TNO Built Environment and Geosciences

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TNO-report

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Gridded European anthropogenic emission data for NO_x, SO_2, NMVOC, NH_3, CO, PM_{10}, $PM_{2.5}$ and CH_4 for the year 2000

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1. Introduction

TNO developed the gridded anthropogenic emission data to provide UBA with state-of-the-art and consistent data for the substances NOx, SO_2, NMVOC, CH_4, NH_3, PM and CO, on a high geographical resolution (0.25º x 0.125º longitude-latitude, which is on average about 15 x 15 km^2) for the reference year 2000. In discussion between UBA, the Free University of Berlin and TNO it was decided that the emission sectorial totals should be conform to the latest country submissions to EMEP for the year 2000, whenever available, and in a second step scaled to the Baseline scenario's for the CAFE-program as of October 2004. TNO focused on obtaining a spatial distribution that is as accurate and realistic as possible and that provides a full geographical coverage of Europe, from Ireland to Kazakhstan. The TNO methodology is consistent, transparent and documented. It is based on, among other items, recent data on a wide range of point source emissions, agricultural/vegetation spatial distribution patterns, traffic intensities/road maps and rural/urban population distribution. Additionally, the emission data provide full and up-to-date coverage of off-shore emission sources, including sea shipping and oil and gas production. This report describes the development of the anthropogenic part of the emissions.

1.1 Outline of the report

The general methodology followed to make the gridded 2000 European anthropogenic emission data for NO_x, SO_2, NMVOC, NH_3, CO, PM_{10}, $PM_{2.5}$ and CH_4 is outlined in chapter 2. This includes the procedures that were followed to come to gridded emission maps for all substances e.g., checking and pre-processing of official emission data from EMEP (section 2.3) and the construction of reference grids and the subsequent scaling to the processed official emission data (section 2.4). The description of the emission database by substance is presented in chapters 3 -9. The bottom-up methodology used to construct the emission database is described in detail for each substance and the results are summarized. The objective of this lay-out is that the reader interested in specific substance information does not have to scan through the entire report. Each substance chapter consists of a separate section on:

- Important emission sources for the specific pollutant.
- Emission factors used.
- Information sources used to obtain activity data.
- The spatial distribution.
- Results (National emissions, European emissions by source sector) and gridded emission maps.

Chapter 10 is devoted to emissions from international (sea) shipping. The underlying information to estimate shipping emissions is listed and the subsequent data processing by TNO is described. A summary of the country emission totals by substance is presented in Appendix 1.

2. Methodology

The basic procedure to come to a high resolution gridded dataset in line with the EMEP country submissions would be to redistribute the EMEP sectoral emissions using high resolution TNO distribution patterns, also called proxi data. The TNO proxi data consist of recent geographical distribution data for point sources and area sources.

2.1 Proxy data

2.1.1 Point sources

TNO point source data include the location and characteristics of all European:
- Utilities (>50MWth; coal-, oil- and gas-fired)
- Oil refineries
- Oil and gas production facilities (including off-shore)
- Surface and underground coal mines
- Coke ovens
- Primary and secondary iron and steel plants:
  a. Blast furnaces
  b. Open hearth furnaces
  c. Basic oxygen furnaces
  d. Electric arc furnaces
  e. Cold and hot rolling mills
- Primary and secondary non-ferrous metals smelters:
  a. Copper
  b. Aluminum
  c. Lead
  d. Nickel
  e. Zinc/cadmium
- Cement factories
- (Petro)-Chemical Plants
- Fertilizer manufacture
- Major airports

2.1.2 Update of point source data

TNO updated the point source data starting from 1995 to the year 2000 for four countries (The Netherlands, Belgium, The United Kingdom and Germany). The update focused on: 1) new point sources that might have been introduced between 1995 and 2000, 2) point sources that ceased to exist in this period, and 3) significant emission changes due to e.g., partial closure, emission control measures or plant extension. Below a short description of the data origin by country is given:

- The Netherlands: the update is based on the Dutch Individual Emission Registration and sector reportings from e.g., associated electricity producers (SEP) and the chemical industry.
- United Kingdom: the UK national individual emission registration system, maintained and made available to TNO by AEA Technology, is used. This covers nearly all point source categories for the year 2000.
- Belgium: Point sources in Belgium have been updated by VITO, Belgium (H. van Rompaey, Personal communication). VITO maintains a national and annually updated database of the facilities that can be considered point sources.
- Germany: The update for Germany is the most challenging task since the German national authorities do not keep record of point source data for environmental monitoring. This type of information (if available at all) is scattered among information systems maintained by local authorities (the Länder) and inaccessible for third parties. TNO was assisted by Ms Ute Karl from the French-German Institute for Environmental Studies (IFEU) for the power generation sector, especially for the new Länder (former DDR). The remaining information was obtained through sector handbooks such as the 12th edition of 'Iron and Steel Works of the World' and the 7th edition of 'Non-Ferrous Metal Works of the World' by Metal Bulletin Books LTD, England, and by searching the Internet for plant specific information.

2.1.3 Area sources

Next to point source information, the TNO proxi data contain distribution patterns for area sources:

- Location and (partly) traffic intensities of highways and major secondary roads.
- Urban, rural and total population density.
- Distribution patterns of various agricultural activities.
- A detailed land use and land cover dataset, including the locations and densities of forested areas.
- The location and densities of sea shipping routes on European seas (North Sea, Baltic Sea, Atlantic Ocean, Mediterranean Sea, Black Sea and the Caspian Sea)

To model air quality (emission, dispersion, distribution and deposition) of pollutants over the Pan-European domain emission and proxy data are needed for a large number of countries. The countries needed to complete the emission inventory for the model domain in the present study are listed in Table 2.1.

Table 2.1 Countries included in the emission domain of interest and their respective ISO3 code abbreviation.

ISO3 code	Country	ISO3 code	Country
ALB	Albania	LVA	Latvia
ARM	Armenia	LTU	Lithuania
AUT	Austria	LUX	Luxembourg
AZE	Azerbaijan	MKD	Macedonia
BLR	Belarus	*MLT*	*Malta*[1)]
BEL	Belgium	MDA	Moldova, Republic of
BIH	Bosnia and Herzegovina	NLD	Netherlands
BGR	Bulgaria	NOR	Norway
HRV	Croatia	POL	Poland
CYP[1)]	*Cyprus*	PRT	Portugal
CZE	Czech Republic	ROM	Romania
DNK	Denmark	RUS	Russian Federation
EST	Estonia	YUG	Serbia and Montenegro
FIN	Finland	SVK	Slovakia
FRA	France	SVN	Slovenia
GEO	Georgia	ESP	Spain
DEU	Germany	SWE	Sweden
GRC	Greece	CHE	Switzerland
HUN	Hungary	TUR	Turkey
IRL	Ireland	UKR	Ukraine
ITA	Italy	GBR	United Kingdom

1) Not included in the inventory

2.2 The development and use of a reference database

Unfortunately directly distributing the EMEP emission data does not produce accurate results. This has several reasons. Firstly, the level of detail as recorded in the EEA/EMEP emission database is not enough to make an accurate distribution because the EMEP sectors are not compatible with the (TNO) proxi data. This can be illustrated with a few examples:

- Combustion emission from power generation is (with a few exceptions) not specified according to fuel type in the EMEP database. However, the fuel type used in a power station is of crucial importance for the source strength and composition of emissions. Without fuel type specification it is difficult, if not impossible, to allocate the correct amount of emission to a point source. Therefore, this parameter is included in the TNO point source data.
- A similar reasoning applies to industrial process emission: the EMEP data provide inadequate detail on the contribution of the individual process types. Country submissions to EMEP are not properly and/or consistently specified by process, in a way that allows proper harmonization with spatial (proxi) data.

– The division into sub-categories is inadequate for road transport, non-road transport, and agriculture to allow accurate spatial distribution of emissions.

Yet another difficulty with the EMEP data is that there is still no full European coverage and not all countries needed to cover the model domain are included. Although the number of countries that submit data has increased in recent years there are still significant data gaps. Completeness varies by substance but even for a well-covered substance like CH_4, no emission data are available for several countries listed in table 2.1.

The above outlined difficulties are tackled by developing a gridded emission database for the year 2000 using a bottom-up method based on emission factors and activity levels and the TNO proxy information. Throughout this report this database is referred to as the so-called TNO reference database. The function of the reference database is to fill in data gaps when no country data are available and to provide a further sub-division of source contribution ratios. The latter can be used to make the EMEP sectoral data (at SNAP level 1) compatible with the proxy data, thereby allowing the official EMEP emission data to be spatially distributed. For example: the EMEP sector total for power generation is split into sub-categories by fuel type according to the ratio between sub-sector source strengths (e.g. power generation emission by fuel type) in the reference database. With this method, it is possible to divide all EMEP sector totals into small parts that are compatible with available distribution functions. In addition, the use of the reference database enables to re-aggregate EMEP (or TNO) emission data to different source classification systems (e.g. NFR to SNAP or vice versa).

A second merit of a reference database is that it provides a second opinion on the emission estimates. A validation and check on the EMEP data can be performed since differences with the reference database should be limited and/or explainable. However, it should be noted that apart from large deviations (e.g., factor > 5) no conclusion can be drawn on the quality of the emission estimates in the EMEP database or reference database. This would ask an in-depth review of the underlying data of both the official submission and the TNO estimate.

2.3 Check and pre-processing of EMEP data prior to gridding

After checking and some processing, the official emission data, as submitted by European countries to EMEP, serve as input for the scaling procedure in which the TNO gridded emissions from the reference database are scaled to be in accordance with the sector totals as submitted to EMEP. In this study two scaling-processes have been carried out, first with the “working database” of the European Environment Agency (EEA), and finally, with the EMEP emissions for the Baseline Scenarios for the CAFE-programme as of October 2004.

The first source of the EMEP data is the 'working database' of the EEA as of April 2004. In this database country data are stored as soon as they are being submitted, whereas the official EMEP Webdab (http://webdab.emep.int/) data are updated only once a year during the summer period.

A complicating issue when using sectoral emission data submitted to EMEP is that countries may use various reporting structures. The emission source category system used up to some time ago for reporting to EMEP was the so-called SNAP system, of which SNAP level 1 (11 categories) was the most detailed common structure. Recently SNAP is replaced by the Nomenclature For Reporting (NFR), a system originally developed for categorizing greenhouse gas emission but which has now been adapted for general emission reporting purposes in Europe. The minimum level of detail by which countries are required to submit data is indicated by NFR level 1. Not all countries have implemented NFR though, resulting in the current EEA database holding a mixture of NFR and SNAP. Unfortunately SNAP level 1 and NFR level 1 are not fully compatible and there is no completeness for either SNAP or NFR in the EMEP database. Therefore, the data processing by TNO to obtain a consistent input set treats the SNAP and NFR coded data separately to allow scaling at the sector level. The emission data are merged only in a later, final stage.

The raw EMEP/EEA data may contain inconsistencies, therefore some checking and pre-processing of the data is necessary before data could be used as input for the production of the gridded emissions. Especially the NFR coded data sometimes incorrectly include natural emissions that must be removed before gridding in order to avoid double counting. In a few cases the NFR categories seem to have been misinterpreted by submitting countries. Some re-allocation to the correct categories is necessary in those cases. Finally, it should be mentioned that if no data for year 2000 were available than data for 1999 have been used as a substitute (if available) otherwise TNO default emission data are used.

Despite TNO's efforts to find and correct any unintentional mistakes in the EEA/EMEP data there can be various shortcomings in the methodologies countries used to estimate emissions. The country methodologies are not transparent and shortcomings will inevitably return in our results (as they are present in the official emission data). The most commonly occurring shortcoming consists of lacking emission data for a specific source category where emissions of the pollutant in question are expected based on expert knowledge and often reported by other countries.

2.3.1 The first scaling exercise

It was agreed upon that the emission totals by substance should be in line with the official emissions data as submitted by the countries to EMEP. Therefore, the TNO reference emission totals for all substances (except PM) were scaled to official submitted emissions available from EMEP as of April 2004. Table 2.2 gives an overview of the origin of the country emissions data for CO, NH_3, NMVOC, NO_x and SO_2. The coding NFR or SNAP in Table 2.2 indicates that official data were available in this reporting format. The pre-processing of the official (EMEP) emission data, if available, results in two consistent datasets/matrices: anthropogenic emission by country and substance at either SNAP level 1 or NFR level 1. If both formats were available from EMEP, the NFR data were used as this is the most recent reporting format. Furthermore, if emission data from various submission dates were available, the most recent submission was chosen. If no official emission data were available the values from the TNO reference database were used indicated by "TNO" and a grey shading in Table 2.2. Approximately ⅔ of the emission data in Table 2.2 are available as official emissions (no shading). In this first scaling exercise the PM and CH_4 data were not scaled because no good official emission data were available.

2.3.2 The second scaling exercise

After further consultation and discussion, it was agreed upon that the scaling to official emissions was to be in line with the EMEP Emissions for the Baseline Scenarios for the CAFE-programme, as of October 2004 (Table 2.3). This second scaling exercise was carried out in December 2004. The base line emission data covered almost all countries and only for a number of former Soviet Union (FSU) states TNO reference values have been used (Russian federation, Armenia, Azerbaijan, Ukraine and Georgia). For the Russian Federation the emissions are scaled to the official emissions as available from EMEP. The numbers provided cover the map domain part of the Russian Federation.

Table 2.2 The origin of country emission totals for CO, NH_3, NMVOC, NO_x and SO_2.

Substance	**CO**	**NH_3**	**NMVOC**	**NO_X**	**SO_2**
Country code (iso3)	**Origin of country totals[1)]**				
ALB	TNO	TNO	TNO	TNO	TNO
ARM	TNO	TNO	TNO	TNO	TNO
AUT	NFR	NFR	NFR	NFR	NFR
AZE	TNO	TNO	TNO	TNO	TNO
BEL	SNAP	SNAP	SNAP	SNAP	SNAP
BGR	SNAP	SNAP	SNAP	SNAP	SNAP
BIH	TNO	TNO	TNO	TNO	TNO
BLR	TNO	TNO	TNO	TNO	TNO
CHE	SNAP	SNAP	SNAP	SNAP	SNAP
CZE	SNAP	SNAP	SNAP	SNAP	SNAP
DEU	SNAP	SNAP	SNAP	SNAP	SNAP
DNK	NFR	NFR	NFR	NFR	NFR
ESP	SNAP	SNAP	SNAP	SNAP	SNAP
EST	SNAP	SNAP	SNAP	SNAP	SNAP
FIN	SNAP	SNAP	SNAP	SNAP	SNAP
FRA	NFR	NFR	NFR	NFR	NFR
GBR	NFR	NFR	NFR	NFR	NFR
GEO	TNO	TNO	TNO	TNO	TNO
GRC	TNO	TNO	TNO	TNO	TNO
HRV	SNAP	SNAP	SNAP	SNAP	SNAP
HUN	SNAP	SNAP	SNAP	SNAP	SNAP
IRL	SNAP	SNAP	SNAP	SNAP	SNAP
ISL	TNO	TNO	TNO	TNO	TNO
ITA	SNAP	SNAP	SNAP	SNAP	SNAP
KAZ	TNO	TNO	TNO	TNO	TNO
LTU	SNAP	SNAP	SNAP	SNAP	SNAP
LUX	SNAP	SNAP	SNAP	SNAP	SNAP
LVA	NFR	NFR	NFR	NFR	NFR
MDA	TNO	TNO	TNO	TNO	TNO
MKD	SNAP	TNO	TNO	SNAP	SNAP
NLD	NFR	NFR	NFR	NFR	NFR
NOR	NFR	NFR	NFR	NFR	NFR
POL	SNAP	SNAP	SNAP	SNAP	SNAP
PRT	NFR	NFR	NFR	NFR	NFR
ROM	TNO	TNO	TNO	TNO	TNO
RUS	SNAP	TNO	SNAP	SNAP	SNAP
SVK	NFR	NFR	NFR	NFR	NFR
SVN	SNAP	SNAP	SNAP	SNAP	SNAP
SWE	NFR	NFR	NFR	NFR	NFR
TUR	TNO	TNO	TNO	TNO	TNO
UKR	TNO	TNO	TNO	TNO	TNO
YUG	TNO	TNO	TNO	TNO	TNO

[1)] TNO = TNO reference database, no official emission estimate available; NFR = Official emission as available from EMEP webdab, source sector split in NFR format; SNAP = Official emission as available from EMEP webdab, source sector split in SNAP format.

Table 2.3 National emissions for NH_3, NMVOC, NO_x, SO_x, $PM_{2.5}$ and PM_{10} according to the EMEP emissions for the Baseline Scenarios for the CAFE-programme, October 2004 (personal comm.. L. Tarason, 2004).

species: ISO-3	CO	NH_3	NMVOC	NO_x (tons)	SO_x	$PM_{2.5}$	PM_{10}
ALB	102000	22393	29390	21625	32296	6483	9032
ARM	109660	15000	15960	9970	8403	5070	7320
AUT	858745	53549	190573	191648	37981	36497	48544
AZE	293000	25000	9000	43000	15000	19220	29530
BEL	1099620	81089	241706	333251	187300	42208	68485
BGR	667270	91840	136158	190612	1312916	56600	92345
BIH	193000	17309	40347	52780	420031	20280	48139
BLR	717500	128106	228676	247760	351271	36488	55967
CHE	393900	66057	146929	97141	20276	10119	15076
CYP	83490	5723	12821	26821	49609	2523	3292
CZE	648000	73691	243754	320197	250741	71411	109262
DEU	4768000	638233	1521574	1656612	641199	167395	254960
DNK	578570	90815	127883	206943	28412	21876	31869
ESP	2774001	394220	1115821	1327977	1486140	165290	228943
EST	201660	9608	37010	37381	91170	21650	41649
FIN	526300	34697	170915	212960	79410	35705	42552
FRA	6639581	728408	1540796	1443731	646379	285801	367676
GBR	4025050	314725	1457165	1749579	1188703	125225	196889
GEO	222500	97000	19000	30140	9000	7560	11810
GRC	1531000	55014	280241	321252	477501	48658	65176
HRV	402100	32544	101872	87373	107658	18707	28558
HUN	633040	77762	150970	187650	487418	59622	85940
IRL	279571	126777	87646	129441	132373	13738	20892
ITA	5207198	433843	1728348	1387831	755306	207341	270433
LTU	281500	50003	63239	49053	43359	16880	20136
LUX	48939	6507	13226	33036	4109	3243	4176
LVA	272926	12199	32781	35246	16779	7405	9799
MDA	100200	36064	41435	64300	113929	22885	40789
MKD	76940	14693	26063	38437	90193	9453	20867
MLT	20570	1462	4470	9283	25601	578	805
NLD	678579	156796	264486	401582	85001	34819	56004
NOR	568181	25598	373825	210720	27110	26516	31900
POL	3463001	309248	581723	843117	1514778	211513	299117
PRT	675000	68373	261184	264845	231619	46200	58490
ROM	2325000	223444	378514	330876	838488	106469	161220
RUS							
SVK	290139	31593	88211	106393	124133	17982	28450
SVN	68000	18358	54241	57963	96768	14985	20692
SWE	832962	53473	305038	251893	57561	66694	78161
TUR	3778201	274978	773793	942405	2121891	302242	414066
UKR	2671800	485537	743670	1146287	1404105	314845	517699
YUG	553000	66036	142375	166438	396258	44427	91805

2.4 Construction of the TNO reference grids and scaling to the official EMEP data

The gridded TNO data consists of a large set of activity data and emission factors that are organized by substance (see substance paragraphs). For each substance the emissions, calculated as the product of the emission factor and the activity value, are stored at the level of each individual factor and value, thus maintaining the highest level of detail. Emissions can be aggregated to various source category systems for reporting purposes. Prior to the production of the TNO reference grids, the emission data are not aggregated. Aggregated data would not be suitable for gridding because of incompatibility with the proxy data. So gridding (both to point as well as area sources) must be performed at the highest level of sector detail to obtain the most accurate results. For a given substance, the proxy data consist of a set of records that include location data, source characteristics, and a number that represents the fraction of the country's sectoral emission that must be allocated to the entry in question. After gridding the emission data can be aggregated to any source classification system or combination of systems.

The EMEP sector totals are split into sub-sectors (needed for compatibility with proxy data and for reporting purposes) according to the ratio between source strengths in the TNO reference database. All sub-divided data are subsequently gridded and re-aggregated to NFR – format (which is unlike NFR level 1) and SNAP level 1. The gridded data are aggregated at SNAP level 1 with a more detailed split for the road transport sector (Table 2.4). For each category defined in Table 2.4. and each substance a different emission map is made for the entire modeling domain.

Table 2.4 Source sector numbering and description as used for the gridded emission maps. Classification is based on the SNAP level 1 system with a more detailed split in SNAP 7 (road transport).

Source sectors	Description
1	Energy sector, utilities, refinaries
2	Fossil fuels, small sources
3	Fossil fuels, industry
4	Process emissions
5	Mining
6	Solvent use, use of products
7	Road transport
71	Road transport gasoline
72	Road transport diesel
73	Road transport LPG
74[1)]	Road transport non-exhaust (volatilization)
75[2)]	Road transport non-exhaust (tire, break and road wear)
8	Non-road transport
9	Waste processing
10	Agriculture

1) Relevant for NMVOC emissions
2) Relevant for PM emissions

A few important remarks need to be made with respect to the scaling of the country emissions.

1. The objective of scaling the final delivered data to the official EMEP emissions for the Baseline Scenarios for the CAFE-programme is to make the dataset most compatible with on-going policy analysis and scenario studies. No analysis or judgement is made of the quality of the official emission data and the differences between official emissions and expert estimates.
2. Furthermore, the emissions for the Baseline Scenarios for the CAFE-programme, as obtained through EMEP October 2004, do not exactly match with the official emissions as they can be downloaded from the EMEP webdab tool (http://webdab.emep.int/). This is illustrated for the pollutant SOx in Table 2.5. The third column in Table 2.5 presents the difference between both inventories. As can be seen the official emission data obtained from the WebDab tool are incomplete because some countries are missing. These have been replaced by expert estimates. However, for some countries the difference between official emissions and the base line data can be substantial (e.g. Turkey, Ukraine).
3. As indicated earlier TNO reference values have been used for some former soviet union states (FSU), indicated in Table 2.5 with blue italics)

Table 2.5 Comparison of SO_x emissions by country according to the EMEP Base Line (BL) Scenarios for the CAFE-programme, official emission data, difference between base line data and official submitted emissions, emissions in the TNO reference database and the final delivered "scaled" TNO_UBA database.

			Database			
Country	**EMEP_CAFE _BL[1)]**	**Official country emissions[2)]**	**Difference EMEP CAFE_BL – Official emissions**	**TNO reference**	**TNO_first scaling**	**Final Scaled TNO-UBA[3)]**
			SO_x (GG)			
ALB	32			24	24	32
ARM	8	8	0	7	7	*7*
AUT	38	35	3	34	38	38
AZE	15			185	185	*185*
BEL	187	165	23	252	181	187
BGR	1313	1226	87	1235	982	1313
BIH	420			275	275	420
BLR	351	552	-201	165	165	351
CHE	20			25	19	20
CZE	251	264	-13	727	265	251
DEU	641	636	5	369	637	641
DNK	28	29	0	141	28	28
ESP	1486	1522	-36	1754	1401	1486
EST	91	99	-7	103	95	91
FIN	79	116	-37	192	74	79
FRA	646	627	19	785	652	646
GBR	1189	1189	-1	1823	1188	1189
GEO	9	6	3	14	14	*14*
GRC	478	483	-5	641	641	478
HRV	108			110	60	108
HUN	487	486	1	640	486	487
IRL	132			235	131	132
ITA	755	752	3	1483	758	755
LTU	43	43	0	49	43	43
LUX	4	3	1	10	3	4
LVA	17	16	0	22	17	17
MDA	114	13	101	8	8	8
MKD	90			87	105	90
)	85	77	8	82	91	85
NOR	27	27	1	76	26	27
POL	1515	1511	4	2360	1511	1515
PRT	232	232	-1	301	286	232
ROM	838			896	896	838
RUS		1997		6643	1611	*1611*
SVK	124	124	0	65	124	124
SVN	97	99	-2	155	90	97
SWE	58	55	3	67	57	58
TUR	2122	1347	775	2894	2894	2122
UKR	1404	2310	-906	1263	1263	*1263*
YUG	396	387	9	593	593	396
Sum	15930	16436	-163	26793	17924	17468

1) Emissions for the Baseline Scenarios for the CAFE-programme, October 2004.

