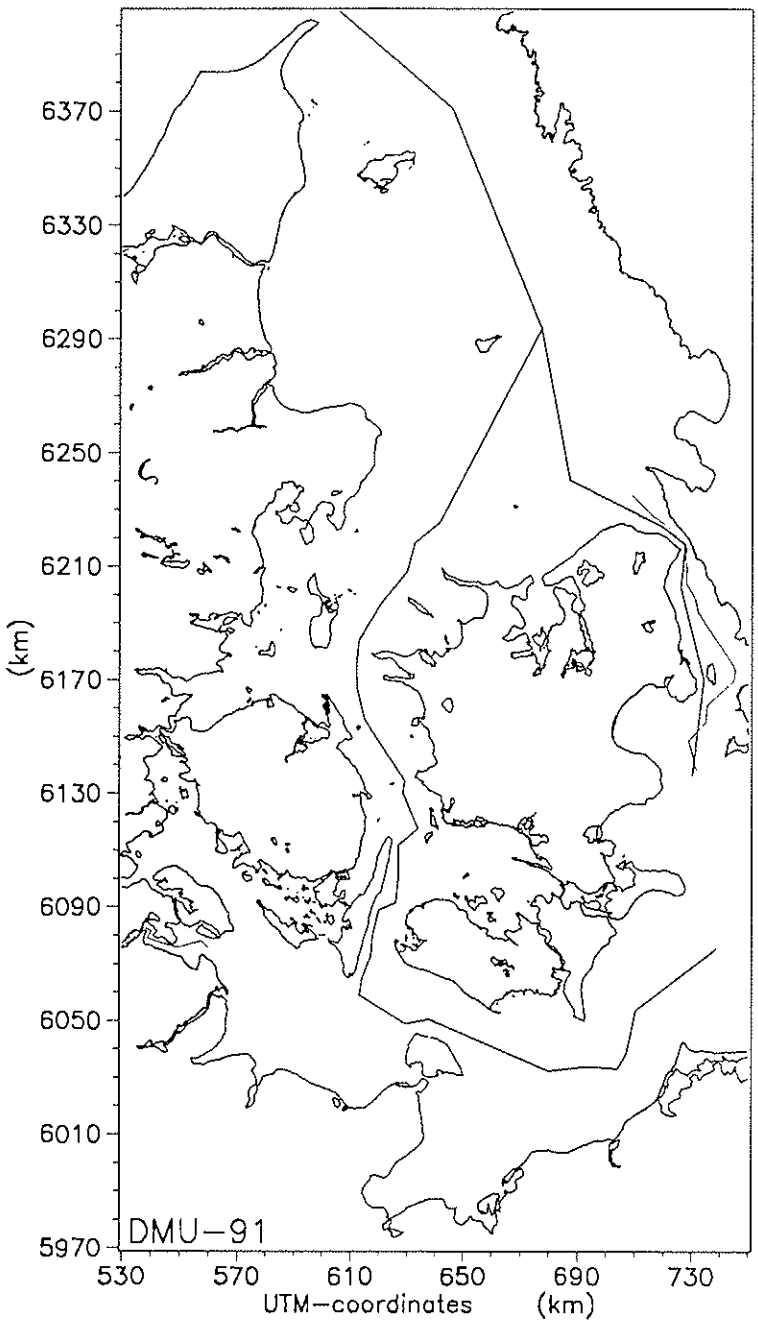
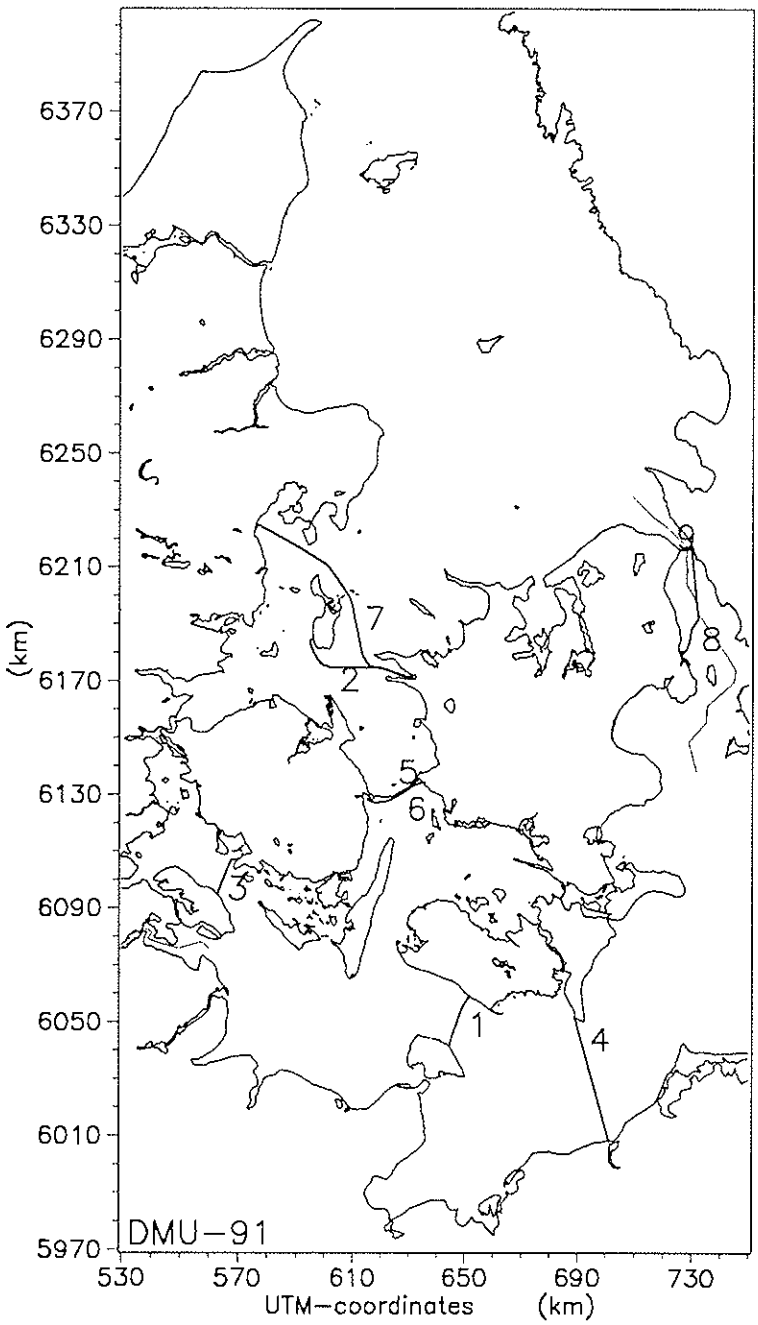