2) Downloaded from EMEP through theWebdab tool in February 2005.

3) Blue italics indicate where TNO expert estimates have been used for the national totals.

The difference between the TNO reference database and the EMEP CAFÉ BL data is substantial (Table 2.5), the total SOx emission for the countries considered is about 10.000 GG higher in the TNO reference database. A detailed analysis of the origin of such differences is not made and outside the scope of the project but a few remarks can be made.

- As the objective of the TNO reference database is to be a tool for accurate spatial distribution of officially submitted emission data, the absolute emissions levels are of less importance than the proper representation and spatial allocation of the sources. Hence, not every effort possible is made to update the emission factors and in some cases less up to date emission factors may lead to an overestimation of emissions. Also the status and impact of the 2nd S protocol may not have been entirely incorporated. Again for the end use of the database – spatial distribution – this is not relevant.
- For Russia, the TNO reference database considers the entire country whereas the EMEP data are limited to the European part of Russia.
- In general an important cause of differences is the assumed effectiveness of S removal during solid fuel combustion.

A further analysis of differences in the databases is recommended and may lead to a better insight in actual emissions and the uncertainties surrounding current estimates.

Table 2.6 is similar to table 2.5, but than for NOx.

Table 2.6 Comparison of NO_x emissions by country according to the EMEP Base Line (BL) Scenarios for the CAFE-programme, official emission data, difference between base line data and official submitted emissions, emissions in the TNO reference database, TNO first scaling and the final delivered "scaled" TNO_UBA database.

Country	EMEP_CAFE _BL[a)]	Official country emissions[b)]	Difference EMEP CAFE_BL – Official emissions NO_x (GG)	TNO reference	TNO_first scaling	Final Scaled TNO-UBA[c)]
ALB	22			21	21	22
ARM	10	10	0	9	9	9
AUT	192	190	1	225	191	192
AZE	43	0	43	90	90	***90***
BEL	333	308	25	345	303	333
BGR	191	280	-89	167	184	191
BIH	53	0	53	62	62	53
BLR	248	135	113	205	205	248
CHE	97	96	1	169	96	97
CZE	320	321	-1	468	398	320
DEU	1657	1639	17	2359	1542	1657
DNK	207	208	-1	218	206	207
ESP	1328	1431	-103	1163	1282	1328
EST	37	47	-9	54	41	37
FIN	213	224	-11	200	236	213
FRA	1444	1431	12	1236	1430	1444
GBR	1750	1718	32	1517	1737	1750
GEO	30	42	-12	44	44	***44***
GRC	321	321	0	393	393	321
HRV	87	77	11	96	77	87
HUN	188	185	2	200	185	188
IRL	129	125	4	120	125	129
ITA	1388	1373	15	1643	1373	1388
LTU	49	48	2	67	47	49
LUX	33	17	16	24	17	33
LVA	35	38	-3	32	34	35
MDA	64	27	37	18	18	***18***
MKD	38	30	8	31	30	38
NLD	402	423	-22	482	409	402
NOR	211	224	-13	191	219	211
POL	843	838	5	1185	838	843
PRT	265	261	3	250	397	265
ROM	331	289	42	298	298	331
RUS	NA[d)]	2357	NA[d)]	4109	1891[e)]	1891[e)]
SVK	106	107	-1	125	106	106
SVN	58	58	0	61	58	58
SWE	252	250	1	212	250	252
TUR	942	951	-9	804	804	942
UKR	1146	561	585	849	849	***849***
YUG	166	50	116	148	148	166
Sum	15229	16691		19890	16646	16836

a) Emissions for the Baseline Scenarios for the CAFE-programme, October 2004

b) Downloaded from EMEP through the Webdab tool in June 2005 (National totals; preferably NFR N02, else N01, else SNAP)

c) Blue italics indicate where TNO expert estimates have been used for the national totals.

d) NA = not available

e) The Baseline Scenarios for the CAFE-programme did not contain an estimate for the Russian federation. Scaling was done with the official estimate to remain in line with EMEP (as was requested in the first scaling exercise). The presented 1891 GG NOx covers the Pan European (Map domain) part of the official national total (2357 GG, see 2nd column, RUS).

3. Nitrogen oxide (NO_x)

The main emission sources of NO_x are large stationary combustion plants and transport activities. NO_x emission in stationary combustion plants is roughly proportional to the combustion temperature which implies that the specific NO_x emission increases as the size (and hence flame temperature) of the combustion plant rises. Fuel type is of somewhat lesser importance since the source of nitrogen in the formation of NO_x is primarily air nitrogen. In some cases NO_x emissions are abated by various catalytic and chemical control techniques. Removal efficiencies up to about 80% can be reached. However, at present (year 2000) NO_x emission control techniques for stationary combustion find only limited use in Europe. Transport activities (combustion engines) are the second most important source of NO_x. With the introduction of the EURO emission standards for vehicles NO_x emission from this source is significantly abated due to e.g., catalytic converters. Aside from combustion and transport, several chemical production processes involving nitrogen oxidation are important NO_x sources (e.g. nitric and adipic acid production), as well as a few processes in the iron and steel sector. NOx emissions from international shipping activities are described in chapter 10.

3.1 Activity data

3.1.1 Energy

The activity data for the stationary combustion of fossil fuels are taken from the IEA Energy Statistics [IEA 2003]. The IEA distinguishes a large range of sectors. Each sector is characterized with respect to representative average boiler or furnace sizes. The IEA data covers different solid, liquid and gaseous fuels.

3.1.2 Industrial Processes

The activity data for process emissions (chemical and iron and steel industry) is taken from the IIASA RAINS7.2 model [Cofala et al. 1998]. The 'Current Legislation Scenario' is used to estimate the 2000 activity levels.

3.1.3 Transport

NO_x road transport emissions are estimated based on kilometres driven by vehicle class and average speed (urban, rural and highway). For the EU countries, Norway and Switzerland data are taken from Ntziachristos et al. [2002]. These data are compiled for the year 2000 within the framework of the COPERT III road transport emission model [Ntziachristos et al. 2000]. Four basic vehicle classes are distinguished: heavy duty vehicles (HDV), light duty vehicles (LDV), passenger cars (PC) and motor cycles (MC). For each fuel type (gasoline, diesel and LPG) and vehicle class, up to 10 different engine technologies are distinguished, based on technological standards (e.g., EURO I, II, III IV and pre-EURO). A distinction is made between average speeds (urban, rural and highway), which are important factors in estimating NO_x emission. For non-EU countries except Norway and Switzerland detailed road transport activity data are only available for 1998 at the most recent. 2000 activity data have been estimated based on the growth rate from 1998 to 2000 in total energy consumption by fuel type for road transport [IEA 2003], assuming no significant changes in vehicle fleet between 1998 and 2000 in non-EU countries.

Air transport NO_x emissions are estimated using the total number of flight movements for the 300 largest airports in Europe [ACI 2003]. .Activity data for the remaining modes of transport (e,g, internal water ways, rail etc.) are gathered from the IEA in the form of fuel consumption data [IEA 2003].

3.2 Emission factors

NO_x emission factors for large stationary combustion plants have been taken from the TROTREP project [Monks et al. 2003]. These emission factors comprise two sets for two country groups, being the EU(15) plus Norway and Sweden and the other European countries. Industrial combustion has (depending on the sector) been characterized into small (5 - 50MWth), medium (50 – 200MWth) and large (above 200MWth) sized combustion plants, each size class having different emission factors. For stationary engines and small combustion plants emission factors from the LOTOS/EDGAR emission databases [Olivier et al. 2002] have been used.

Emission factors for process emissions (iron and steel sub-processes, chemical production processes) have also been taken from the LOTOS/EDGAR emission databases. For industrial processes, 2 country groups are defined with different emission factors: Western Europe (EU(15) + Norway and Switzerland) and Central and Eastern Europe (all other countries).

Emission factors for road transport activities are taken from Ntziachristos et al. (2002) as developed for the COPERT III model [Ntziachristos et al. 2000]. This is combined with country-specific vehicle fleet data as available from the respective road transport activity data set (section 3.1). For each vehicle class, technological standard and average speed separate emission factors are available. In total, this set comprises several tenths of emission categories and emission factors.

Air transport emission is estimated based on a NO_x emission factor by unit of flight movement, derived from information given in the annual environmental report by the Netherlands's largest airport, Schiphol. [Hulskotte and den Boeft, 2003]

Emission from other mobile sources and machinery is estimated with the use of emission factors from the LOTOS/EDGAR emission databases [Olivier et al. 2002].

3.3 Spatial distribution

The emission of power plants and large heat plants (>50MWth) is distributed based on point source information such as country, capacity and primary fuel type (TNO updated point source data 2003). For industrial combustion in the iron and steel sector, the chemical industry, the non-metallic minerals sector, the oil refineries, the non-ferrous metals production sector and oil and gas production sector, point source information is also used but in this case emission is distributed according to process type and capacity ratio, irrespective of fuel type. The industrial combustion emissions from sectors other than mentioned above, is distributed according to total (urban + rural) population density [CIESIN, 2001].

Emission from the Residential, Commercial and Institutional sector is distributed according to total (urban + rural) population density [CIESIN, 2001]. An exception is made for fuel wood combustion (although an insignificant source for NO_x) for which the emission is distributed according to rural population density only [AEAT – TNO 2000].

For the spatial distribution of the emission from road transport, the emission totals have been split into HDV and LDV as well as into an urban, rural and highway part [Ntziachristos et al. 2002]. The highway part is distributed according to digitized maps of highways, using traffic intensities by highway section for LDV and HDV from Eurostat [Eurostat 2003b]. Digitized maps of highway locations are available for all countries in the area while traffic intensities are only available for the majority of the EU(15) countries. For countries other than EU(15), traffic intensities by highway section have been estimated based on an overlay with a low resolution (0.5 x 0.5 °) population density distribution map (since transport activity correlates with population density). The higher the total population within a 0.5 x 0.5 degree lo-la square cell, the higher the transport intensity in the cell's highways. The rural part of the road transport emission is distributed according to the digital maps of the European rural road network. Relative traffic intensities are again estimated by an overlay with population density, on a 0.5 x 0.5 ° resolution. The 0.5 x 0.5 ° resolution is a compromise in order to include trans-regional traffic movement and maintain a rational level of geographic detail within a country. The urban part of the road transport emissions is distributed according to a high resolution population density map, since trans-regional transport is of lesser importance in an urban environment with mainly local traffic. Emission from agricultural activities (which, for Europe as a whole, mainly comprise vehicular emissions for NO_x) are distributed according to rural population density.

Emission from air transport (LTO cycli plus emission up to 915 m) is distributed according to the location and total number of flight movements of the 300 largest airports in Europe [ACI 2003], [ESRI, 2002].

3.4 Results

The final delivered data are summarized in Table 3.1. as emission by country by source sector. The relative contribution by source sector is presented in Figure 3.1, indicating that road transport is the most important sector for NO_x emissions followed by the Energy sector (including refineries) and non-road transport. Figure 3.2. and 3.3 present the spatial distribution of the NO_x emission data in the form a gridded map.

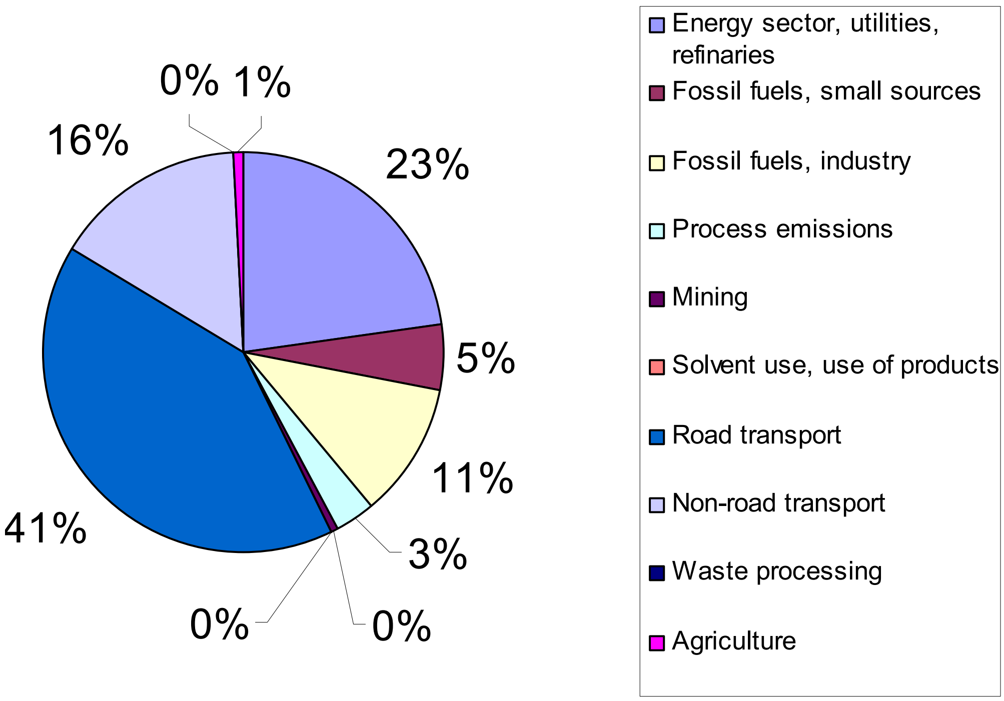

Figure 3.1 NO_x emission by source sector for the entire domain (total emission is 16836 GG, Table 3.1).

Table 3.1 NO_x emission data for year 2000 by country and source sector.

ISO 3	Energy sector, utilities, refineries	Fossil fuels, small sources	Fossil fuels, industry	Process emissions	Mining	Solvent and product use	Road transport	Non-road transport	Waste	Agri-culture	Total
	(tons)										
ALB	1825	1064	2236	1430	0	0	15028	0	0	43	21625
ARM	3245	439	2803	0	0	0	2064	51	0	42	8642
AUT	13774	15499	25295	4038	0	0	91890	41135	15	3	191648
AZE	44112	5731	9027	0	0	0	28803	0	668	2090	90431
BEL	52685	24633	66185	5981	0	0	156762	25761	1244	0	333251
BGR	70626	2596	16695	23092	0	0	52433	25097	14	60	190612
BIH	27134	951	3206	1938	0	0	14674	4877	0	0	52780
BLR	98045	8510	11768	15976	0	0	68257	44871	0	332	247760
CHE	3379	12301	12794	1744	0	0	52899	13874	95	55	97141
CZE	108570	13605	45172	3094	0	0	101610	48023	122	0	320197
DEU	258659	108448	161648	27087	0	0	884371	216398	0	0	1656612
DNK	56013	6995	12780	2415	0	0	77903	50838	0	0	206943
ESP	322314	29911	145797	46139	0	0	551938	229797	321	1759	1327976
EST	14826	1222	2268	0	0	0	14715	4350	0	0	37381
FIN	34917	8843	37385	3224	0	0	82955	45572	65	0	212960
FRA	138846	95653	156559	35897	0	0	759557	256287	931	0	1443731
GBR	435327	104013	157206	12264	0	0	854592	182706	3471	0	1749579
GEO	4054	1620	1183	0	0	0	29431	0	0	7339	43626
GRC	79623	8896	34782	6309	0	0	115774	74333	148	1387	321252
HRV	13567	6745	7944	6518	0	0	38992	13597	10	0	87373
HUN	43272	15330	16909	2930	0	0	88685	20524	0	0	187650
IRL	40088	8182	10255	816	0	0	51245	18855	0	0	129441
ITA	160050	76520	167217	17306	0	0	713848	251963	655	274	1387833
LTU	11092	2139	2775	2100	0	0	25304	5644	0	0	49053
LUX	169	1279	3889	0	0	0	26412	1285	2	0	33036
LVA	7704	909	2988	0	0	0	17604	5773	24	244	35246
MDA	7920	1558	1259	133	0	0	3452	241	0	3799	18362
MKD	12814	476	2835	3871	0	0	13353	5088	0	0	38437
NLD	64319	25682	33513	2310	0	0	182469	93093	197	0	401582
NOR	14145	2781	12201	19600	0	0	47939	99295	14665	94	210719
POL	350098	54953	123498	8137	0	0	211805	94627	0	0	843117
PRT	65944	11142	31304	1680	0	0	109685	44596	217	277	264845
ROM	118600	12134	34975	20830	0	0	81937	61684	53	663	330876
RUS	485000	74686	87567	76595	77684	0	695615	393616	0	0	1890764
SVK	32628	5267	22269	3929	0	0	34707	6632	0	960	106393
SVN	14838	2845	3860	0	0	0	27933	8486	0	0	57963
SWE	26498	14823	43381	2967	0	0	110676	53548	0	0	251893
TUR	203584	44417	154902	74019	0	0	342999	122484	0	0	942405
UKR	311432	76673	172121	108480	830	0	50226	20423	4773	103937	848894
YUG	71937	2175	9185	8616	0	0	48716	25810	0	0	166438
Total (GG)	***3824***	***892***	***1850***	***551***	***79***	***0***	***6879***	***2611***	***28***	***123***	***16836***

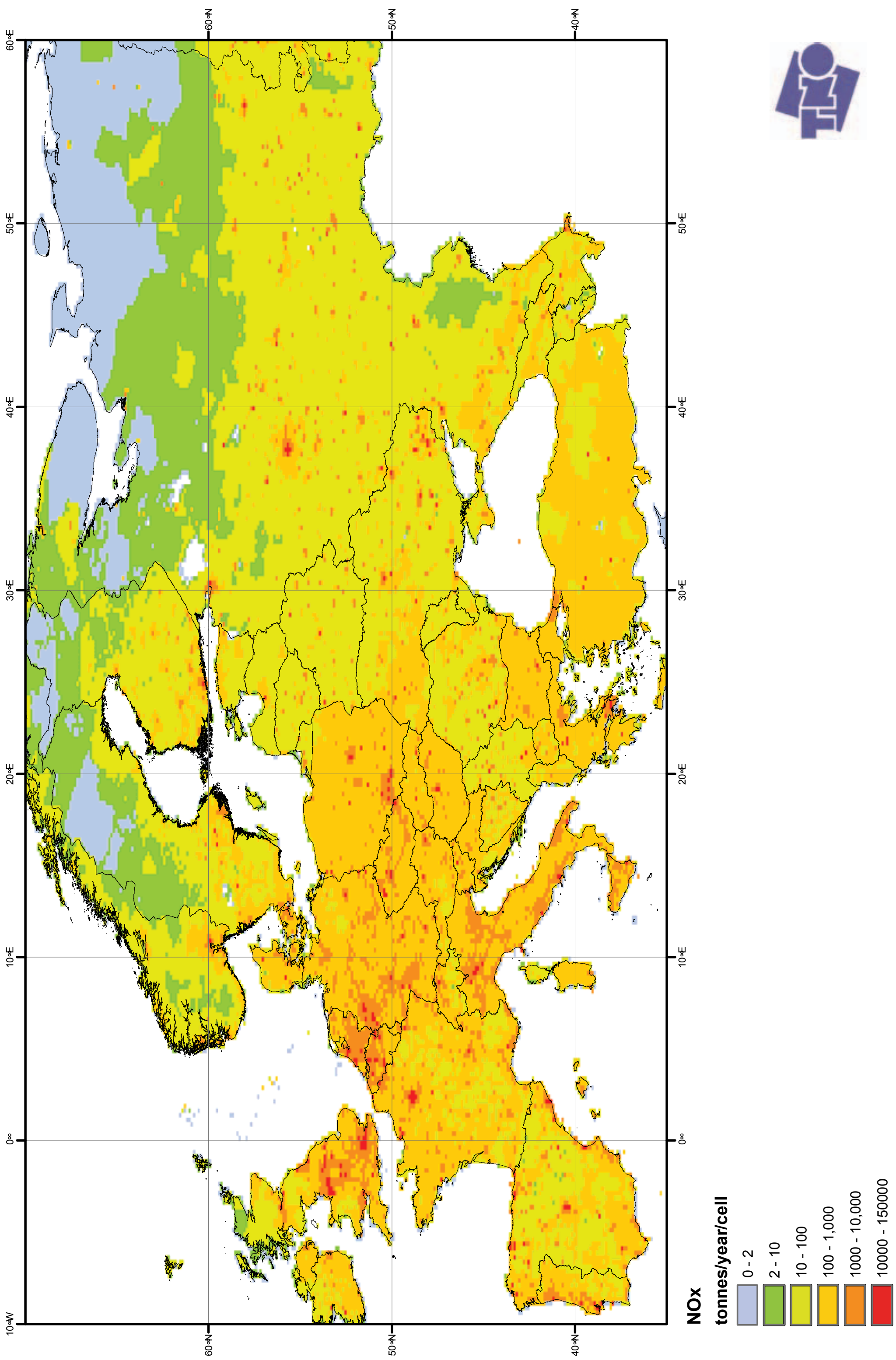

Figure 3.2 Spatial distribution of NO_x emission in Europe for the year 2000 excluding shipping emissions

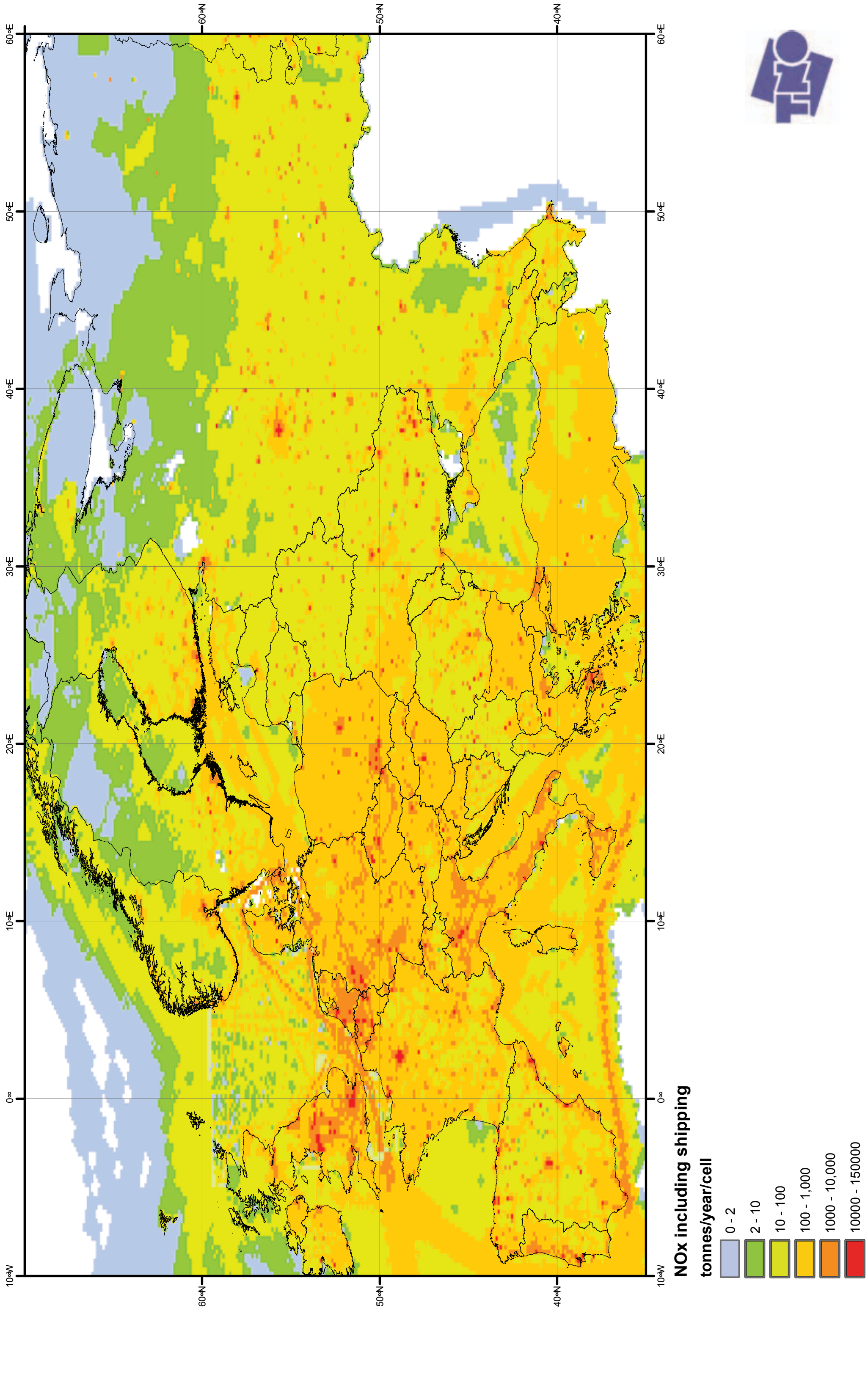

Figure 3.3 Spatial distribution of NO_x emission in Europe for the year 2000 including shipping emissions

4. Sulphur dioxide (SO_2)

The main emission sources of SO_2 are combustion processes, especially the combustion of coal and heavy fuel oil. In addition there are non-ferrous metals smelting processes of which the ores are generally in sulphide form. During chemical reduction of the metal sulphides sulphur is released as SO_2. In many cases SO_2 emissions are abated by various emission control techniques. Sulphur removal efficiencies for large combustion plants and large non-ferrous metal smelters show a large range of zero (uncontrolled) to 90% abatement in Europe.

4.1 Activity data

The activity data for fossil fuel combustion are taken from the IEA Energy Statistics [IEA 2003]. This includes transport emission, contrary to other substances for which transport emission is estimated using mileage data. The IEA distinguishes several coal ranks and heavy and medium distillate fuel oils, as well as different types of lighter fuels and gasses. An extended sector detail is provided. The activity data for non-ferrous metals smelters is taken from the IIASA RAINS 7.2 model [Cofala et al. 1998]. The 'Current Legislation Scenario' is used to estimate the 2000 activity levels.

4.2 Emission factors

In case of SO_2, each country is treated individually in terms of emission factors. Combustion related SO_2 emission by fuel type *i* and process *j* is calculated according to:

$$Emission_{fuel(i)} = [Use_{fuel(i)} \times Sulphur\ content_{fuel(i)} - Sulphur\ retention_{process(j)}] \times Removal\ efficiency_{process(j)}$$

Values per country, by fuel type and by process for sulphur contents, sulphur retention in ashes and removal efficiencies have been taken from RAINS 7.2. [Cofala et al. 1998]. The Current Legislation Scenario is assumed to estimate these values for the year 2000. Emission control technologies are restricted to large combustion plants and large non-ferrous metals smelters, if applied. In most countries however, emission is uncontrolled.

Process emission factors by country and process for non-ferrous metal smelters for the year 2000 are again derived from the RAINS model, according to the Current Legislation Scenario. The processes covered are the primary production of copper, lead, zinc and nickel.

The methodology used for emission from international shipping is different from above and is described in chapter 10.

4.3 Spatial distribution

The emission of power plants and large heat plants (>50MWth) is distributed based on point source information such as country, capacity, primary fuel type and removal efficiency (TNO updated point source data, 2003). For industrial combustion in the iron and steel sector, the chemical industry, the non-metallic minerals sector, the oil refineries, the non-ferrous metals production sector and oil and gas production sector, point source information is also used but in this case emission is distributed according to process type and capacity ratio, irrespective of fuel type [Olivier et al. 2002]. The industrial combustion emissions from sectors other than mentioned above, are spatially distributed according to total (urban + rural) population density.

For the 100 most important SO_2 emitting point sources individually registered emission data is available [Barret 2001]. These data are self-reported by plants and are considered more accurate than the TNO emission data obtained by generic distribution methods. Therefore, the point source emission data estimated based on capacity/fuel type ('TNO-values') are corrected by replacing the TNO value by the registered emission and subsequent correction of the remaining point source emissions to remain conform to the emission tables (calculated as described above). The facilities for which individually registered emissions are available mostly concern power stations but also include some chemical production plants, non-ferrous metal smelters, iron and steel plants and oil refineries.

Combustion emission from the Residential, Commercial and Institutional sector is distributed according to total (urban + rural) population density [CIESIN 2001]. An exception is made for fuel wood combustion (insignificant source for SO_2) for which the emission is distributed according to rural population density only [Olivier et al. 2002].

Emission from road transport is considered a relatively minor source for SO_2 and is distributed according to total population density. SO_2 emission is mainly emitted by diesel-fuelled vehicles and in a number of central and Eastern European countries diesel powered transport is neglected in the transport statistics whereas it is not in the energy statistics. In other words SO_2 emissions calculated based on energy data can, in some cases, not be distributed with road transport statistical data. Therefore, the spatial distribution patterns used for NO_x etc. could unfortunately not be used for SO_2 and population density is used as a default distribution.

Emission from air transport (LTO cycli plus emission up to 915 m) is distributed according to the location and total number of flight movements of the 300 largest airports in Europe [ACI 2003], [ESRI, 2002].

The spatial distribution of emission from international shipping is described in chapter 10. Agricultural emission is distributed according to rural population density.

All other sources for which the spatial distribution is not specifically discussed above, its contribution can be considered as relatively minor for this substance. For all minor sources the same default distribution pattern is used, which is total population density.

4.4 Results

The final delivered data are summarized in Table 4.1. as emission by country by source sector. The relative contribution by source sector is presented in Figure 4.1, indicating that the Energy sector (including refineries) is by far the most important sector for SO_2 emissions followed by fossil fuel use in the industry. Figure 4.2. presents the spatial distribution of the SO_2 emission data in the form a gridded map.

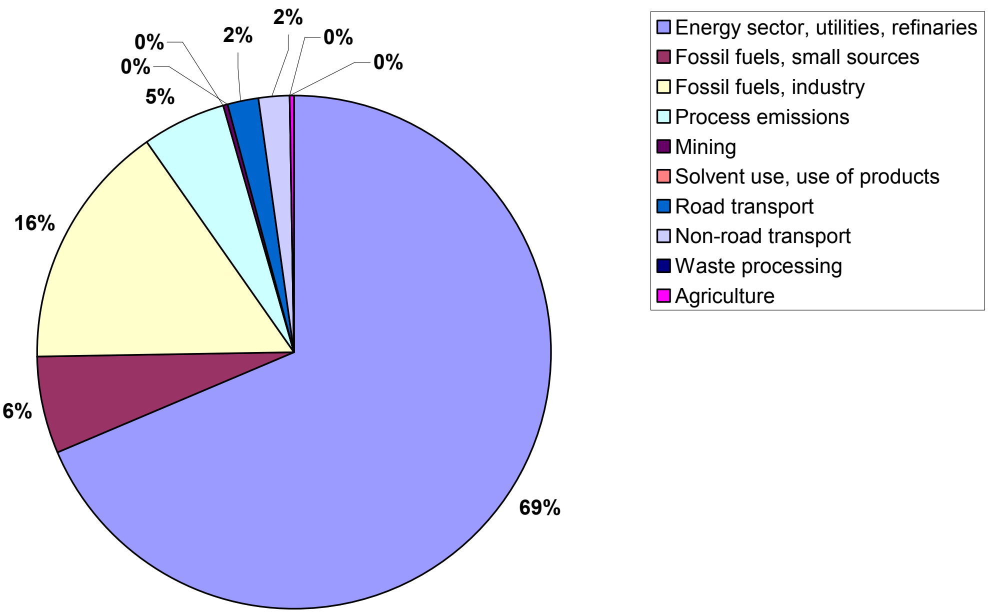

Figure 4.1 SO_x emission by source sector for the entire domain (total emission is 17471 GG, Table 4.1).

Table 4.1 SO_x emission data for year 2000 by country and source sector

ISO 3	Energy sector, utilities, refineries	Fossil fuels, small sources	Fossil fuels, industry	Process emissions	Mining	Solvent and product use	Road transport	Non-road transport	Waste	Agri-culture	Total
	SO_x (tons)										
ALB	12175	2807	10956	1152	0	0	5165	0	0	41	32296
ARM	0	789	6060	0	0	0	0	2	0	0	6851
AUT	7892	10024	10574	6047	0	0	2485	939	16	3	37981
AZE	168896	810	12911	0	0	0	0	1500	0	1249	185366
BEL	61798	27202	59928	28124	0	0	4961	5135	152	0	187300
BGR	1226886	11896	60342	9352	0	0	772	3653	15	0	1312916
BIH	384743	6929	16009	7759	0	0	3187	1404	0	0	420031
BLR	260897	21673	16958	27147	0	0	12736	11504	0	356	351271
CHE	2068	7717	7568	668	0	0	1632	558	42	24	20276
CZE	147623	32738	54467	8065	0	0	3620	4173	54	0	250741
DEU	310560	101052	109122	93201	0	0	21949	5315	0	0	641199
DNK	13617	3146	8241	0	0	0	397	3011	0	0	28412
ESP	1089958	37621	195232	122151	0	0	16018	24247	142	770	1486140
EST	81446	2765	5274	448	0	0	670	567	0	0	91170
FIN	30428	5071	34121	7028	0	0	69	2692	0	0	79410
FRA	256634	65184	165935	113011	0	0	22770	22198	648	0	646379
GBR	906893	60728	144468	38777	0	0	7147	29353	1337	0	1188703
GEO	9062	925	721	0	0	0	2026	574	0	1049	14357
GRC	386402	13160	34708	14661	0	0	4782	23180	0	608	477501
HRV	54846	36355	9161	5534	0	0	505	1246	11	0	107658
HUN	416035	33049	23993	10208	0	0	1539	2594	0	0	487418
IRL	81106	22836	24886	0	0	0	1426	2119	0	0	132373
ITA	432909	27893	133620	63898	0	0	10912	85787	287	0	755306
LTU	23688	5981	4948	7504	0	0	785	453	0	0	43359
LUX	95	651	2364	0	0	0	936	62	1	0	4109
LVA	6956	2257	5690	1	0	0	1147	620	0	107	16779
MDA	4090	1452	386	0	56	0	777	121	0	705	7588
MKD	72552	1753	12143	594	0	0	1683	1468	0	0	90193
NLD	30403	2275	8156	24777	0	0	3162	16029	198	0	85001
NOR	1543	2125	9497	9167	0	0	888	3849	0	41	27110
POL	1011532	180033	230105	50893	0	0	30552	11664	0	0	1514779
PRT	166814	8786	22322	24414	0	0	5370	3697	95	121	231619
ROM	754384	6322	47532	18226	0	0	1465	9849	0	710	838488
RUS	925000	36611	377889	40700	57254	0	133264	40285	0	0	1611003
SVK	71468	15860	24451	10709	0	0	745	480	0	420	124133
SVN	91718	3607	0	0	0	0	764	679	0	0	96768
SWE	14042	4959	24273	12434	0	0	787	1067	0	0	57561
TUR	1404217	73529	597461	0	0	0	28640	18043	0	0	2121891
UKR	751848	145015	217917	107565	3519	0	0	16421	0	20578	1262863
YUG	325733	13581	29597	11934	0	0	7870	7543	0	0	396258
Total (GG)	***11999***	***1037***	***2760***	***876***	***61***	***0***	***344***	***364***	***3***	***27***	***17471***

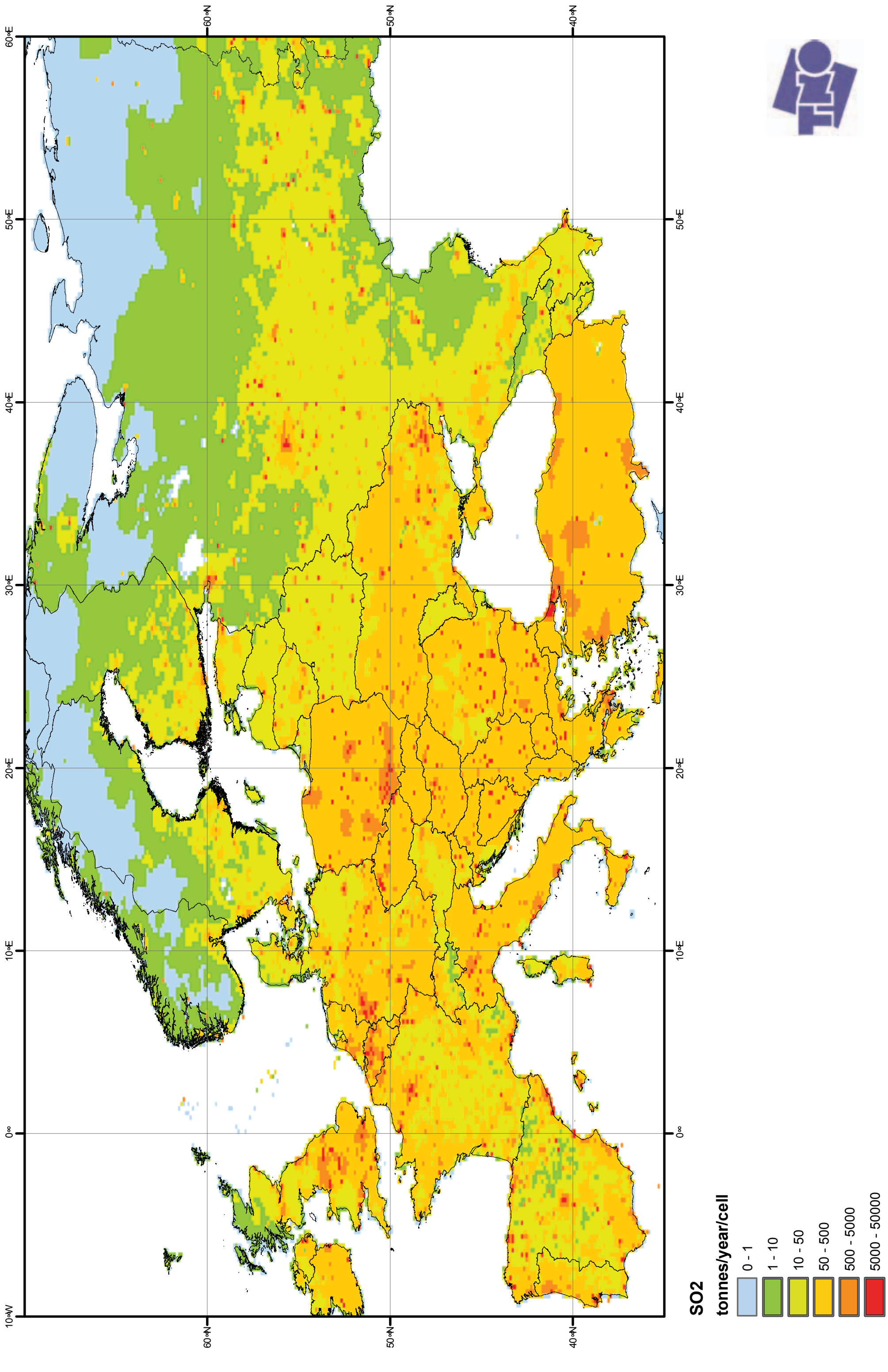

Figure 4.2 Spatial distribution of SO_2 emission in Europe (Table 4.1) for the year 2000 excluding shipping.

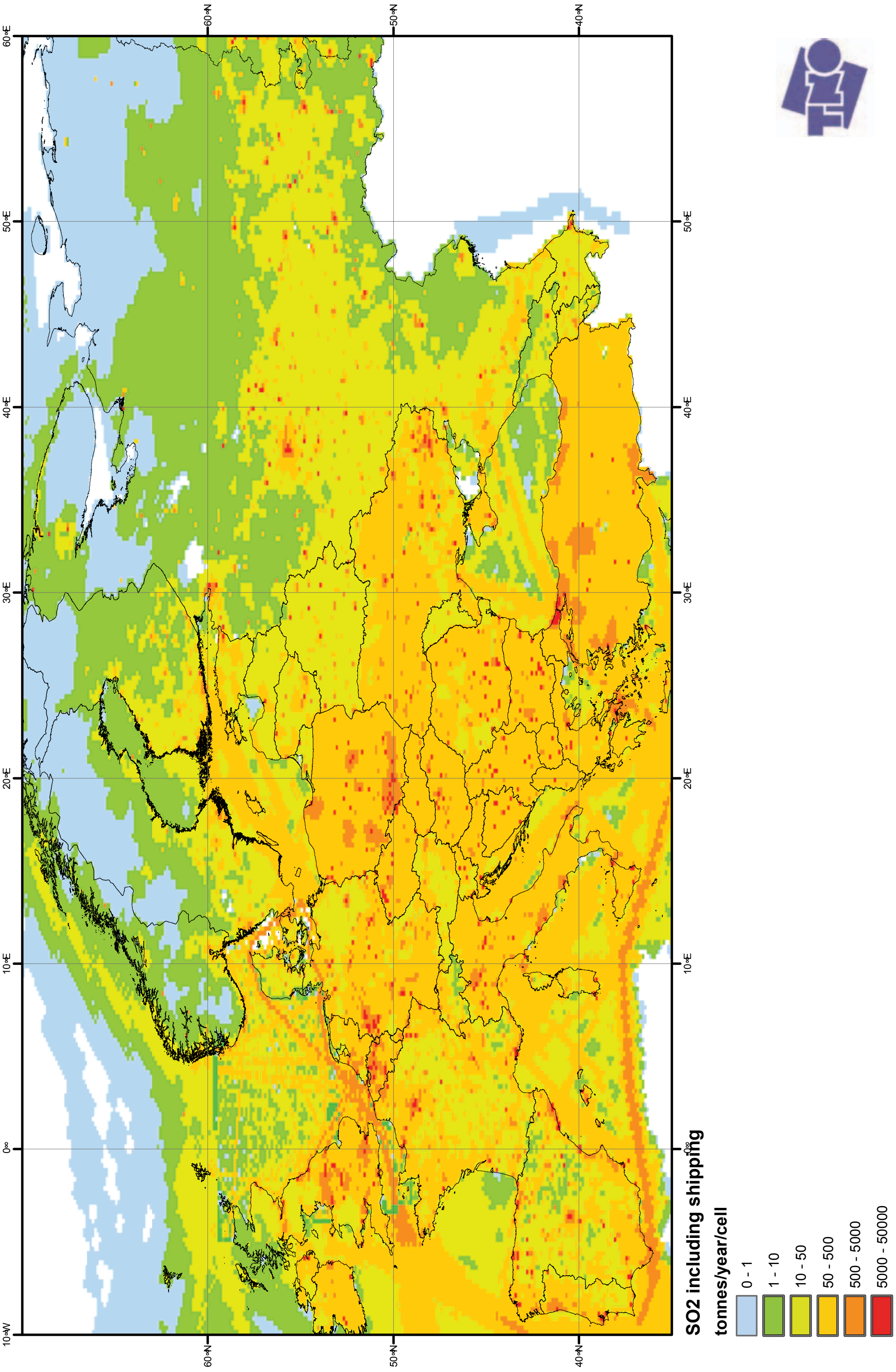

Figure 4.3 Spatial distribution of SO_2 emission in Europe (Table 4.1) for the year 2000 including shipping.

5. Non-methane volatile organic carbons (NMVOC)

The major sources of NMVOC emission are more diverse compared to other substances such as NO_x or SO_2. Several types of stationary combustion processes are important but there is also a strong fugitive component. Fugitive emission includes evaporation of gasoline and other petrochemical components at various points, leakage and solvent use emission. Fugitive NMVOC emission occurs among others during the production and distribution of oil and gas, in the (petro-) chemical industry, in the gasoline distribution chain and whenever solvent-based products such as paint are used. The most relevant stationary combustion processes tend to be those where poor combustion conditions prevail, such as residential combustion (especially of organic solid fuels) and the uncontrolled and small scale combustion of various types of waste. Another major source of NMVOC emission is road transport, with exhaust (tail-pipe) and evaporative emission from gasoline fuelled vehicles being the most important.
As mentioned, the sources of NMVOC are very diverse and so are the applied emission control measures. Measures can be aimed at improving combustion conditions, abating leakage and evaporation, reducing the solvent content of products or restriction of a certain activity altogether. Reduction of NMVOC emission in the road transport sector is one of the major goals of the EURO emission standards.

As will be detailed below, the emission data for NMVOC is mainly based on the TNO/EDGAR speciated NMVOC emission inventory for 1990/1995 [Olivier et al. 2002], updated to the year 2000 (mainly based on the results of the TROTREP project [Monks et al. 2003]. Only for road, air and sea transport different methodologies have been used.

5.1 Activity data

The 2000 activity data for the stationary combustion of fossil fuels is taken from the IEA Energy Statistics [IEA 2003]. The IEA also lists the throughput of energy transformation processes, such as refineries and coke ovens. In addition, activity levels for the production, transport and distribution of fossil fuels (including gasoline) have also been taken from the IEA Statistics. The use of non-commercial fuels such as fuel wood is an important benzene source, yet insufficiently covered by the IEA Statistics. For the EU(15) more realistic data on fuel wood consumption are available from Eurostat [Eurostat 2001]. For the Netherlands the Eurostat data are based on questionnaires sent to hundreds of Dutch households, inquiring about the amount of wood used in wood stoves and fireplaces. For the other countries the fuel wood use is estimated by TNO, based on the known per capita use in a number of reference EU countries and similarities in the availability to households of potential fuel wood sources, or other fuels for domestic heating such as natural gas, gas oil and coal [AEAT-TNO 2000].

The basis for the activity data for (petro-) chemical processes are data for 1995, as collected within the framework of the TROTREP and EDGAR projects [Monks et al. 2003; Olivier et al. 2002]. Starting from 1995, the 2000 levels are estimated using growth indices derived from the IIASA RAINS 7.2 model [Cofala et al. 1998]. The 'Current Legislation Scenario' is used to estimate these indices.

Road transport emissions are estimated based on kilometres driven by vehicle class and average speed (urban, rural and highway). For EU countries these data are taken from the LAT database [Ntziachristos et al. 2002]. The data have been compiled for the year 2000 within the framework of the COPERT III road transport emission model [Ntziachristos et al. 2000]. Four basic vehicle classes are distinguished, heavy duty vehicles (HDV), light duty vehicles (LDV), passenger cars (PC) and motor cycles (MC). For each fuel type (gasoline, diesel and LPG) and vehicle class, up to 10 different engine technologies are discerned, based on technological standards such as EURO1-2-3-4 and pre-EURO. A distinction is made between average speeds (urban, rural and highway) which are important factors in estimating NMVOC emission. For non-EU countries detailed road transport activity data are only available for 1998 at the most recent. 2000 activity data have been estimated based on the growth rate from 1998 to 2000 in total energy consumption by fuel type for road transport [IEA 2003], assuming no significant changes in vehicle fleet between 1998 and 2000 in non-EU countries.

Non-road transport activity data (for inland shipping and inland aerial transport, rail transport and other mobile sources and machinery) comprising fuel consumption rates is taken from the IEA Statistics [IEA 2003]. Emission due to international air transport (LTO only) is estimated based on the total number of flight movements by airport from the ACI [ACI 2003]. Activity data for sea shipping are described in chapter 10.