Figure 8. Main freighter routes through Danish waters.



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.

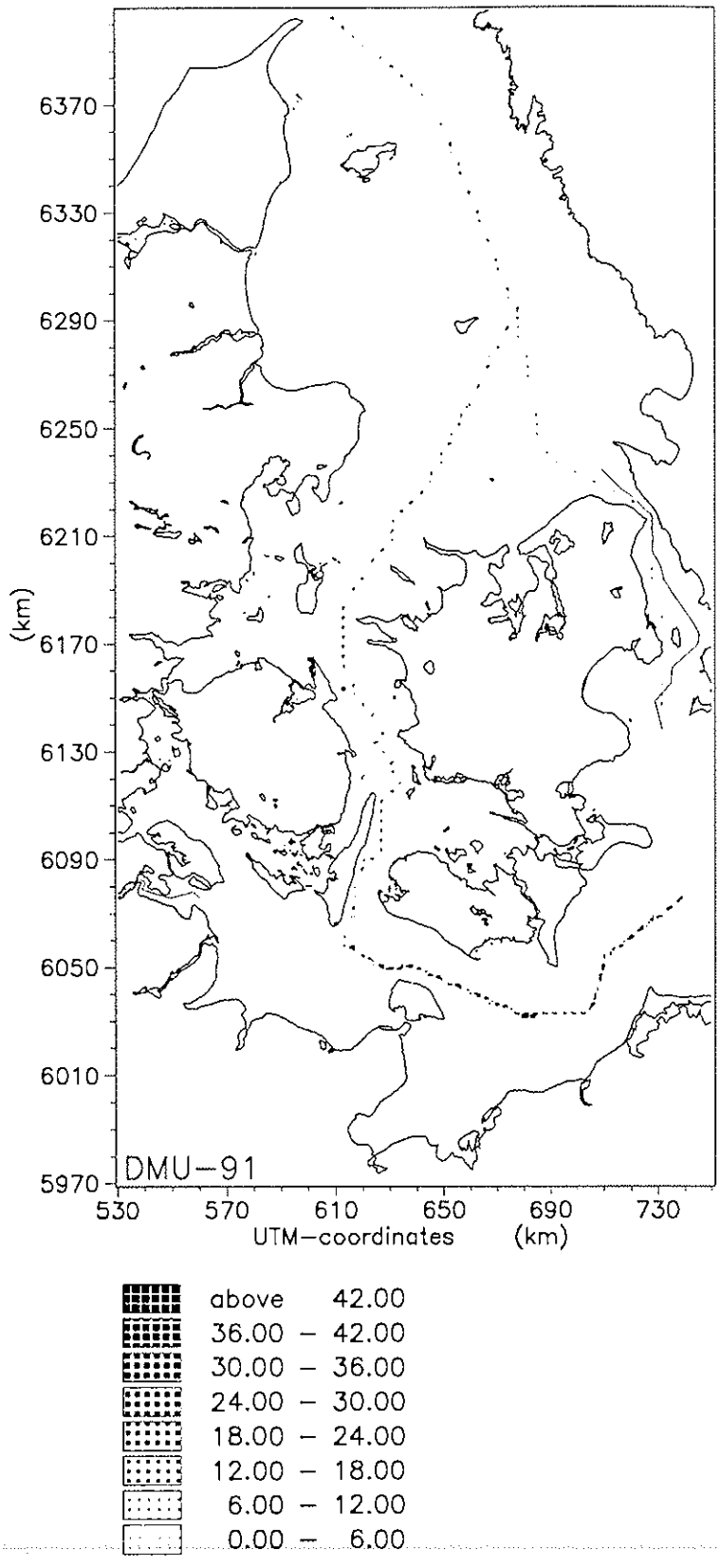


Figure 10. SO_2 emissions density from international freight traffic (tonne SO_2 km^{-2} a^{-1}).
(Note that the scale is not linear).