Solvent use activity data have been taken from the TROTREP and EDGAR inventories [Monks et al. 2003; Olivier et al. 2002]. The TROTREP data for 2000 comprise an updated version of the 1990/1995 TNO/EDGAR speciated NMVOC inventory. The methodology used in this inventory consists of a complex combination of national and regional sales data for solvents and solvent containing products in various sectors, production and consumption statistics of solvent containing products, products for which solvents are used for production and/or application and other (chemical and non-chemical) products (e.g. leather, plastics), and a range of socio -economic indicators for countries and/or regions.

Activity data for the uncontrolled combustion of agricultural and domestic waste is taken from the EDGAR inventories [Olivier et al. 2002].

5.2 Emission factors

NMVOC emission factors for large stationary combustion plants have been taken from the TROTREP project [Monks et al. 2003] and have originally been developed by TNO within the framework of LOTOS/EDGAR inventories [Olivier et al. 2002]. Combustion processes are characterized with respect to fuel type and capacity class. Regional (countries grouped based on socio-economic indicators) emission factors are used for NMVOC. Emission factors for the controlled and uncontrolled combustion of non-commercial fuels (such as biofuels and domestic waste) are taken from the TNO/EDGAR speciated NMVOC emission inventory [Olivier et al. 2002]. Also taken from this source are the emission factors for energy transformation processes (such as refineries and coke ovens), oil and gas production, transport and distribution facilities, and the various types of industrial fugitive emissions.

Emission factors for road transport activities are based on the COPERT III model [Ntziachristos et al. 2000]. For all countries, the same set of factors is used, which have been taken from the LAT data for the year 2000 [Ntziachristos et al. 2002]. For the EU(15), country-specific vehicle fleet data is available from the activity data set. For each vehicle class, technological standard and average speed separate emission factors are available. In total, this set comprises several tenths of emission categories and emission factors. The LAT data include both exhaust (tail-pipe) emissions as well as (stationary) evaporative emission from gasoline-fuelled vehicles.

Emission factors for other modes of transport, except international aircraft LTO and sea shipping are calculated on a fuel basis with emission factors from the EDGAR and TROTREP inventories. Air transport emission is estimated based on a NMVOC emission factor by unit of flight movement derived from information given in the annual environmental report by the Netherlands's largest airport, Schiphol.

Solvent use emission is usually calculated with a unity emission factor, assuming that all used solvent eventually emits to the ambient air, unless spent solvent is somehow recuperated. Recuperation of solvent takes place during a limited number of industrial activities involving large amounts of solvent used (such as automobile manufacturing and vegetable oil production). Recuperation is accounted for in the EDGAR/TROTREP inventories. The most important solvent use category is paint application for which solvent emissions are only partly abated. In case solvent usage data are lacking, emission factors are used. Examples are pesticide application, leather and food processing and the metal and plastic products manufacturing industries.

5.3 Spatial distribution

The emission of power plants and large heat plants (>50MWth) is distributed using point source information such as country, capacity and primary fuel type (TNO updated point source data 2003). For industrial combustion in the iron and steel sector, the chemical industry, the non-metallic minerals sector, the oil refineries, the non-ferrous metals production sector and oil and gas production sector, point source information is also used but in this case emission is distributed according to process type and capacity ratio, irrespective of fuel type. The industrial combustion emissions from sectors other than mentioned above, are distributed according to total (urban + rural) population density [CIESIN, 2001].

Combustion emission from the Residential, Commercial and Institutional sector is distributed according to total (urban + rural) population density [CIESIN, 2001]. An alternative distribution pattern is used for fuel wood combustion, for which the emission is distributed according to rural population density only [AEAT - TNO 2000]. The emission from the uncontrolled burning of domestic waste is distributed according to rural population density.

For the spatial distribution of the emission from road transport, the totals have been split into HDV and LDV as well as into an urban, rural and highway part. The highway part is distributed according to digitized maps of highways, using traffic intensities by highway section for LDV and HDV from Eurostat [Eurostat 2003b]. Digitized maps of highway locations are available for all countries in the area while traffic intensities are only available for the majority of the EU(15) countries. For countries other than EU(15), traffic intensities by highway section have been estimated based on an overlay with a low resolution (0.5 x 0.5 °) population density distribution map (since transport activity correlates with population density). The higher the total population within a 0.5 x 0.5 degree lo-la square cell, the higher the transport intensity in the cell's highways. The rural part of the road transport emission is distributed according to the digital maps of the European rural road network. Relative traffic intensities are again estimated by an overlay with population density, on a 0.5 x 0.5 ° resolution. The 0.5 x 0.5 ° resolution is a compromise in order to include trans-regional traffic movement and maintain a rational level of geographic detail within a country. The urban part of the road transport emissions is distributed according to a high resolution population density map, since trans-regional transport is of lesser importance in an urban environment with mainly local traffic.

Furthermore:
– Emissions from agricultural activities (which mainly comprise vehicular emissions for CO) are distributed according to rural population density.
– Emission from air transport (LTO cycli plus emission up to 915 m) is distributed according to the location and total number of flight movements of the 300 largest airports in Europe [ACI, 2003; ESRI, 2002].

- Other non-road transport activities are spatially distributed with population density.
- The spatial distribution of emission from international shipping is described in chapter 10.
- All emission from solvent use is distributed according to population density, except the chemical industry for which point source data of chemical plants is used.
- For all other sources for which the spatial distribution is not specifically discussed above, the contribution can be considered as relatively minor for this substance. For all minor sources the same default distribution pattern is used, being total population density.

5.4 Results

The final delivered data are summarized in Table 5.1. as NMVOC emission by country by source sector. The relative contribution by source sector is presented in Figure 5.1, indicating that solvent use and product use and road transport (volatilization) are the major sources of NMVOC emissions. Figure 5.2 presents the spatial distribution of the NMVOC emission data.

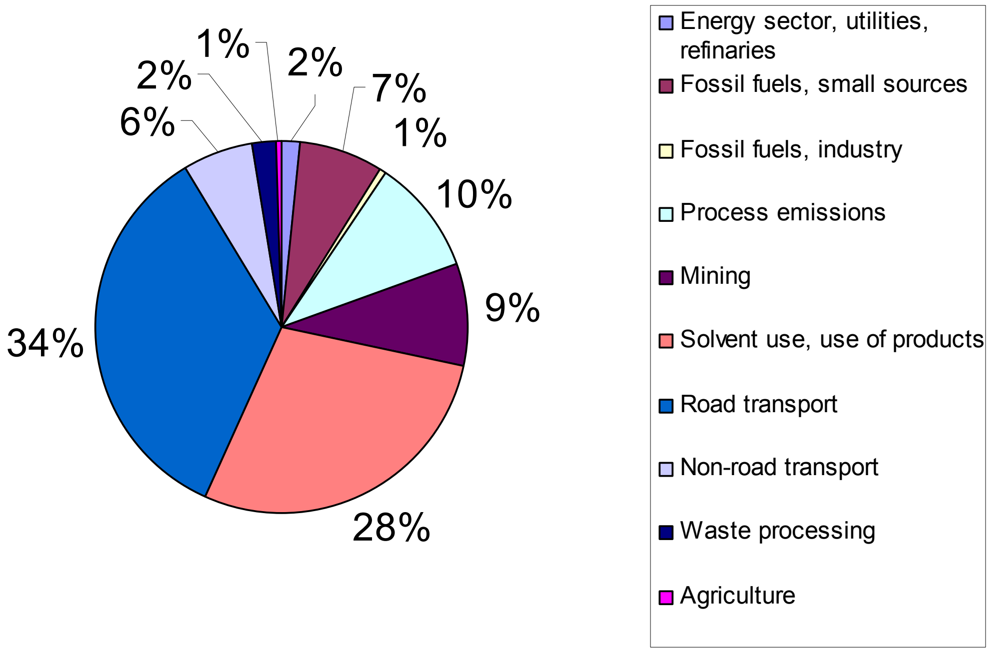

Figure 5.1 NMVOC emission by source sector for the entire domain (total emission is 16006 GG, Table 5.1).

Table 5.1 NMVOC emission data for year 2000 by country and source sector.

ISO 3	Energy sector, utilities, refineries	Fossil fuels, small sources	Fossil fuels, industry	Process emissions	Mining	Solvent and product use	Road transport	Non-road transport	Waste	Agri-culture	Total
	NMVOC (tons)										
ALB	51	6564	2419	0	648	9256	8920	0	0	1532	29390
ARM	130	6647	75	974	110	15777	780	10	1480	6	25988
AUT	1578	29698	1545	23575	2753	82242	37629	11235	200	118	190573
AZE	38893	14548	262	849	10511	19861	10890	295	7110	6	103225
BEL	2139	5395	1865	36423	15705	75817	91908	9833	1484	1137	241706
BGR	3274	13878	495	26659	4824	31836	49479	2949	337	2427	136158
BIH	1588	558	115	4381	1045	14651	15690	1818	500	0	40347
BLR	2368	11915	396	29431	29092	43227	85143	8714	5000	13390	228676
CHE	912	3973	1485	13578	8363	75095	35493	3228	4464	338	146929
CZE	9073	10809	2250	29288	5633	81169	81965	23242	325	0	243754
DEU	24676	60743	6634	111959	55387	741968	396376	123831	0	0	1521574
DNK	3614	11288	435	2331	5519	38998	47976	16771	500	450	127883
ESP	8024	45973	4540	213916	49041	424566	297955	42257	17600	11950	1115822
EST	1577	8426	168	6922	968	3663	12650	2467	169	0	37010
FIN	0	27762	3040	15423	3966	33471	47696	36439	1500	0	169298
FRA	5456	179900	5698	102792	76182	576350	421173	148045	25200	0	1540796
GBR	16170	25214	4181	209929	293516	410412	413475	58812	25455	0	1457164
GEO	646	9745	42	898	1660	22632	11127	0	4237	16	51003
GRC	4078	16284	659	11502	16162	72055	119714	31122	98	8567	280241
HRV	869	9551	993	3666	7262	23128	49841	6562	0	0	101872
HUN	2374	11739	295	11189	19372	36974	49347	3572	0	16108	150970
IRL	1669	4952	5889	0	4487	31579	35460	3610	0	0	87646
ITA	8711	70985	4492	74251	78866	500839	743339	219148	26024	1692	1728347
LTU	8935	13559	96	3275	5729	7599	18515	5530	0	0	63239
LUX	32	339	1370	0	1020	2455	7469	501	40	0	13226
LVA	416	2789	348	610	1001	4661	17697	3754	0	1506	32781
MDA	286	8090	41	3999	235	9999	19712	33	12198	16	54608
MKD	696	122	84	1433	1284	4729	15488	827	200	1200	26063
NLD	2206	9569	1344	50092	22849	81074	83444	12208	1700	0	264486
NOR	625	11676	1196	11881	257474	34939	33330	22097	25	583	373825
POL	19993	97322	3979	73512	32668	172312	130597	49779	150	1410	581723
PRT	2626	16223	1355	32097	30131	69504	94693	7946	4900	1709	261184
ROM	4636	59161	1311	55739	21332	118410	80112	11117	3	26693	378514
RUS	7000	953	8149	295217	271207	62239	1237398	26516	0	0	1908679
SVK	1210	1799	619	5118	7355	41500	22237	0	600	5928	86365
SVN	829	8683	160	1358	3235	10972	26992	2012	0	0	54241
SWE	3021	78781	4208	38996	3901	65427	67937	42700	67	0	305038
TUR	8058	205463	4060	43545	22282	175455	281862	21828	11240	0	773793
UKR	46611	65665	8007	47660	33616	289090	268081	4492	165690	367	929279
YUG	4158	1324	293	9494	4394	36544	70563	15106	500	0	142375
Total (GG)	***249***	***1168***	***85***	***1604***	***1411***	***4552***	***5540***	***980***	***319***	***97***	***16006***

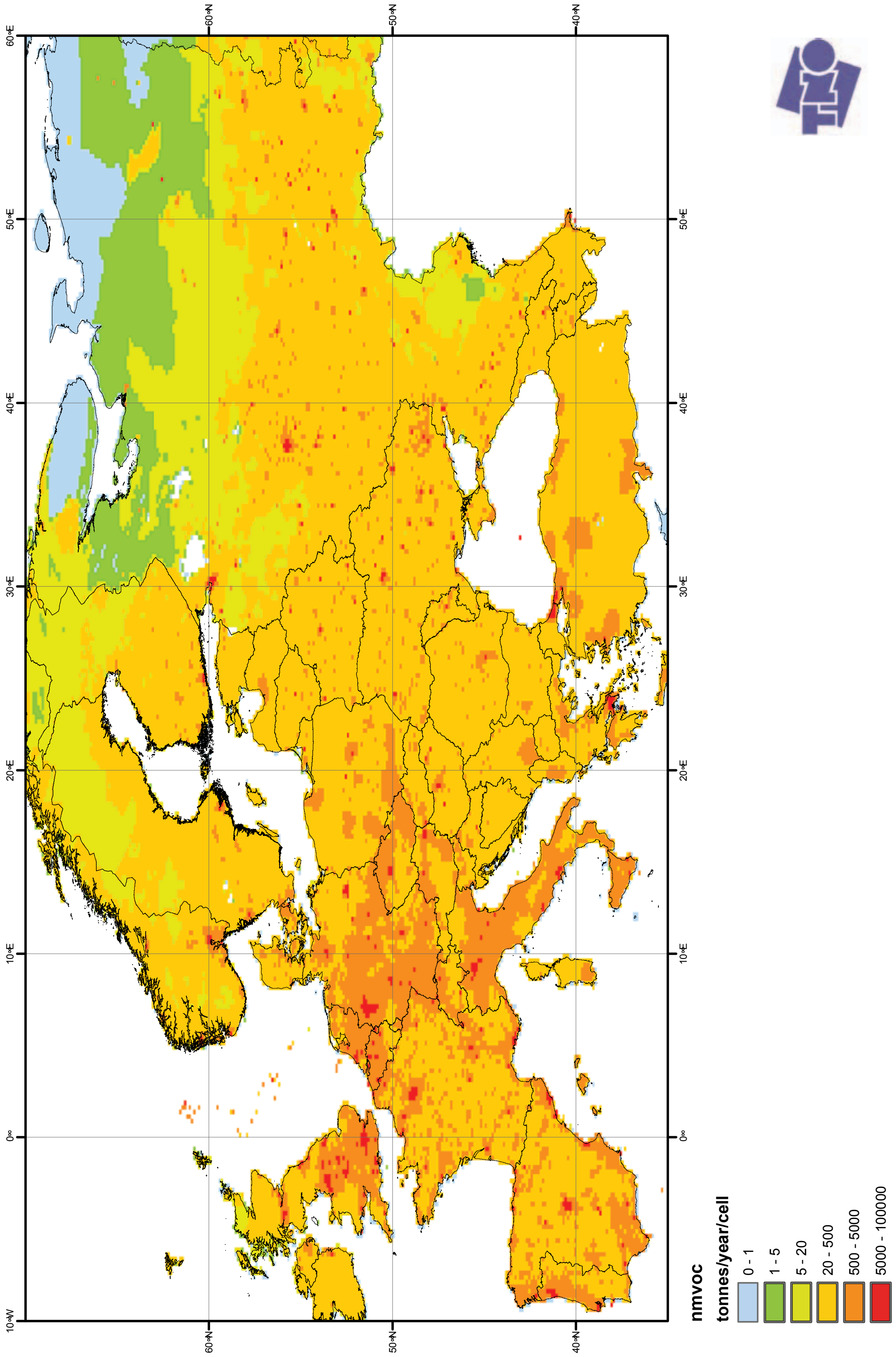

Figure 5.2 Spatial distribution of NMVOC emission in Europe for the year 2000 excluding shipping.

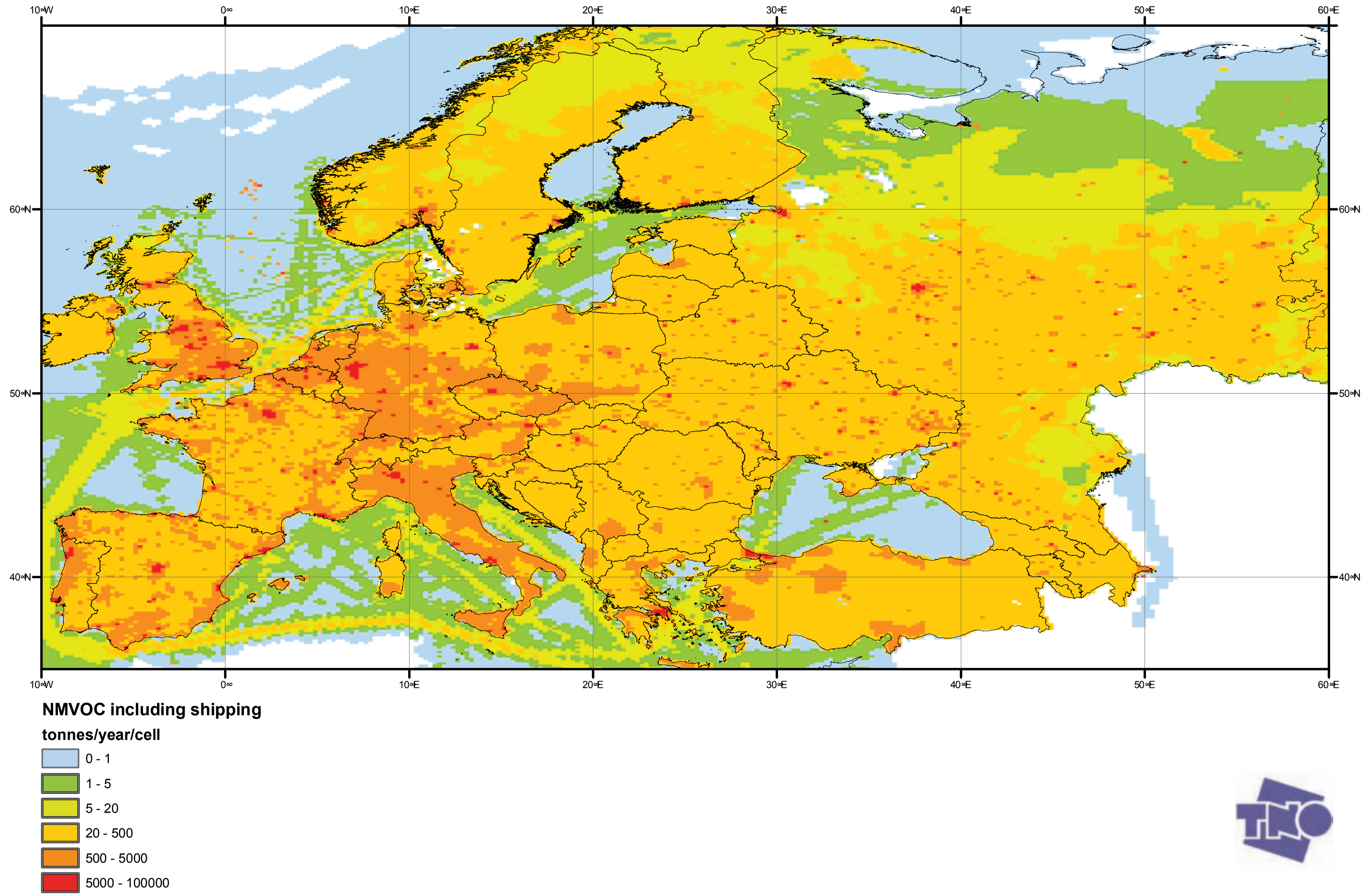

Figure 5.3 Spatial distribution of NMVOC emission in Europe for the year 2000 including shipping.

6. Ammonia (NH_3)

By far, the main source of NH_3 air emission is animal husbandry, where NH_3 is released from animal excretions (either when produced, stored or spread). Manure production by farm animals by far outnumbers that of any population of pets or wildlife. Less than one tenth of the total European NH_3 emission is caused by sources other than animal farming. A secondary source is the production and use of fertilizer from which NH_3 is slowly released. Furthermore, humans emit slight quantities of NH_3 and lastly, road transport is a small NH_3 source.

6.1 Activity data

Animal populations for 2000 by country have been taken from FAO [FAOSTAT 2003]. The following animals are included: Pigs, Cattle, Asses, Buffaloes, Horses, Mules, Goats, Sheep, Chicken, Turkeys, Ducks and Geese.
The production and consumption of nitrogen fertilizer is taken from statistics by the International Fertilizer Manufacturing Association IFA [IFA 2002].
Road transport activity data for the EU(15) is taken from LAT project [Ntziachristos et al. 2002]. For non-EU countries detailed road transport activity data are only available for 1998 as the most recent. 2000 activity data have been estimated based on the growth rate from 1998 to 2000 in total energy consumption by fuel type for road transport [IEA 2003].
NH_3 emitted by humans is calculated using the population data by country from UN Statistics [UN 2003].

6.2 Emission factors

By animal type, the following emission sources have been taken into account: emission from stables, emission from manure storage (outside and inside the stable), emission through pasture (grazing) and emission from manure application. The emission factors used are taken from the standard methodology given by CORINAIR Guidebook [EEA 2004].
Emission factors for NH_3 emission due to fertilizer production and application are taken from the IIASA RAINS v7.2 emission module [Cofala et al. 1998].
Emission factors for road transport activities are based on the COPERT III model [Ntziachristos et al. 2000] and the LAT data for the year 2000 [Ntziachristos et al. 2002].
The emission factor for the human release of NH_3 is taken from [VROM 1999].

6.3 Spatial distribution

Except for Germany, the spatial distribution of the NH_3 emission from agricultural activities in EU(15) countries is accomplished as follows. Eurostat [Eurostat, 2003a] provides animal population data on the NUTS geographical administrative level. The available level of detail in the animal population data depends on the country and usually varies between NUTS 2 and 3. The standard approach is to subdivide the NUTS-animal total between the grid cells within the NUTS area according to land use data. Wherever possible, use is made of the very detailed CORINE Land Cover database (250 x 250 m) [CORINE 2003].

The following CORINE classification categories have been used for fertilizer and manure spreading:

2.1.1 Non-irrigated arable land
2.1.2 Permanently irrigated land
2.1.3 Rice fields
2.4.1 Annual crops associated with permanent crops
2.4.3 Land principally occupied by agriculture, with significant areas of natural vegetation

Manure production and storage is distributed according to the CORINE categories:

2.3.1 Pastures
2.4.3 Land principally occupied by agriculture, with significant areas of natural vegetation

Not all countries are covered by CORINE especially a number of non-EU(15) countries are not covered. In those cases the PELINDA land cover data (1 x 1 km) for agricultural activity (arable land and pastures) is used [De Boer et al. 2000]. Moreover, for these countries no regional animal population data is available, which brings about that animal population is allocated to cells with arable land and pastures on a national level.
Germany is another exception because of its high relevance for this project and the fact that only the rather coarse NUTS level 2 animal data are available for Germany. The spatial distribution for this country is derived from emissions calculated on the German ‘Kreis’ administrative level (which is even more detailed than NUTS 3). These data conform to the same source classification as described above and have been developed by the University of Braunsweig [Dämmgen 2004]. In order to subdivide the Kreis data to the 5 x 5 km grid, the CORINE Land Cover database is used, as if it where NUTS 3 data. [Note: The same official CORINE/Phare Land Cover data base is used as starting point for producing the forest database, see overall report of FKZ 20243270]

For the spatial distribution of the emission from road transport, the totals have been split into HDV and LDV as well as into an urban, rural and highway part. The highway part is distributed according to digitized maps of highways, using traffic intensities by highway section for LDV and HDV from Eurostat [Eurostat 2003b]. Digitized maps of highway locations are available for all countries in the area while traffic intensities are only available for the majority of the EU(15) countries. For countries other than EU(15), traffic intensities by highway section have been estimated based on an overlay with a low resolution (0.5 x 0.5°) population density distribution map (since transport activity correlates with population density). The rural part of the road transport emission is distributed according to the digital maps of the European rural road network. Relative traffic intensities are again estimated by an overlay with population density, on a 0.5 x 0.5 ° resolution. The urban part of the road transport emissions is distributed according to a high resolution population density map [CIESIN, 2001].

The emissions due to fertilizer manufacture have been distributed based on TNO point source data of large chemical plants. Ammonia production capacity serves as the allocation key. Human release of NH_3 is distributed based on population density [CIESIN, 2001].

All other sources for which the spatial distribution is not specifically discussed above, its contribution can be considered as relatively minor for this substance. For all minor sources the same default distribution pattern is used, which is total population density.

6.4 Results

The final delivered data are summarized in Table 6.1. as NH_3 emission by country by source sector. The major source of NH_3 are agricultural activities, other source sectors contribute less than 10% to the total NH_3 emission in the domain (Figure 6.1.). Figure 6.2 presents the spatial distribution of the NH_3 emission data.

Table 6.1 NH_3 emission data for year 2000 by country and source sector.

ISO 3	Energy sector, utilities, refineries	Fossil fuels, small sources	Fossil fuels, industry	Process emissions	Mining	Solvent and product use	Road transport	Non-road transport	Waste	Agri-culture	Total
	(tons)										
ALB	0	0	0	0	0	0	7	0	0	22386	22393
ARM	0	0	0	103	0	1442	3	0	0	0	1549
AUT	0	0	0	152	0	0	1741	0	0	51656	53549
AZE	0	0	0	45	0	3164	56	0	0	47487	50751
BEL	0	0	0	1064	0	0	1398	0	0	78627	81089
BGR	0	0	0	1569	0	0	38	0	0	90233	91840
BIH	0	0	0	30	0	0	9	0	0	17270	17309
BLR	0	0	0	1764	0	0	40	0	0	126302	128106
CHE	0	0	0	1154	0	0	3600	0	0	61303	66057
CZE	0	0	0	918	0	0	564	0	0	72209	73691
DEU	0	0	0	10994	0	0	21912	0	0	605328	638233
DNK	0	0	0	0	0	0	1299	0	0	89516	90815
ESP	0	0	0	14400	0	0	3301	0	0	376519	394220
EST	0	0	0	114	0	0	85	0	0	9409	9608
FIN	0	0	0	428	0	0	0	0	0	34269	34697
FRA	0	0	0	5684	0	0	8671	0	0	714054	728409
GBR	0	0	0	2798	0	0	13120	0	0	298807	314725
GEO	0	0	0	225	0	2200	41	0	0	35681	38146
GRC	0	0	0	515	0	0	1593	0	0	52906	55014
HRV	0	0	0	981	0	0	26	0	0	31537	32544
HUN	0	0	0	990	0	0	0	0	0	76772	77762
IRL	0	0	0	0	0	0	898	0	0	125879	126777
ITA	0	0	0	1074	0	0	8399	0	0	424370	433843
LTU	0	0	0	5950	0	0	0	0	0	44053	50003
LUX	0	0	0	0	0	0	532	0	0	5975	6507
LVA	0	0	0	0	0	0	0	0	0	12199	12199
MDA	0	0	0	0	0	1867	5	0	0	31193	33066
MKD	0	0	0	0	0	0	9	0	0	14684	14693
NLD	0	0	0	2852	0	0	3259	0	0	150685	156796
NOR	0	0	0	1106	0	0	1300	0	0	23192	25598
POL	0	0	0	3179	0	0	0	0	0	306070	309249
PRT	0	0	0	3406	0	0	981	0	0	63986	68373
ROM	0	0	0	4345	0	0	62	0	0	219037	223444
RUS	0	0	0	10066	0	46913	761	0	0	1021344	1079084
SVK	0	0	0	786	0	0	261	0	0	30546	31593
SVN	0	0	0	0	0	0	0	0	0	18358	18358
SWE	0	0	0	137	0	0	3406	0	0	49929	53472
TUR	0	0	0	0	0	0	216	0	0	274762	274978
UKR	0	0	0	3818	0	22129	218	0	0	440537	466701
YUG	0	0	0	255	0	0	0	0	0	65781	66036
Total (GG)	***0***	***0***	***0***	***81***	***0***	***78***	***78***	***0***	***0***	***6215***	***6451***

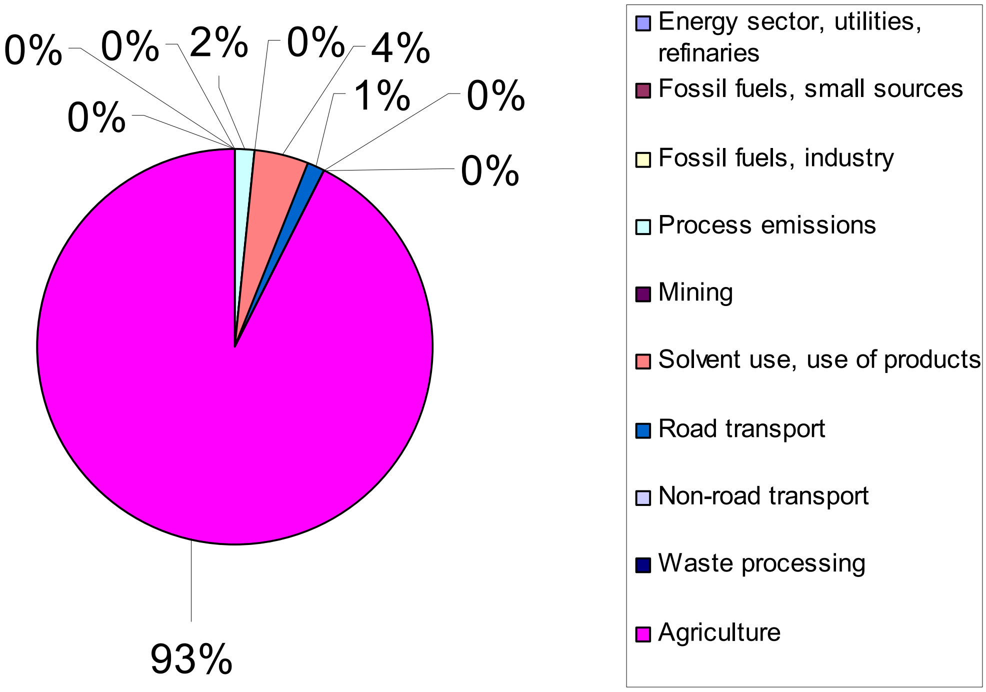

Figure 6.1 NH_3 emission by source sector for the entire domain (total emission is 6451 GG, Table 6.1).

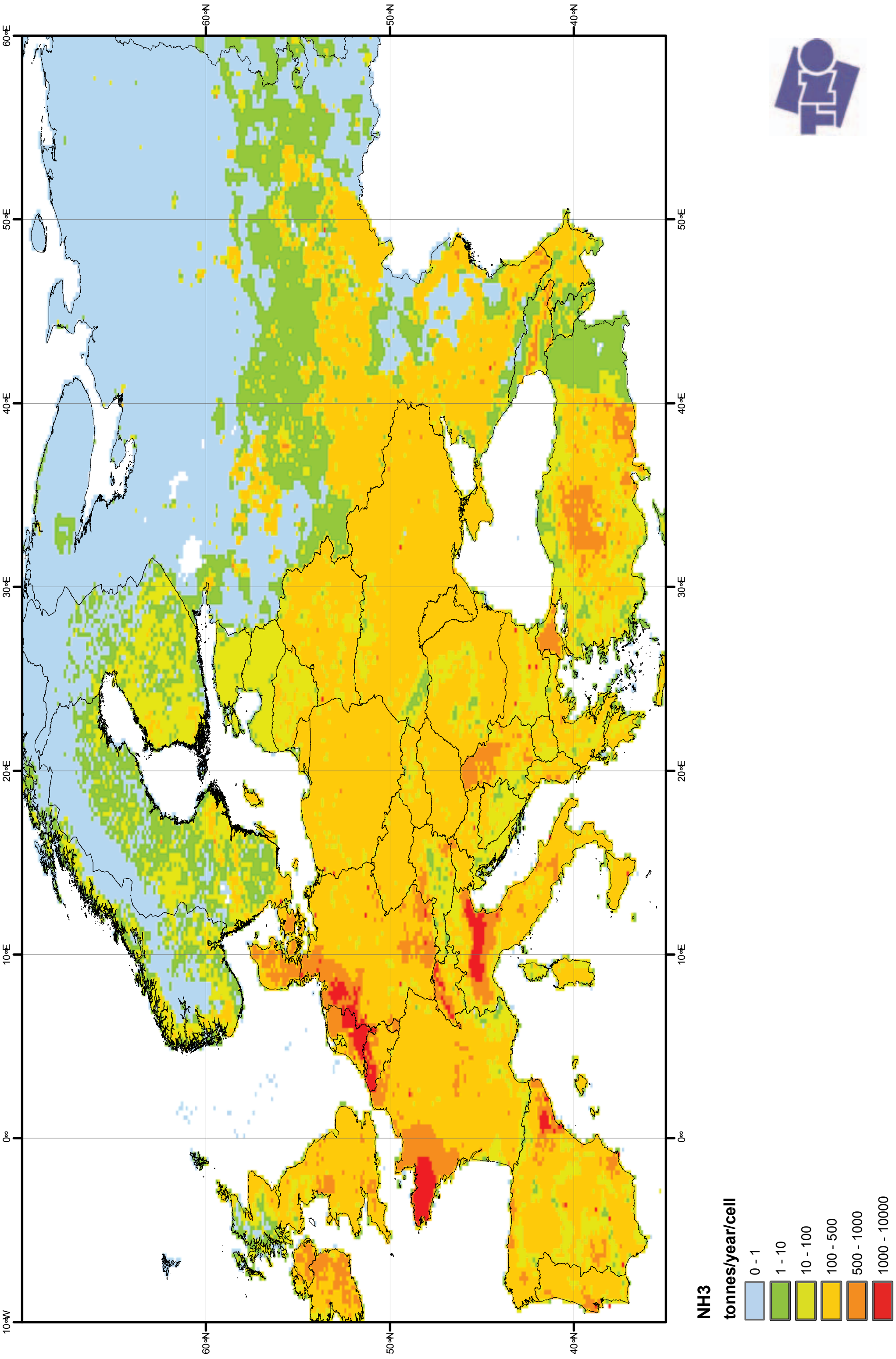

Figure 6.2 Spatial distribution of NH_3 emission in Europe for the year 2000

7. Carbon monoxide (CO)

Emission of CO is mainly the result of incomplete combustion. All combustion processes produce CO in various degrees but incomplete combustion occurs primarily in engines, domestic heating plants and uncontrolled (waste) combustion. These are the main sources of CO emission. There are also several industrial processes that produce CO in significant quantities, being sinter agglomeration plants and various non-ferrous metals production processes. CO emission can be abated by improving combustion conditions. The implementation of the EURO standards in the automotive industry has had a large effect on transport related CO emission. A limited number of countries has set emission limit values for small combustion plants like wood stoves. There are also developments to optimize industrial processes in order to attain lower CO concentrations.

7.1 Activity data

The activity data for the stationary combustion of fossil fuels are taken from the IEA Energy Statistics [IEA 2003]. The IEA distinguishes a large range of sectors. Each sector is characterized with repect to representative average boiler or furnace sizes. The IEA data cover different solid, liquid and gaseous fuels.

The use of non-commercial fuels such as fuel wood is insufficiently covered by the IEA Statistics, since these fuel types fall outside the commercial administration registers. For the EU(15) more realistic data on fuel wood consumption is available from Eurostat [Eurostat 2001]. For the Netherlands, the Eurostat data is based on questionnaires sent to hundreds of Dutch households, inquiring about the amount of wood used in wood stoves and fireplaces. For the other countries the fuel wood use is estimated by TNO, based on the known per capita use in a number of reference EU countries and similarities in the availability to households of potential fuel wood sources, or other fuels for domestic heating such as natural gas, gas oil and coal [AEAT-TNO 2000].

The activity data for process emissions (non-ferrous metals and iron and steel industry) is taken from the IIASA RAINS 7.2 model [Cofala et al. 1998]. The 'Current Legislation Scenario' is used to estimate the 2000 activity levels.

CO Road transport emissions are estimated based on kilometres driven by vehicle class and average speed (urban, rural and highway). For EU(15) countries this data is taken from LAT project [Ntziachristos et al. 2002]. The data is compiled for the year 2000 within the framework of the COPERT III road transport emission model [Ntziachristos et al. 2000]. 4 Basic vehicle classes are distinguished, heavy duty vehicles (HDV), light duty vehicles (LDV), passenger cars (PC) and motor cycles (MC). For each fuel type (gasoline, diesel and LPG) and vehicle class, up to 10 different engine technologies are discerned, based on technological standards such as EURO1-2-3-4 and pre-EURO. A distinction is made between average speeds (urban, rural and highway), which are important factors in estimating CO emission. For non-EU countries detailed road transport activity data are only available for 1998 as the most recent. 2000 activity data have been estimated based on the growth rate from 1998 to 2000 in total energy consumption by fuel type for road transport [IEA 2003], assuming no significant changes in vehicle fleet between 1998 and 2000 in non-EU countries.

The basis for the estimation of CO emission from air transport is the total number of flight movements, available from [ACI 2003] for the 300 largest airports in Europe. Activity data for the remaining modes of transport are gathered from the IEA [IEA 2003] in the form of fuel consumption data.

7.2 Emission factors

CO emission factors for large stationary combustion plants have been taken from the TROTREP project [Monks et al. 2003] and have originally been developed by TNO within the framework of LOTOS/EDGAR inventories [Olivier et al. 2002]. Combustion processes are characterized with respect to fuel type and capacity class. CO Emission factors for stationary combustion activities are uniform for all countries.

Emission factors for various industrial processes have been developed for two country groups, being the EU(15) plus Norway, Switzerland and the other European countries. The process emission factors used for CO have been developed by TNO within the framework of LOTOS/EDGAR inventories [Olivier et al. 2002].

Emission factors for road transport activities are based on the COPERT III model [Ntziachristos et al. 2000]. For all countries, the same set of factors is used, which have been taken from the LAT data for the year 2000 [Ntziachristos et al. 2002]. For the EU(15), country-specific vehicle fleet data is available from the activity data set. For each vehicle class, technological standard and average speed separate emission factors are available. In total, this set comprises several tenths of emission categories and emission factors.

Air transport emission is estimated based on a CO emission factor by unit of flight movement derived from information given in the annual environmental report by the Netherlands's largest airport, Schiphol. Emission from other mobile sources and machinery is estimated with the use of emission factors from the LOTOS/EDGAR emission databases [Olivier et al. 2002].

7.3 Spatial distribution

The emission of power plants and large heat plants (>50MWth) is distributed based on point source information such as country, capacity and primary fuel type (TNO updated point source data 2003). For industrial combustion in the iron and steel sector, the chemical industry, the non-metallic minerals sector, the oil refineries, the non-ferrous metals production sector and oil and gas production sector, point source information is also used but in this case emission is distributed according to process type and capacity ratio, irrespective of fuel type. The industrial combustion emissions from sectors other than mentioned above, emission is distributed according to total (urban + rural) population density [CIESIN, 2001].

Emission from the Residential, Commercial and Institutional sector combustion is distributed according to total (urban + rural) population density [CIESIN, 2001]. An alternative distribution pattern is used for fuel wood combustion, for which the emission is distributed according to rural population density only [AEAT – TNO 2000].

For the spatial distribution of the emission from road transport, the totals have been split into HDV and LDV as well as into an urban, rural and highway part. The highway part is distributed according to digitized maps of highways, using traffic intensities by highway section for LDV and HDV from Eurostat [Eurostat 2003b]. Digitized maps of highway locations are available for all countries in the area while traffic intensities are only available for the majority of the EU(15) countries. For countries other than EU(15), traffic intensities by highway section have been estimated based on an overlay with a low resolution (0.5 x 0.5 °) population density distribution map (since transport activity correlates with population density). The higher the total population within a 0.5 x 0.5 degree lo-la square cell, the higher the transport intensity in the cell's highways. The rural part of the road transport emission is distributed according to the digital maps of the European rural road network. Relative traffic intensities are again estimated by an overlay with population density, on a 0.5 x 0.5 ° resolution. The 0.5 x 0.5 ° resolution is a compromise in order to include trans-regional traffic movement and maintain a rational level of geographic detail within a country. The urban part of the road transport emissions is distributed according to a high resolution population density map, since trans-regional transport is of lesser importance in an urban environment with mainly local traffic.

Emission from air transport (LTO cycli plus emission up to 915 m) is distributed according to the location and total number of flight movements of the 300 largest airports in Europe [ACI 2003], [ESRI, 2002]. The spatial distribution from emission from international sea shipping is described in chapter 10. Emissions from agricultural activities (which mainly comprise vehicular emissions for CO) are distributed according to rural population density. Other non-road transport activities are spatially distributed with total population density.

All other sources for which the spatial distribution is not specifically discussed above, its contribution can be considered as relatively minor for this substance. For all minor sources the same default distribution pattern is used, which is total population density.

7.4 Results

The final delivered data are summarized in Table 7.1. as CO emission by country by source sector. The relative contribution by source sector is presented in Figure 7.1. Road transport is the dominating source of CO emissions, followed by fossil fuel combustion from small sources (residential heating), fossil fuel combustion in the industry and process emissions. Figure 7.2 and 7.3 present the spatial distribution of the CO emission data without and with including shipping emissions.

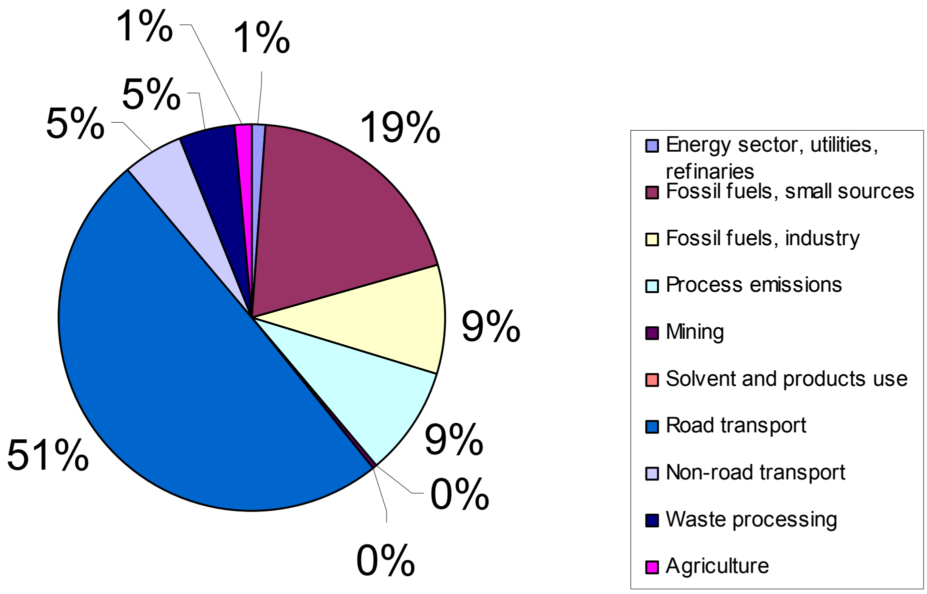

Figure 7.1 CO emission by source sector for the countries listed in Table 7.1. (total emission is 58582 GG).

Table 7.1 CO emission data for year 2000 by country and source sector.

ISO 3	Energy sector, utilities, refineries	Fossil fuels, small sources	Fossil fuels, industry	Process emissions	Mining	Solvent and product use	Road transport	Non-road transport	Waste	Agri-culture	Total
	CO (tons)										
ALB	165	38881	309	97	0	0	49765	0	2712	10072	102000
ARM	649	66505	611	0	0	0	5185	41	1351	58	74400
AUT	2283	355503	5523	209620	0	0	206702	57694	19999	1421	858745
AZE	4150	145854	2091	1025	0	0	72370	62	3227	116	228895
BEL	8573	61452	214666	239729	0	0	568570	6183	447	0	1099620
BGR	3670	321502	72601	42300	0	0	212702	12600	195	1700	667270
BIH	698	64915	22685	6631	0	0	77479	20591	0	0	193000
BLR	6099	24441	27617	23537	0	0	634018	1788	0	0	717500
CHE	280	38843	16769	11483	0	0	220081	60563	2740	43052	393811
CZE	11477	153277	129694	24122	20	0	230704	98685	20	0	648000
DEU	102000	919000	663000	561000	0	0	2379005	144000	0	0	4768005
DNK	12957	175825	7405	0	0	0	289890	90649	1844	0	578570
ESP	16634	470424	225566	323800	0	0	1353722	136275	190715	56867	2774002
EST	16084	81451	4042	529	196	0	96967	2391	0	0	201660
FIN	7100	96800	53200	500	0	0	251000	117700	0	0	526300
FRA	19439	1679336	760509	823635	0	0	2612187	459913	284565	0	6639583
GBR	90798	225063	368021	130401	966	0	2782851	411488	15455	0	4025043
GEO	531	98097	270	4200	0	0	73949	7	3515	174	180742
GRC	46000	180000	26000	22000	0	0	952000	93000	0	212000	1531000
HRV	1260	127296	35429	11570	8	0	191894	34639	4	0	402100
HUN	14270	27430	5420	150000	0	0	433131	2790	0	0	633041
IRL	4035	45611	10207	0	0	0	211584	8135	0	0	279571
ITA	38688	450148	379974	118047	0	0	3478204	480770	249578	11792	5207199
LTU	3600	124900	11900	0	0	0	139400	1700	0	0	281500
LUX	46	6395	2603	6521	0	0	31046	2321	8	0	48939
LVA	13093	110374	16576	0	0	0	132883	0	0	0	272926
MDA	1566	82558	305	6630	0	0	23068	50	5961	176	120315
MKD	2500	1600	18700	4800	0	0	48140	1200	0	0	76940
NLD	31099	60898	94497	48699	0	0	391588	44499	5200	0	676479
NOR	6889	167386	10358	33551	0	0	277075	62320	1464	9137	568180
POL	50000	1688003	54000	25000	0	0	688001	117000	841000	0	3463003
PRT	2443	150972	21797	23340	0	0	452979	12731	450	10288	674999
ROM	8996	265886	601741	103955	0	0	314865	15993	1013564	0	2325000
RUS	95000	34028	1221945	595653	216739	0	6047876	89329	0	0	8300570
SVK	3402	50124	118657	0	0	0	110453	1701	0	5803	290139
SVN	903	3009	702	0	0	0	62484	903	0	0	68000
SWE	13985	117364	11346	13764	0	0	467298	209206	0	0	832962
TUR	17840	1637421	75790	13590	0	0	1549743	0	0	483810	3778193
UKR	26690	960947	59150	1805965	593	0	610802	730	52733	3670	3521279
YUG	16282	1703	4000	15380	0	0	374153	130473	11009	0	553000
Total (GG)	***702***	***11311***	***5356***	***5401***	***219***	***0***	***29106***	***2930***	***2708***	***850***	***58582***

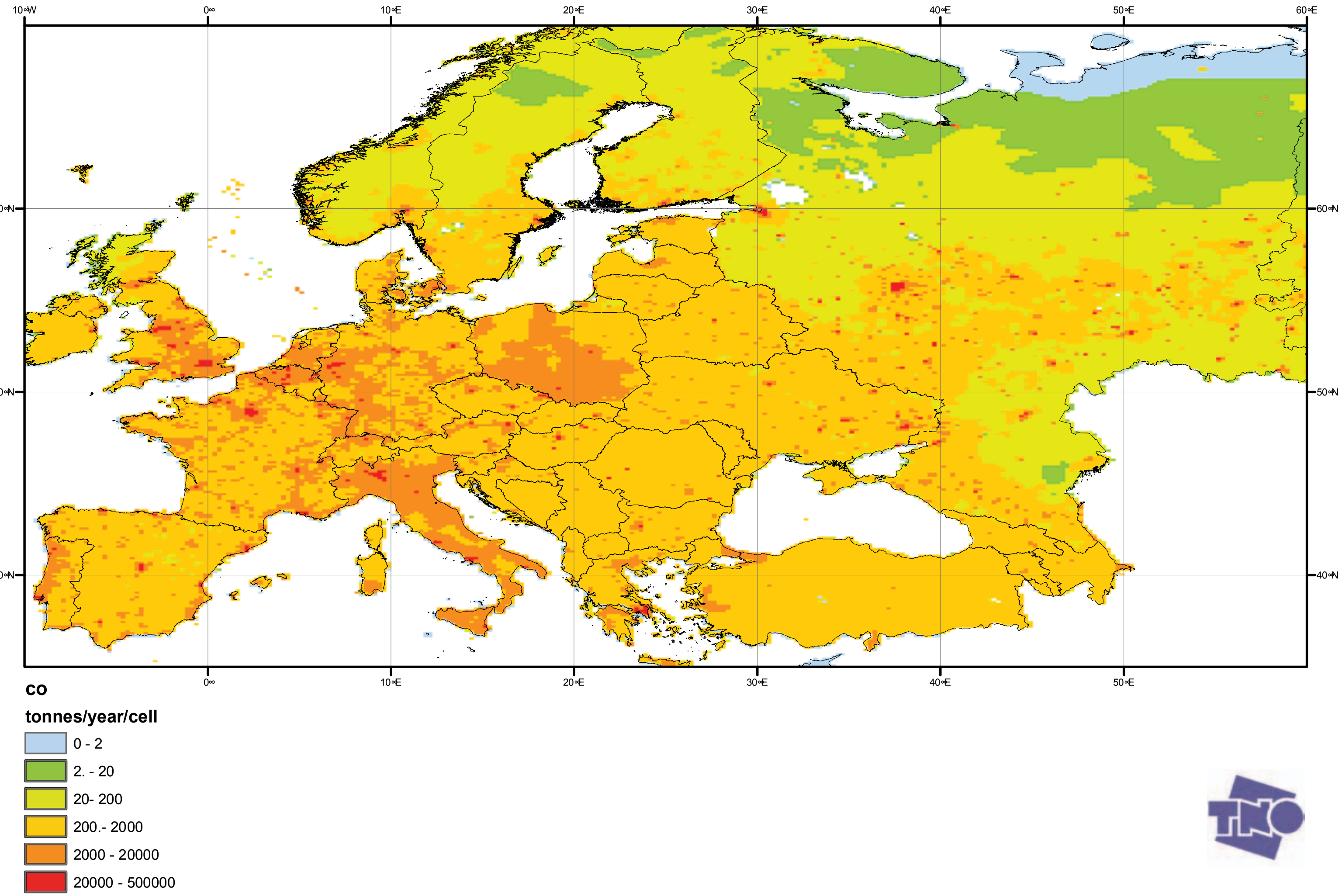

Figure 7.2 Spatial distribution of CO emission in Europe for the year 2000 excluding shipping.