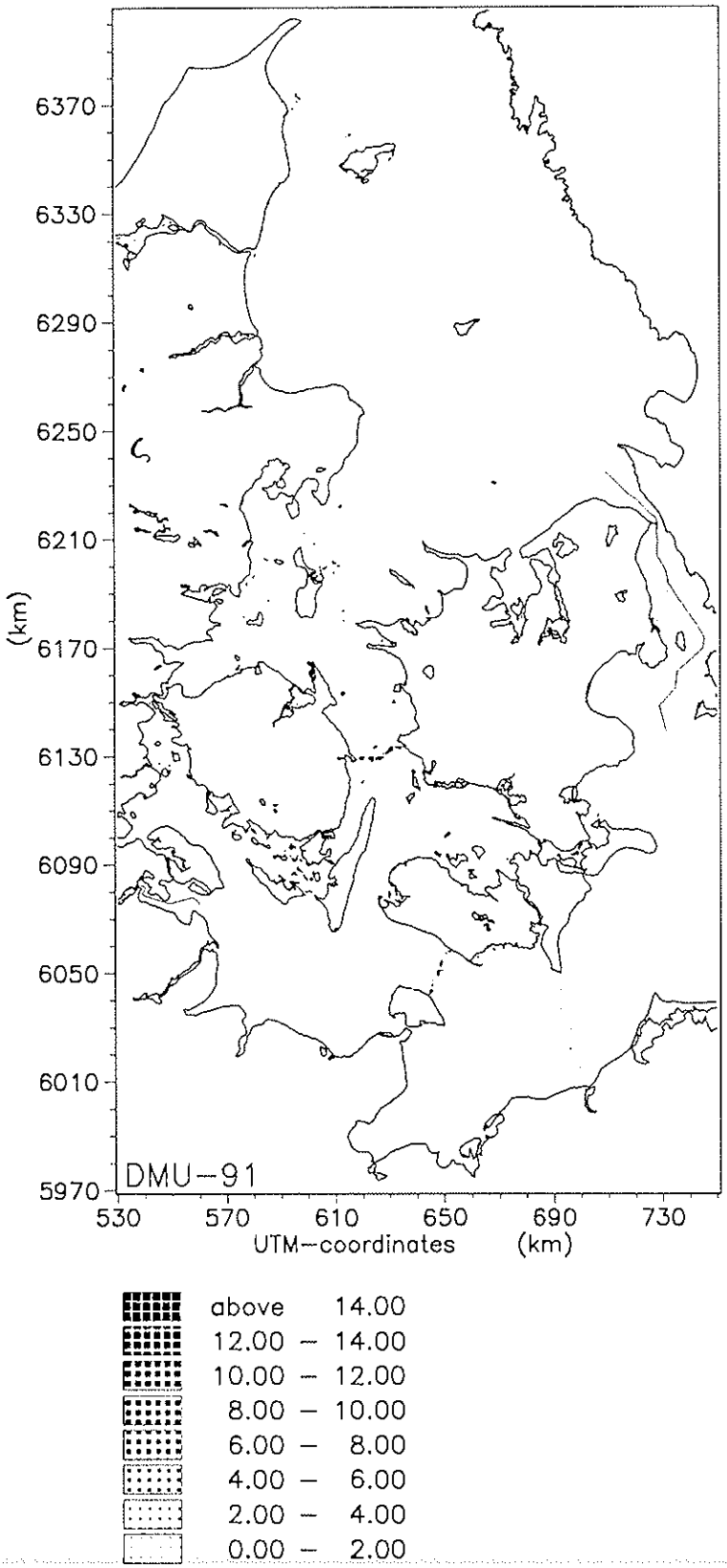
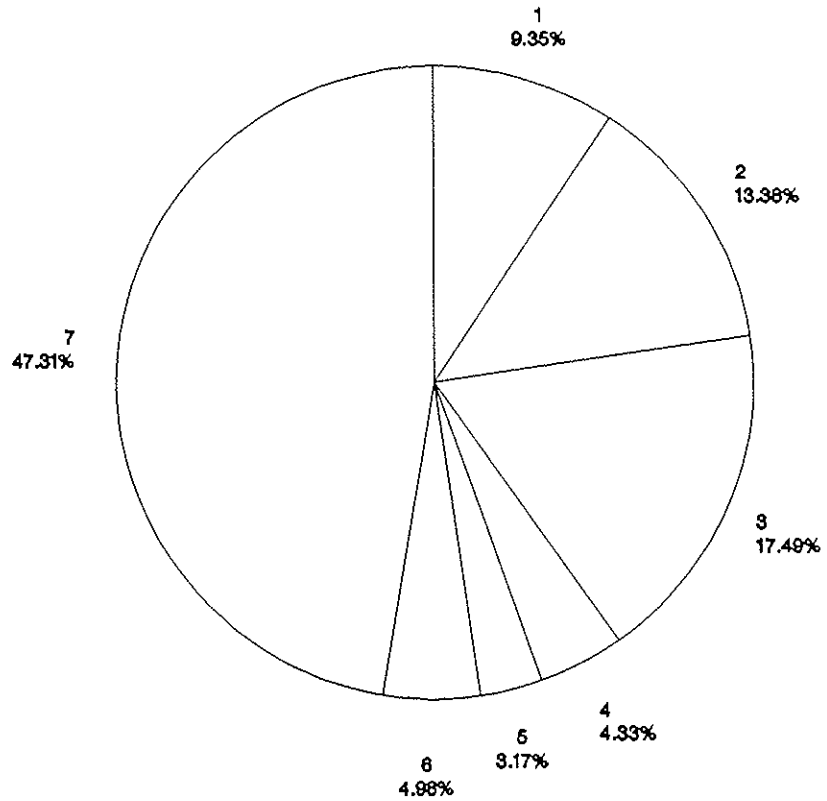


Figure 11. SO_2 emissions density from main ferry services (tonne SO_2 km^{-2} a^{-1}). (Note that the scale is not linear).



1 = Domestical heating
2 = Energy generation
3 = Industrial combustion
4 = Industrial production
5 = Road traffic
6 = Maritime vessels
7 = Point sources

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 (1x, 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}).

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Abstract (Max. 2000 characters)

The Danish SO_2 emissions from domestic heating, energy generation, industry, road traffic, point sources and maritime vessels have been distributed on a 1 × 1 km^2 grid and on municipalities.

The total SO_2 emission is calculated to 351 Ktonne SO_2 a^{-1}. This report describes the distribution, of the emissions from the different categories on the grid and municipalities.

Descriptors INIS/EDB

COMPILED DATA; DENMARK; EMISSION; FOSSIL-FUEL POWER PLANTS; HEATING; INDUSTRY; INVENTORIES; POINT POLLUTION SOURCES; POLLUTION SOURCES; POWER GENERATION; REGIONAL ANALYSIS; RESIDENTIAL BUILDINGS; ROAD TRANSPORT; SHIPS; SPATIAL DISTRIBUTION; STATISTICAL DATA; SULFUR DIOXIDE; VEHICLES

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