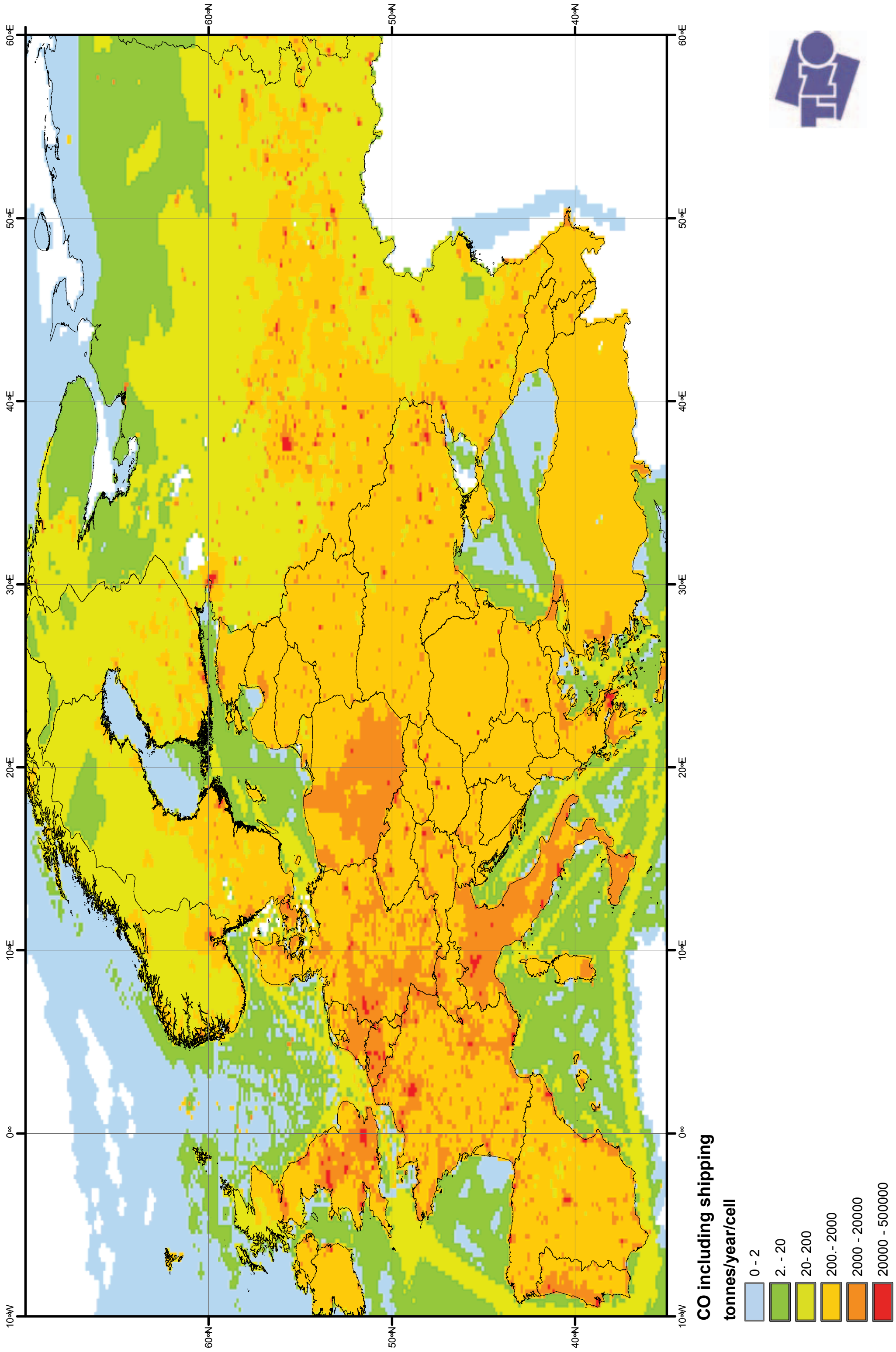

Figure 7.3 Spatial distribution of CO emission in Europe for the year 2000 including shipping.

8. Particulate matter (PM_{10} and $PM_{2.5}$)

For PM_{10} and $PM_{2.5}$ the data from the "Coordinated European Particulate Matter Emission Inventory Program" (CEPMEIP) is used as the TNO reference database. CEPMEIP was initiated within the EMEP working programme and supported by the European Environment Agency (EEA) to develop default methods and emission factors for the use of national experts when submitting primary particulate matter (PM) emission inventories within the CRLTAP/EMEP framework. CEPMEIP started in 2000, it was attempted to include all available information on primary PM emissions thus far and make an emission inventory for the year 1995. The emission inventory was not updated to the year 2000 because it was anticipated that due to the uncertainty in emission factors and sources this exercise would be time consuming but not result in a significant better emission estimate than the available 1995 inventory. However, compared to the original CEPMEIP inventory a better spatial distribution was pursued by including new proxy data and spatial maps, most notably digital maps of the major roads in Europe and an update of point source data in near-by countries. Finally the TNO reference data (being the 1995 PM emissions from CEPMEIP) were scaled to the EMEP_CAFE_BL (Table 2.3)

8.1 Methodology used in CEPMEIP

The CEPMEIP study envelops 44 countries; the EU-15, the 13 accession countries, 3 non-EU Western European countries (Norway, Switzerland, and Iceland) and 13 non-EU countries in Eastern Europe. The intention of CEPMEIP was to compile a general and consistent methodology to estimate the emission of all known anthropogenic sources of primary PM in Europe. CEPMEIP started with collecting and re-organizing all PM emission-related information within TNO that was available from relevant previous projects (e.g. within UNECE context). This information included among others results of stack concentration measurement and size distribution data from European countries and sources. A 'library' of PM related reports (e.g., from UBA, BUWAL, MSC-East, TNO, US-EPA) was compiled and incorporated in the emission factor database. Visits to other research organizations where made and NILU (a co-executive of CEPMEIP) provided additional stack measurement data for Central European countries. Subsequently, a literature survey was made to identify other important information that was not yet accounted for. Finally, a questionnaire was sent out to national experts asking for any information underlying the existing national PM emission inventories. Twenty European countries responded to the questionnaire and provided additional data.
The above mentioned information was used to list about 200 source categories covering nearly all known anthropogenic emission sources: production and combustion of fossil fuels, combustion of biofuels, industrial activities, the use of products, transport, waste disposal and agriculture. For each source category TSP, PM_{10}

and $PM_{2.5}$ emission factors have been derived. Since many source contributions depend heavily on the effectiveness of emission abatement, CEPMEIP has paid considerable attention to differences in control technologies used in Europe.

8.2 Results

8.2.1 Emission factors

Where appropriate, emission factors were specified according to 3 to 4 levels of technological "sophistication" to account for different degrees of emission abatement (Table 8.1). CEPMEIP contains ultimately over 800 emission factors for TSP, PM_{10} and $PM_{2.5}$ that can be used by national experts in preparing primary PM emission inventories by selecting the most appropriate emission level reflecting the local/national situation. Fuel consumption in industry is corrected downwards to avoid double counting since combustion emissions are partly accounted in the emission factors for 'processes with contact' (as defined by UNECE).
An overview of the emission factors used in CEPMEIP is presented by Visschedijk et al [2004], for a further documentation of the emission factors we refer to http://www.air.sk/tno/cepmeip/.

Table 8.1 Distinguished emission levels due to technological sophistication.

Emission level	Description
Low	Modern advanced facility, as in use in a small number of countries; strict enforcement of stringent emission standards
Medium	Average age, well maintained; as in-use in a large number of European countries; no BAT though, and might not meet latest European emission standards yet
Medium high	Older equipment and technology, reasonably maintained but not meeting current EU/UNECE emission standards
High	Old facility with limited emission control and often obsolete technology; currently not meeting EU/UNECE emission standards

8.2.2 Limitations, remarks and future improvements

Although CEPMEIP is extensive in source coverage, improvements are still needed as emission factors for some anthropogenic sources of primary particulate matter are still lacking or only partly covered (e.g., resuspension, drying equipment in the food industry and (some) fugitive emissions from industry and agriculture). With respect to traffic emissions the wear-related emissions (brake/tyre/road wear) are included (sector 7.5., table 2.4.) but the emissions factors are uncertain. Resuspension by road transport is not included in the inventory because 1) it is unclear whether this should be seen as primary emissions and, more important. 2) the emission factors are highly uncertain or unknown. Off-road vehicles used in agriculture is reported under sector 8 off-road transport and not under agriculture (sector 10, Table 2.4).

8.2.3 Emissions for 1995

The CEPMEIP emission factors have been applied in a PM inventory for the year 1995 using activity data obtained from national and international statistical information sources (e.g., FAO, Eurostat, UN) and TNO estimates. Through the collaboration with country experts, information on the sophistication level installed for each sector in most countries was available, enabling us to select the appropriate emission level for each activity in each country. The inventory provides a better understanding of the extent of PM emissions in Europe and regional differences in source contributions (Figures 8.1 and 8.2). The results show that in the EU15 and western non-EU countries the fraction of $PM_{2.5}$ in PM_{10} is considerably larger than in the eastern non-EU countries (Figure 8.1 and 8.2). Furthermore, the source contributions differ between West and Eastern Europe: The EU15 and western non-EU countries have a relatively low contribution of stationary combustion (~ 27 % of TSP emission) to the emissions of particulates as compared to the accession countries and the other countries (~ 70 % of the TSP emissions). Mobile sources contribute in Western Europe ~25 % and in Eastern Europe ~8 % to PM_{10} emissions.

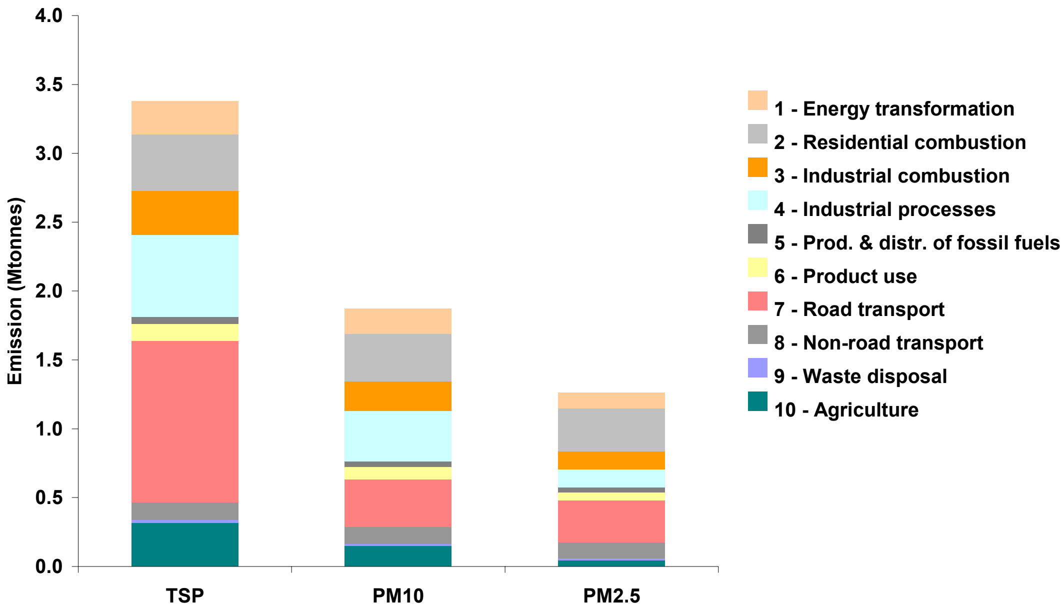

Figure 8.1 Anthropogenic TSP, PM_{10} and $PM_{2.5}$ emissions from EU-15 countries, Iceland, Norway and Switzerland in 1995.

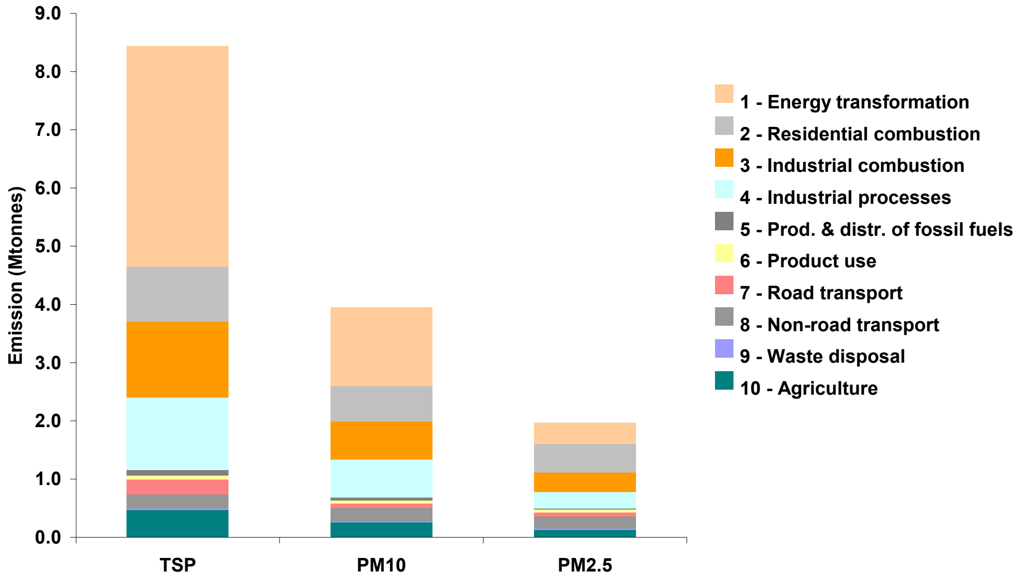

Figure 8.2 Anthropogenic TSP, PM_{10} and $PM_{2.5}$ emissions for eastern non-EU countries in 1995.

8.3 The delivered scaled emissions for year 2000

The 1995 emission totals are scaled to the PM_{10} and $PM_{2.5}$ country totals as presented in Table 2.3 except for the FSU states. The underlying source attribution is maintained to facilitate a high resolution spatial distribution. The final delivered data are summarized in Table 8.2 and 8.3 as emission by country by source sector. The relative contribution by source sector is presented in Figure 8.3 and 8.4, indicating that almost all sectors contribute to particulate matter emissions. For PM_{10}, the Energy sector (including refineries), fossil fuel use (residential/small sources) and process emissions are the most important sectors. The same sectors are important for $PM_{2.5}$ emissions but the relative importance of fossil fuel use in residential/small sources has increased as well as the importance of (non) road transport & machinery Figure 8.5-8.7 present the spatial distribution of the PM emission data in the form of gridded maps.

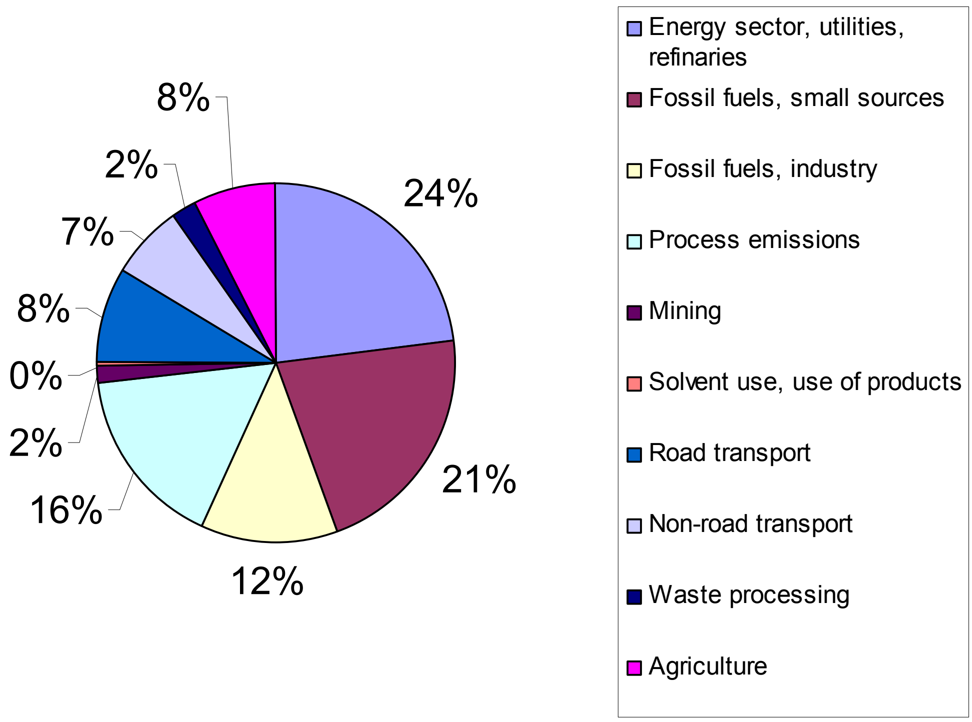

Figure 8.3 PM_{10} emissions by source sector for the entire domain (Table 8.2).

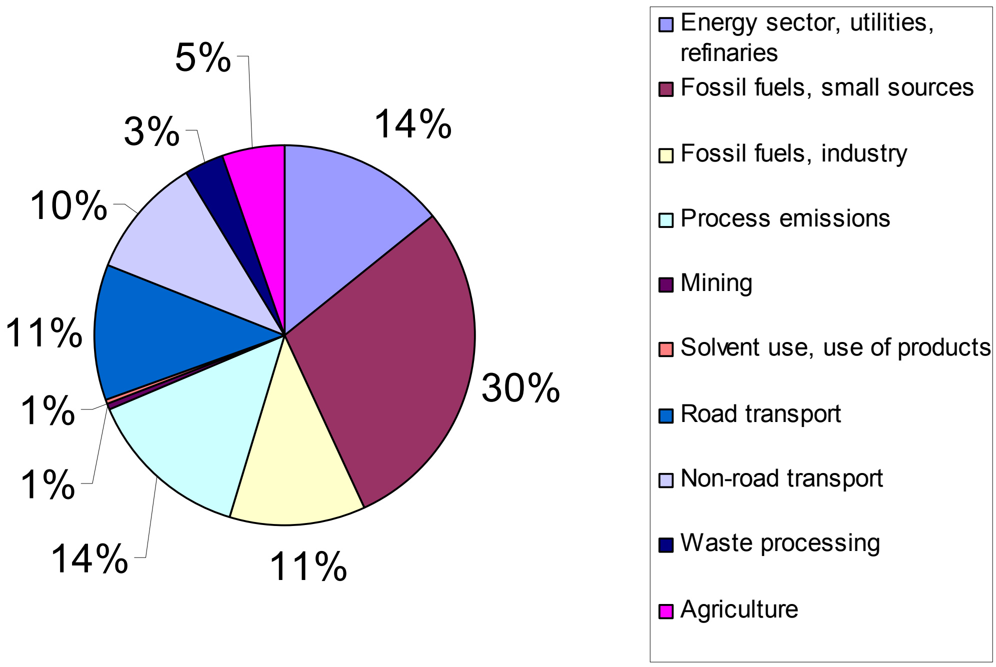

Figure 8.4 PM2.5 emissions by source sector for the entire domain (Table 8.3).

Table 8.2 PM_{10} emissions for the year 2000 in the final "scaled" TNO_UBA database.

Source	Energy sector	Fossil fuels, small sources	Fossil fuels, industry	Process emissions	Mining	Solvent and product use	Road transport	Non-road transport	Waste	Agri-culture	Total
ALB	306	4310	387	755	40	0	985	0	723	1525	9032
ARM	84	3160	702	1170	0	369	164	30	168	0	5847
AUT	786	12098	2486	14804	434	0	7885	5768	1452	2830	48544
AZE	6225	6919	1444	2091	1212	1189	4208	562	503	2593	26945
BEL	3980	7572	11402	19551	1280	0	13098	2569	1534	7499	68485
BGR	49432	10778	6854	12969	1819	0	3278	1758	1438	4020	92345
BIH	39357	3524	644	858	89	0	1001	524	805	1337	48139
BLR	8937	12596	2549	6220	1466	0	5090	5345	1810	11953	55967
CHE	202	1966	1506	2961	0	0	3453	1798	1325	1865	15076
CYP	37	368	535	124	0	203	0	9	33	0	1308
CZE	46884	23174	6953	6770	3131	0	5269	5135	1835	10111	109262
DEU	21994	19187	19932	56077	12902	0	58329	30925	12922	22691	254960
DNK	1594	9071	1109	1815	1088	0	4440	4758	1263	6732	31869
ESP	25175	39150	34318	29810	3408	0	42385	23203	6451	25043	228943
EST	30448	7423	496	281	655	0	849	392	234	871	41649
FIN	640	21186	1845	3820	0	0	6082	6373	937	1670	42552
FRA	12656	158487	16341	46533	1810	0	73742	20473	10416	27218	367676
GBR	18794	43855	16587	25151	8115	0	42527	16055	12682	13124	196889
GEO	54	4762	379	2025	2	503	195	2	328	1801	10051
GRC	16042	14282	5216	4864	1876	0	7043	7448	1979	6425	65176
HRV	3307	11803	2940	2699	38	0	2249	1695	887	2941	28558
HUN	14513	19356	8148	21012	851	0	5533	2132	2045	12351	85940
IRL	2052	5404	895	1926	303	0	4927	2142	709	2533	20892
ITA	15670	62812	37318	39547	592	0	53433	34117	10177	16767	270433
LTU	393	12599	228	717	0	0	1760	885	600	2954	20136
LUX	5	286	431	1158	0	0	1966	163	62	106	4176
LVA	831	3339	257	1780	0	0	1250	736	404	1203	9799
MDA	3599	4648	323	2278	2	465	440	1399	318	2937	16409
MKD	14595	677	1216	559	367	0	610	639	376	1828	20867
NLD	1208	5432	1979	9358	164	0	12701	9878	2513	12770	56004
NOR	111	11860	1908	3833	235	0	4289	5290	2823	1552	31900
POL	32948	153235	27133	22086	18234	0	14608	11998	6994	11882	299117
PRT	4089	19202	8174	4486	0	0	11209	4936	2218	4174	58490
ROM	55574	23109	13396	28248	1961	0	6153	4239	4343	24197	161220
RUS	528358	167192	141096	278809	17371	13618	18883	97996	3917	95955	1363194
SVK	7766	5083	2191	3904	674	0	2647	641	1014	4530	28450
SVN	7941	7415	535	834	166	0	1471	968	397	965	20692
SWE	897	49804	2892	8995	0	0	7038	4936	1345	2254	78161
TUR	62762	128671	91067	79304	3810	0	19575	15753	8534	4591	414066
UKR	155575	46543	183991	132401	4329	5280	4496	30914	2303	43627	609459
YUG	53281	10362	4669	4114	2039	0	3076	2864	2119	9122	91646
Total (GG)	***1249***	***1153***	***662***	***887***	***90***	***22***	***458***	***367***	***113***	***409***	***5410***

Table 8.3 $PM_{2.5}$ emissions for the year 2000 in the final "scaled" TNO_UBA database.

Source	Energy sector	Fossil fuels, small sources	Fossil fuels, industry	Process emissions	Mining	Solvent and product use	Road transport	Non-road transport	Waste	Agri-culture	Total
ALB	111	3266	291	314	4	0	871	0	723	902	6483
ARM	29	2992	427	325	0	335	149	30	168	0	4455
AUT	507	11220	1740	8794	43	0	6686	5461	1452	594	36497
AZE	1896	6546	951	678	1212	1125	3813	513	503	988	18224
BEL	1714	5922	6276	11002	134	0	11291	2432	1534	1903	42208
BGR	27323	7641	4214	9577	182	0	2857	1665	1438	1704	56600
BIH	14879	1798	423	338	9	0	879	496	805	653	20280
BLR	3981	8001	1658	3985	147	0	4465	5063	1810	7378	36488
CHE	55	1867	1222	1049	0	0	2410	1689	1325	503	10119
CYP	37	349	248	34	0	103	0	9	33	0	813
CZE	28677	17781	3723	3028	388	0	4470	4861	1835	6648	71411
DEU	16983	16925	15105	23870	1579	0	46329	29219	12922	4462	167395
DNK	1128	8559	801	640	121	0	3606	4496	1263	1263	21876
ESP	15192	36836	25672	13815	364	0	36045	21982	6451	8932	165290
EST	12400	6942	254	75	82	0	723	371	234	569	21650
FIN	428	20323	1419	1628	0	0	5177	5457	937	337	35705
FRA	5906	149113	10482	21119	201	0	63592	19303	10416	5669	285801
GBR	11309	27962	10798	9946	923	0	33668	15171	12682	2767	125225
GEO	18	4435	222	786	0	482	177	2	328	551	7000
GRC	10409	13193	3986	1505	252	0	5817	7032	1979	4484	48658
HRV	1347	7275	2217	1584	4	0	1946	1605	887	1843	18707
HUN	8516	13654	4974	15106	87	0	4793	2019	2045	8429	59622
IRL	1239	3894	739	479	35	0	4088	2029	709	525	13738
ITA	8922	60407	27627	19367	62	0	44549	32123	10177	4107	207341
LTU	230	11553	185	221	0	0	1521	545	600	2025	16880
LUX	3	274	345	819	0	0	1591	129	62	21	3243
LVA	391	2843	211	1096	0	0	1099	562	404	800	7405
MDA	850	4011	162	724	0	411	401	1313	318	1662	9851
MKD	5518	342	972	255	37	0	516	605	376	832	9453
NLD	865	5043	1568	3489	164	0	10511	8112	2513	2553	34819
NOR	43	11462	1231	1791	27	0	3605	4996	2823	539	26516
POL	20619	129035	15213	11136	1966	0	12400	11335	6994	2815	211513
PRT	1904	18504	6249	1850	0	0	9768	4222	2218	1485	46200
ROM	28655	21296	8042	19735	196	0	5439	4011	4343	14752	106469
RUS	148650	125666	78179	138607	8516	10664	16965	92038	3917	52159	675359
SVK	4205	3619	1330	1725	77	0	2301	606	1014	3105	17982
SVN	4162	7066	410	373	22	0	1207	917	397	431	14985
SWE	584	48124	2266	3924	0	0	5632	4362	1345	457	66694
TUR	33694	111017	54888	60980	381	0	16806	14922	8534	1020	302242
UKR	36336	28371	85833	66303	565	4288	3901	29408	2303	25057	282366
YUG	20228	5254	3110	2111	204	0	2678	2864	2119	5859	44427
Total (GG)	***480***	***970***	***386***	***464***	***18***	***17***	***385***	***344***	***113***	***181***	***3358***

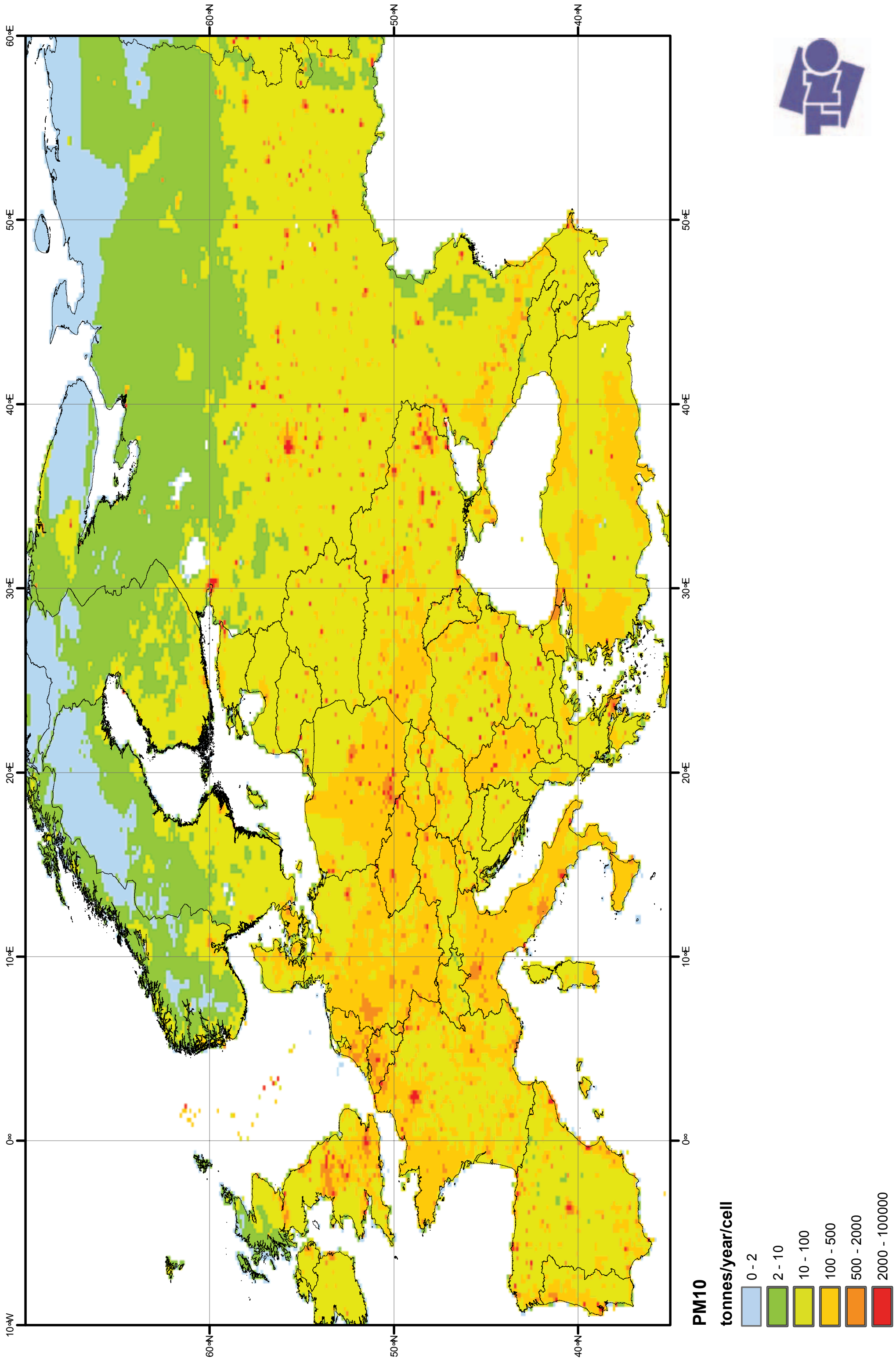

Figure 8.5 Spatial distribution of PM_{10} emission in Europe for the year 2000.

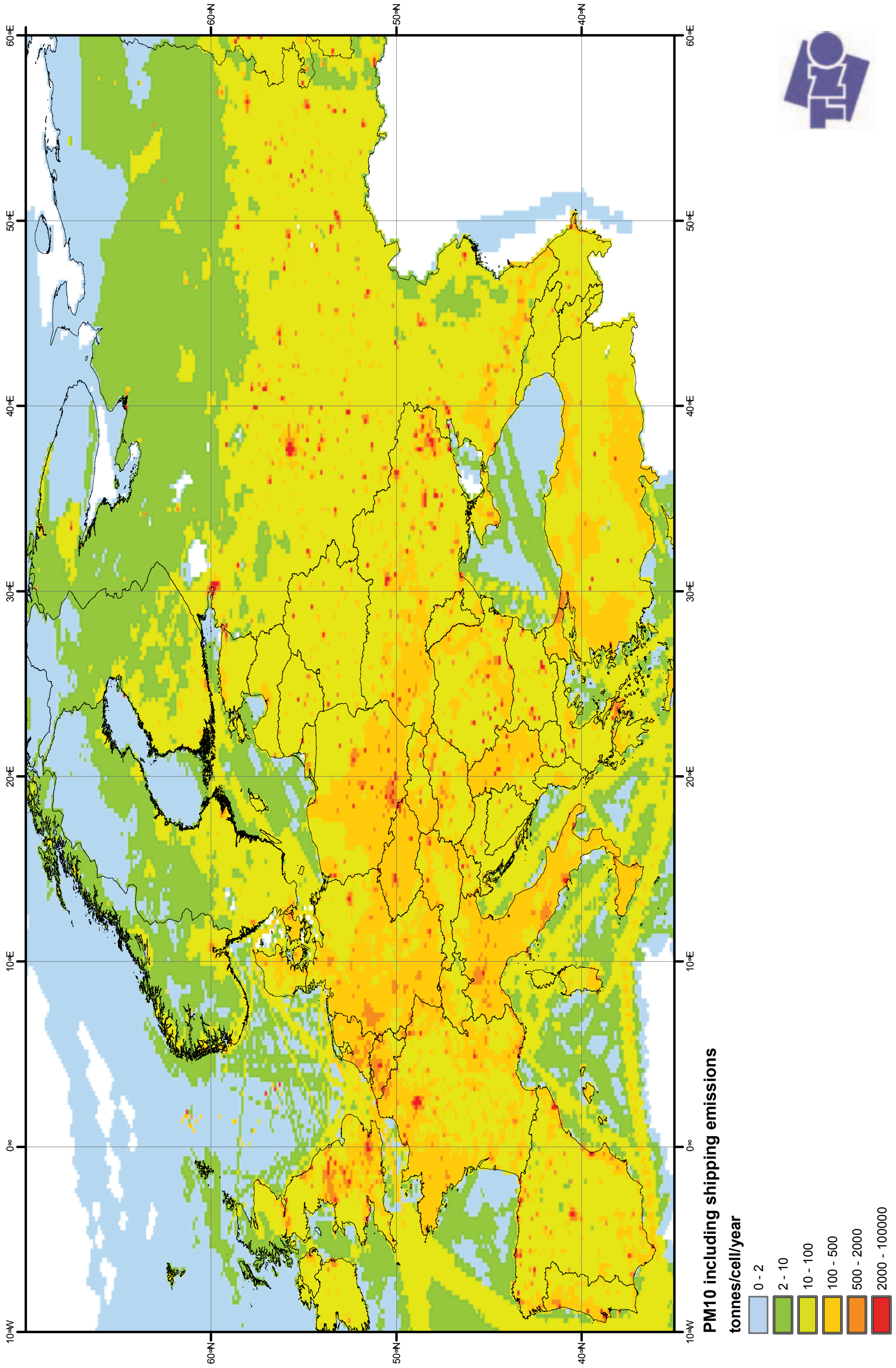

Figure 8.6 Spatial distribution of PM_{10} emission in Europe for the year 2000 including shipping

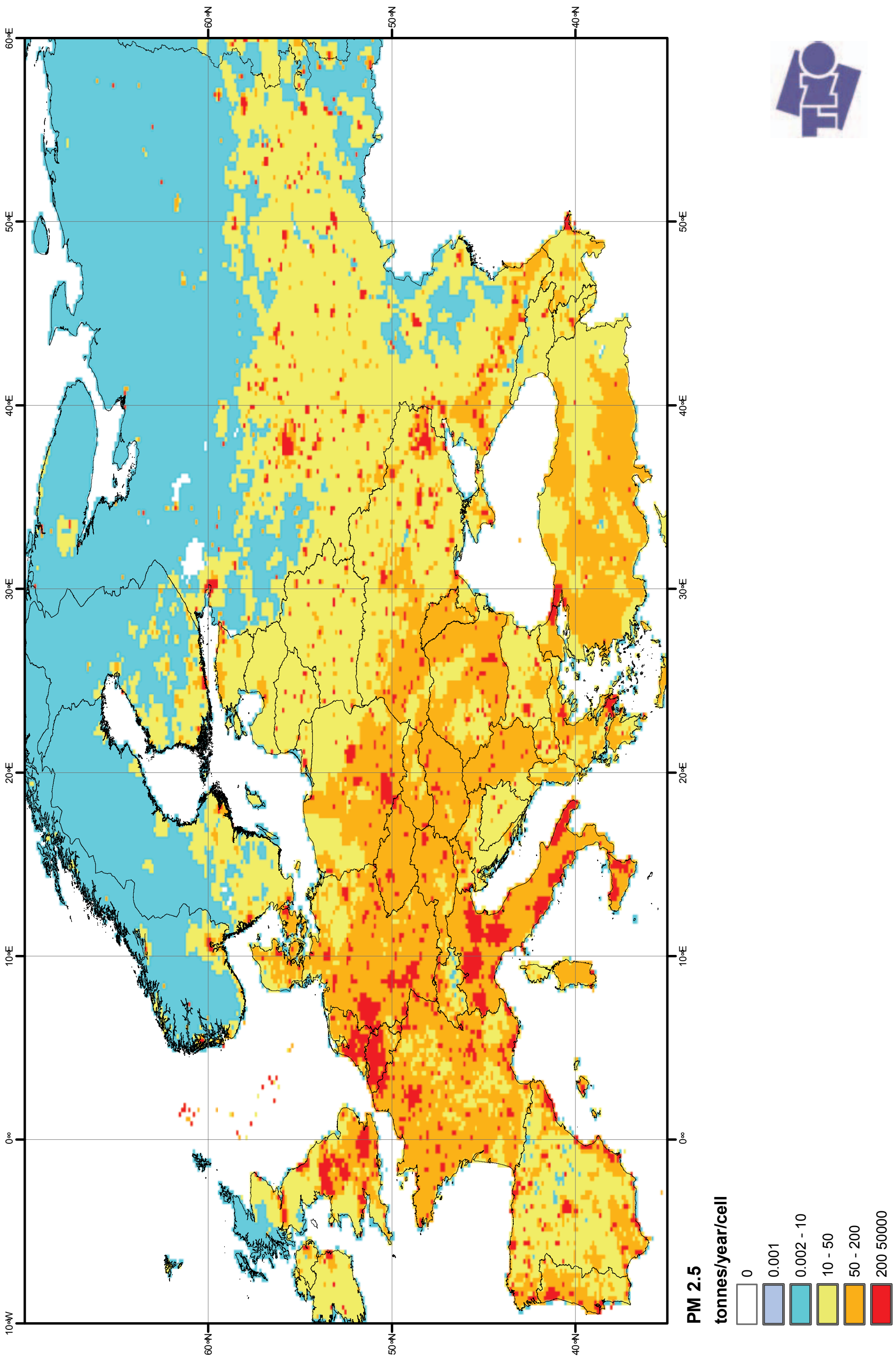

Figure 8.7 Spatial distribution of $PM_{2.5}$ emission in Europe for the year 2000

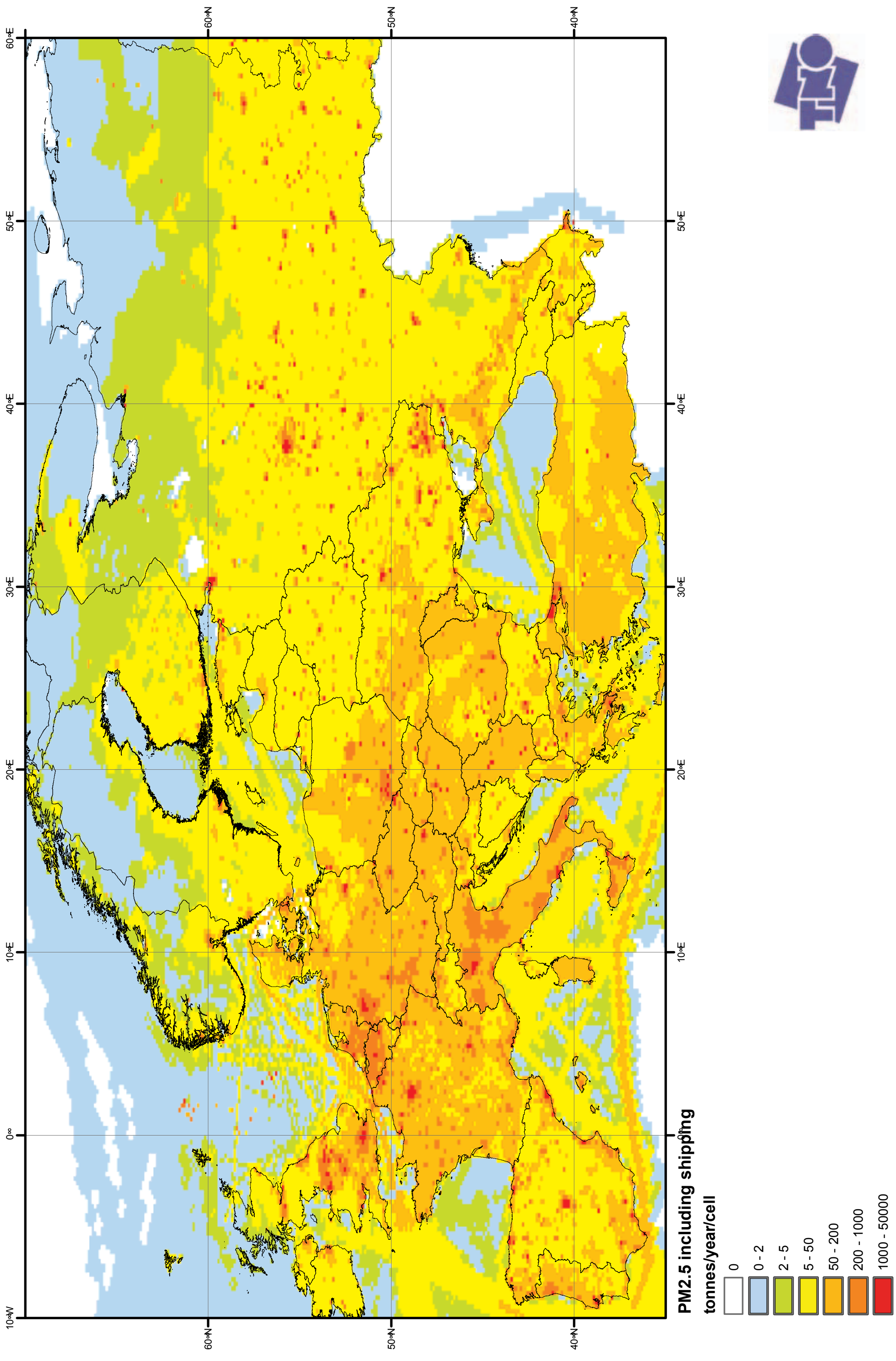

Figure 8.8 Spatial distribution of $PM_{2.5}$ emission in Europe for the year 2000 including shipping.

8.4 The fraction of black carbon or elemental carbon in $PM_{2.5}$

Schaap et al [2004] presented a new emission inventory for Black Carbon (BC) based on the CEPMEIP data. The annual BC emissions of Europe and the Former Soviet Union for 1995 are estimated at 0.47 and 0.26 Tg C, respectively, with highest contributions from transport (off-road and on-road) and households. The BC contribution for Europe (excluding the former USSR) as derived from the CEPMEIP data are presented by source sector in Table 8.4. The original calculations are based on the fractions of BC by source sector and fuel type but from the data in Table 8.4 a generic source sector fraction can be derived (last column, Table 8.4). This derived fraction, which averages the fuel specific impact, can be used to estimate the BC emission from the $PM_{2.5}$ emissions presented in table 8.3. The result of such an exercise is an indicative “scaled” BC emission inventory in line with the EMEP_CAFE_BL data for the European countries (Table 8.5). Total BC emissions for Europe (excluding the former USSR) are in the order of 550 GG BC.

Table 8.4. Particulate matter smaller than 2.5 µm from the CEPMEIP database, estimated black carbon emissions for anthropogenic activities in Europe (excluding the former USSR), and the derived source- specific black carbon fractions [Schaap et al, 2004].

SNAP [2]	Description	PM2.5 (Ktonnes)	Black Carbon emission (Ktonnes)	Derived Fraction Black Carbon of $PM_{2.5}$ [2]
1	Energy transformation	256	28	0.11
2	Small combustion sources	460	96	0.21
3	Industrial combustion	258	64	0.25
4	Industrial process emissions	197	0	0.00
5	Extraction of fossil fuels	36	30	0.85
6	Solvent and product use	81	0	0.00
7	Road transport	332	158	0.48
	Gasoline	44	14	0.32
	Diesel	262	144	0.55
	Volatilisation losses	27	0	0.00
8	Non road transport	160	83	0.52
9	Waste handling and disposal	25	0.1	0.004
10	Agriculture	83	15	0.17
11	Nature [3]	n.e.	n.e.	n.e.
	Total	1889	473	
	International Shipping [4]		23	0.12

[1] Selected Nomenclature Air Pollution

[2] These fractions are the net result of a mix of activities and fuels within each category.

[3] n.e. = not estimated. The CEPMEIP database only considers anthropogenic sources

[4] International sea going ships are not included in the CEPMEIP inventory

Table 8.5 Indicative BC emissions by source sector and country for Europe (excluding the former USSR) based on the $PM_{2.5}$ emission database scaled to EMEP BL scenario.

Source	Energy sector	Fossil fuels, small sources	Fossil fuels, industry	Process emissions	Mining	Solvent and product use	Road transport	Non-road transport	Waste	Agri-culture	Total
ALB	12	686	73	0	3	0	418	0	3	153	1349
AUT	56	2356	435	0	37	0	3209	2840	6	101	9039
BEL	189	1244	1569	0	114	0	5420	1265	6	324	10129
BGR	3006	1605	1054	0	155	0	1371	866	6	290	8351
BIH	1637	378	106	0	8	0	422	258	3	111	2922
CHE	6	392	306	0	0	0	1157	878	5	86	2830
CYP	4	73	62	0	0	0	0	5	0	0	144
CZE	3154	3734	931	0	330	0	2146	2528	7	1130	13960
DEU	1868	3554	3776	0	1342	0	22238	15194	52	759	48783
DNK	124	1797	200	0	103	0	1731	2338	5	215	6513
ESP	1671	7736	6418	0	309	0	17302	11431	26	1518	46411
FIN	47	4268	355	0	0	0	2485	2838	4	57	10053
FRA	650	31314	2621	0	171	0	30524	10038	42	964	76322
GBR	1244	5872	2700	0	785	0	16161	7889	51	470	35171
GRC	1145	2771	997	0	214	0	2792	3657	8	762	12345
HRV	148	1528	554	0	3	0	934	835	4	313	4319
HUN	937	2867	1244	0	74	0	2301	1050	8	1433	9913
IRL	136	818	185	0	30	0	1962	1055	3	89	4278
ITA	981	12685	6907	0	53	0	21384	16704	41	698	59453
LUX	0	58	86	0	0	0	764	67	0	4	979
MKD	607	72	243	0	31	0	248	315	2	141	1658
NLD	95	1059	392	0	139	0	5045	4218	10	434	11393
NOR	5	2407	308	0	23	0	1730	2598	11	92	7174
POL	2268	27097	3803	0	1671	0	5952	5894	28	479	47193
PRT	209	3886	1562	0	0	0	4689	2195	9	252	12803
ROM	3152	4472	2011	0	167	0	2611	2086	17	2508	17023
SVK	463	760	333	0	65	0	1104	315	4	528	3572
SVN	458	1484	103	0	19	0	579	477	2	73	3194
SWE	64	10106	567	0	0	0	2703	2268	5	78	15791
TUR	3706	23314	13722	0	324	0	8067	7759	34	173	57100
YUG	2225	1103	778	0	173	0	1285	1489	8	996	8059
Total (GG)	***30***	***161***	***54***	***0***	***6***	***0***	***169***	***111***	***0***	***15***	***548***

9. Methane (CH_4)

In Europe, the largest part of atmospheric emission of CH_4 is caused by six sources with comparable source strength [Olivier et al., 2002]:
- Ruminants; CH_4 is produced by methanogeneous processes in the animal's digestive system
- Animal manure, from which CH_4 is released as well
- Landfills; CH_4 is released through anaerobic degradation of carbonaceous compounds in waste
- Oil production and transport; CH_4 emission is caused by venting and flaring of associated gas, as well as low pressure venting of crude
- Natural gas production and distribution; emission is caused mainly by equipment leakage during production and distribution
- Coal production; during deep excavation and processing of hard coal, CH_4 entrapped in coal is released

Besides anthropogenic sources, natural releases of CH_4 are significant. Natural sources include among others degrading processes of organic matter under anaerobic circumstances, mostly in wetlands. Natural sources are not further covered here.

9.1 Emissions

As is the case for the other substances covered in this project, in order to be able to produce gridded emission data, emission estimates on a country and detailed sectoral level are needed. CH_4 is designated to be an important greenhouse gas and therefore recent and detailed official emission inventory data are available for nearly every European country. In this, the situation for CH_4 differs from that for other substances, and as a result of the availability and completeness of official CH_4 emission data, the need for a reference emission database is basically eliminated. Moreover, the limited number of relevant CH_4 emission sources and their relatively simple distribution patterns (e.g. no fuel types or sub-processes to be reckoned with) enables to take the officially estimated data and directly distribute emissions according to geographical distribution information, without having to use emission factors or any other estimating tools. This is how we have proceeded in order to produce the majority of the CH_4 grids, although there was a very small number of countries for which no CH_4 emission data was available. In these rare cases emission estimates have been taken from the EDGAR database [Olivier et al., 2002] in order to get complete coverage for Europe.

9.2 Gridded data

In the emission data as reported by countries within the framework of the United Nations Framework Convention on Climate Change (UNFCCC) the contribution of each of the 6 main CH_4 emission sources for the European situation is individually distinguishable in the reporting structure.

The emission from ruminants and animal manure (SNAP 10, Agriculture) is distributed according to the patterns for agricultural activities developed for NH_3 (see chapter on NH_3). The animal classification used for NH_3 distinguishes ruminants from other animals. This is of some importance since the locations of for instance concentrated dairy cow farming and the farming of other animals such as pigs or chicken can be different.

Landfills are usually located relatively close to populated areas and their geographical distribution roughly follows population density. Since the exact location and size of landfills is not available on a European level population density is used to distribute emission from this source.

The emission from crude oil and natural gas production (SNAP 05, Fossil fuel production) is distributed according to LPS data. The EDGAR database [Olivier et al., 2002] holds locations and production data of most major on- and off-shore oil and gas fields. Natural gas distribution emission is distributed according to urban population density since it is the older cast iron network that tends to leak mostly. The urban population density gridded data is derived by subtracting rural population density from total population density on a grid cell basis (see chapter on CO).

Emission from coal production (SNAP 05) is distributed according to the location and capacity of deep underground hard coal mining sites [Olivier et al., 2002]. CH_4 emission from surface and shallow mining, as well as from coal types lower in rank is insignificant compared to deep hard coal mining [Olivier et al., 2002].

All remaining minor contributions for SNAP 01, 02, 03, 04, 06, 07 and 08 together comprise less than a few percent of the total European CH_4 emission. These emissions are distributed according to total population density.

9.3 Results

The final delivered data are summarized in Table 9.1. as emission by country by source sector. The relative contribution by source sector is presented in Figure 9.1. Extraction and distribution of fossil fuels (“mining”); mainly losses during natural gas and oil extraction and mine gas venting, is the major source of CH_4, followed by Agriculture (ruminants) and waste processing (land fill emissions). Figure 9.2. presents the spatial distribution of the CH_4 emission data. The importance of the off shore emissions is visible in Figure 9.2. as point sources identifiable in the sea regions.

Table 9.1 CH_4 emissions by country and source sector for the year 2000.

ISO 3	Energy sector, utilities, refineries	Fossil fuels, small sources	Fossil fuels, industry	Process emissions	Mining	Solvent and product use	Road transport	Non-road transport	Waste	Agri-culture	Total
	CH_4 (tons)										
ALB		0			8160				13940	79740	101840
ARM		280			80000				26000		106280
AUT		12000		140	6000				248000	182000	448140
AZE		9000			202000				73000	159000	443000
BEL		11000		2000	43000				132000	330000	518000
BGR		4000		3000	129000				233000	115000	484000
BIH		23270			490				16410	28560	68730
BLR				1610	123260				129700	333940	588510
CHE		5000		440	12000				62000	136000	215440
CYP		510							6410		6920
CZE		19000		3000	268000				104000	114000	508000
DEU		60000			825000				794000	1205000	2884000
DNK		34000			15000				57000	168000	274000
ESP		50000		3000	85000				628000	1060000	1826000
EST		5000			32000				57000	24000	118000
FIN		21000		710	1370				80000	83000	186080
FRA		164000		3000	213000				800000	1591000	2771000
GBR		98000		4000	659000				697000	969000	2427000
GEO		900			6000				73000	78000	157900
GRC		22000			56000				253000	170000	501000
HRV		5000		400	53000				41000	48000	147400
HUN		32000		750	265000				145000	110000	552750
IRL		5000			4000				73000	527000	609000
ITA		89000		5000	266000				573000	868000	1801000
LTU		8000		20	17000				68000	83000	176020
LUX		900			2000				3000	17000	22900
LVA		8000			16000				63000	31000	118000
MDA		1450		1440	24000				24000	57000	107890
MKD		12020							13140	40730	65890
NLD		33000		3000	131000				406000	408000	981000
NOR		14000		860	25000				187000	98000	324860
POL		47000		8000	772000				886000	469000	2182000
PRT		20000		340	7000				319000	280000	626340
ROM		24000		5000	847000				228000	357000	1461000
RUS		152000			12860000				1770000	3362000	18144000
SVK		8000			61000				83000	62000	214000
SVN		7000			51000				76000	44000	178000
SWE		26000		250					97000	156000	279250
TUR		157520							262170	786040	1205730
UKR		14000			4387000				859000	1196000	6456000
YUG		55040							61350	339280	455670
Total (GG)	***0***	***1258***	***0***	***46***	***22552***	***0***	***0***	***0***	***10721***	***16165***	***50743***

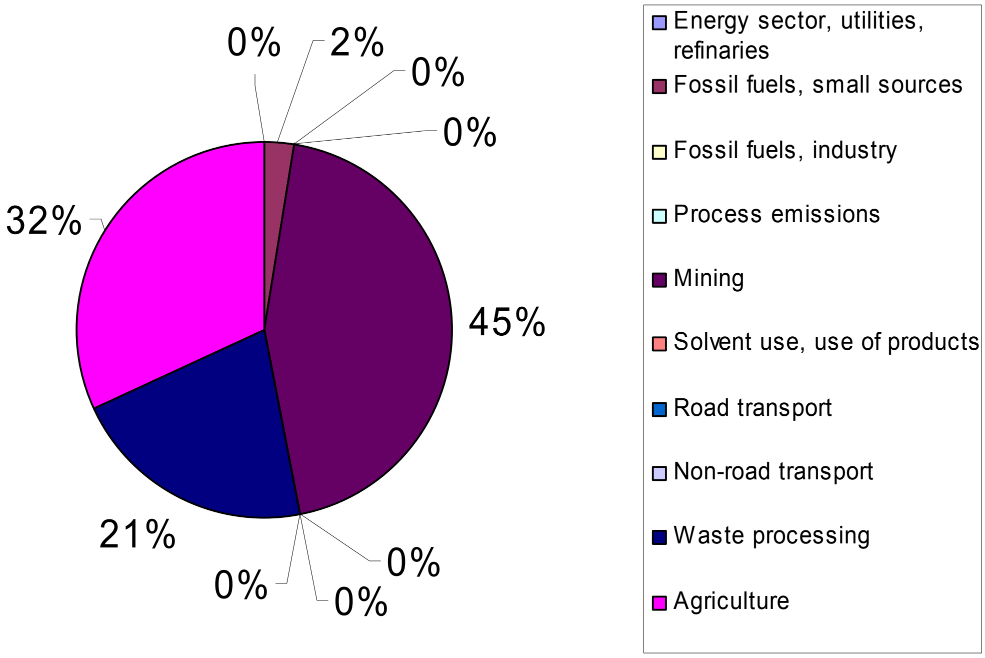

Figure 9.1 CH_4 emissions by source sector for the countries listed in Table 9.1.

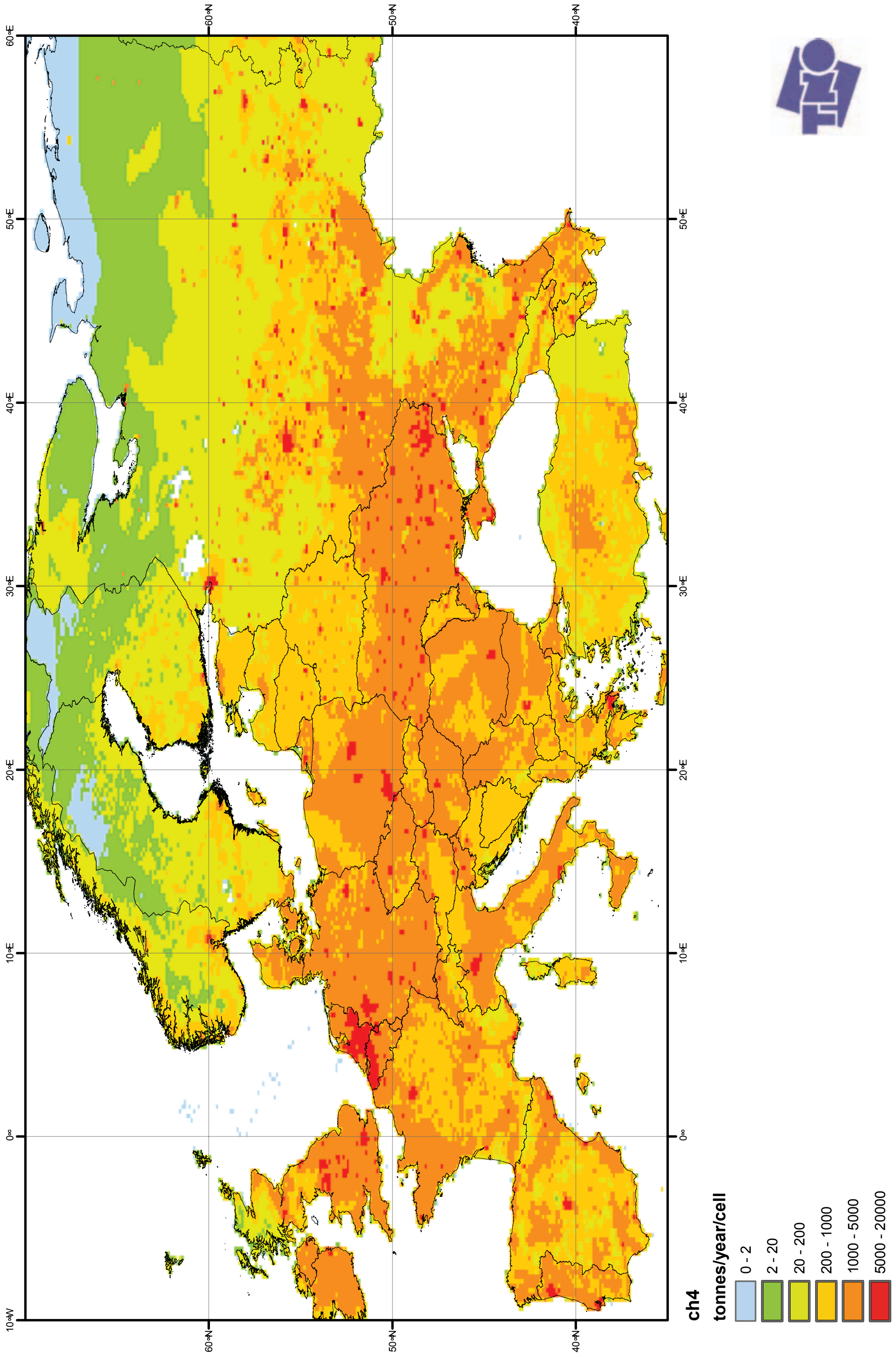

Figure 9.2 Spatial distribution of CH_4 emission in Europe for the year 2000

10. International shipping

Emissions from local, domestic ships, are included as internal navigation in source sector 8 of the national databases (see also Table 2.2) . Emissions from international shipping are specified in a separate database by EMEP. As noted in Vestreng [2003] total releases of SO_x, NO_x, NMVOC and CO from ship traffic in the Atlantic Ocean, the North Sea, the Baltic Sea, the Black Sea and the Mediterranean are used as estimated by Lloyd's Register of Shipping. These emissions refer to 1990 and are disaggregated at 50x 50 km^2 spatial distribution. EMEP [Vestreng 2001, 2003] assumed no changes in shipping emissions for the European domain from 1990 to 2000 (Table 10.1.).

Table 10.1 EMEP WEBDAB download (accessed November 2003) shipping emissions by Sea

Pollutant	Year	Baltic Sea	Black Sea	Mediterranean Sea	North Sea	Remaining North-East Atlantic Ocean
		Gg/yr				
CO	1990	29	8	139	59	111
CO	1995	29	8	139	59	111
CO	2000	29	8	139	59	111
NMVOC	1990	8	2	34	15	25
NMVOC	1995	8	2	34	15	25
NMVOC	2000	8	2	34	15	25
NO_x	1990	352	86	1639	648	1266
NO_x	1995	352	86	1639	648	1266
NO_x	2000	352	86	1639	648	1266
SO_x	1990	228	57	1189	454	901
SO_x	1995	228	57	1189	454	901
SO_x	2000	228	57	1189	454	901
PM_{10}	2000	7.10	0.77	1.19	43.30	63.18
PM_{10}	2001	7.10	0.77	1.19	43.30	63.18

However, MARIN [2003] documents the growth of shipping traffic on the North Sea (Table 10.2). The data summarized in Table 10.2 suggest that a stabilization of emission data from 1990 to 2000 is not correct and would underestimate the 2000 emissions for the North sea.. The higher increase of SO_2 in 1995-2000 as compared to CO_2 (Table 10.2) is probably due to increasing use of (improved) HFO in fast ships whereas these ships previously used MDO. In our opinion these data illustrate that it is unlikely that the emissions from shipping remained unchanged from 1990-2000. However information for other seas is lacking and we therefore follow, for seas other than the North Sea, the assumption of EMEP that emissions were stable between 1990-2000.

Table 10.2 Development in shipping emission on the (Dutch part of the) North Sea

Emission species	*1987 Emission relative to 2000*	*1995 Emission relative to 2000*	*Trend 1987-2000* %. Yr-1	*Trend 1995-2000* %. Yr-1
VOC total	84.00%	97.50%	1.35%	0.51%
NO_X total	67.80%	87.90%	3.03%	2.61%
CO total	81.20%	92.10%	1.61%	1.66%
CO_2 total	73.20%	91.70%	2.43%	1.75%
PM_{10} total	70.10%	86.90%	2.77%	2.85%
SO_2 total	72.90%	79.70%	2.46%	4.64%

10.1 Particulate matter from shipping

For PM_{10}, the emissions from shipping for the year 2000 from ENTEC (facilitated to EMEP from the European Commission, DG Environment) are included (Table 10.1). The PM data have only become available recently (November 2003). These annual emissions are assumed constant through the year and day by EMEP [Vestreng, 2003]. However, the presented PM_{10} data set as it was available from the WebDab tool (http://webdab.emep.int/ as of November /December 2003) was found to be inconsistent and incomplete. Approximately 90 % of the cells in the EMEP 50x50 km grid that have SOx shipping emissions did not have accompanying PM_{10} emission. Furthermore, the ratio between PM_{10} and other pollutants for the different seas clearly indicates that the PM_{10} dataset as available at the time (November 2003) is incomplete. For example compare the ratio between SOx and PM_{10} emissions for different seas in Table 10.1. To estimate PM_{10} shipping emission we assumed 1) all sea shipping to use heavy fuel oil (HFO), 2) this HFO has on average a S content of 2.7% and, 3) the emission factor for SO_2 is 54 g /kg fuel. In the CEPMEIP database the average PM_{10} emission factor for shipping using HFO is ~5 g /kg fuel. Based on this information, the PM_{10} emissions by shipping can be approximated by assuming PM_{10} emission to amount to ~10% of the SO_2 emission (Table 10.3).

A detailed $PM_{2.5}$ emission estimate for shipping emissions has not been made. To derive a $PM_{2.5}$ emission estimate we assumed all PM_{10} from shipping to be derived from the use of HFO as shipping fuel and we assume 95% of the PM_{10} emissions to be smaller than 2.5 µm. This assumption is based on the CEPMEIP PM_{10} and $PM_{2.5}$ emission factors for international navigation using HFO [CEPMEIP, 2001 available at http://www.air.sk/tno/cepmeip/, Visschedijk et al., 2004].

Table 10.3 Summarized emissions from shipping by region for 2000.

Pollutant (Gg/year)	Year	Region				
		Baltic Sea	Black Sea	Mediterranean Sea	North Sea	Remaining North-East Atlantic Ocean
CO	2000	29	8	139	69	111
NMVOC	2000	8	2	34	17	25
NO_x (as NO_2)	2000	352	86	1639	874	1266
SO_x (as SO_2)	2000	228	57	1189	579	901
PM_{10} _EMEP	2000	7.10	0.77	1.19	43.30	63.18
PM_{10} this study	2000	22.8	5.7	118.9	57.9	90.1

(blue) = Unchanged data from the EMEP shipping estimates (1990=1995=2000)
(yellow) = Recalculated from EMEP 1990 with annual growth % (Table 1) extrapolated to 2000
(green) = Original data from EMEP only available for 2000 from ENTEC report
(orange) = Estimated by TNO (2003) see text.

10.2 Summary of final procedure to obtain year 2000 emissions for shipping

1. Download the expert estimates for shipping from EMEP (# WebDab output on Mon Nov 24 10:57:16 2003, Source: Vestreng, V. [2003]. (Table 10.1)
2. The EMEP assumption that shipping emission remain stable from 1990 to 2000 was not followed for the North Sea because a recent report by MARIN [2003] indicated an average growth of ~2.5 % /year in emission (Table 10.2). The annual growth based on 1987_>2000 was used to correct the EMEP 1990 data for NO_x, SO_x, CO, NMVOC. Therefore,
3. North Sea emission data for NO_x, SO_x, CO, NMVOC are TNO extrapolation from EMEP data with MARIN [2003] - based annual % increase
4. PM_{10} data are not taken from EMEP because the dataset as available (November 2003) is incomplete. PM_{10} is approximated by assuming PM_{10} emission to equal 10% of the SO_2 emissions (Table 10.3)
5. The EMEP 50x50 km grids for all shipping emissions are converted with a Fortran programme to ½ x ¼ degrees longitude-latitude (lo-lat). To achieve this, each 50 x 50 km grid is first disaggregated onto a much smaller grid and than re-aggregated in lo-lat coordinates to ½ x ¼ degrees, except for the North Sea where the ½ x ¼ resolution is too coarse.

6. For the North Sea the 50 x 50 km emissions will be redistributed on a finer grid by deriving shipping densities from a map of vessel traffic on the North Sea (Dutch Min. for Transport, Public Works and Water Management). This GENO grid (8x8 km) map is first disaggregated and than re-aggregated to RDM grid on 5 x 5 km. The resulting conversion is an approximation of the original 8 x 8 km map, which is bought from the original data holder [MARIN, SAMSON database]. Disaggregating and reaggregating causes some of the emission locations to shift slightly, this can especially be seen in the Terneuzen area. A similar error is made in the EMEP shipping 50 x 50 km grid for the Channel, however this problem is solved by the much more accurate MARIN map. Although exact location of shipping emission may be slightly off for border cells (sea – land), total emission from shipping will be conserved. The RDM map is also converted to lo-lat.
7. The detailed North Sea map in lo-lat is used to make a cut-out from the total EMEP lo-lat map. All shipping emissions allocated in the cut-out area of the full EMEP map are reallocated using the RDM lo-lat map.
8. The detailed map for the North Sea contains intensity of sea traffic (sea miles traveled), not fuel use. Although the latter would be better to estimate emissions it is far more expensive. However from the number of sea miles traveled per grid cell an intensity map can be derived which provides an acceptable base for allocating the shipping emission. North Sea shipping emissions are now redistributed based on shipping intensity in the RDM 5 x5 km gridmap
9. The final result is 2 different maps
   a. RDM (5 x 5 km) N-Sea area surrounding the Netherlands
   b. Shipping emissions according to EMEP at ½ x ¼ lo-lat (except N-Sea) with approximated PM_{10} emissions

   Total distributed emissions are summarized in Table 10.3. The distribution of shipping emissions is shown for each substance in the respective substance chapters.

Description of the EMEP grid available at http://www.emep.int/index_model.html

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12. Authentication

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Appendix 1 Country emission totals per species

The emission totals presented in table A1 are scaled to the EMEP emissions for the Baseline Scenarios for the CAFE-programme, October 2004 (personal comm. L. Tarason, 2004). TNO reference emissions are used for CH_4 and for all species for the FSU states (see chapter 2 for details). Black carbon is derived from PM2.5 data as described in chapter 8.

Table A1 Country emission totals per species in the “scaled” TNO_UBA emission database

ISO 3	NOx	SO_x	NMVOC	NH_3	CO	PM_{10}	$PM_{2.5}$	BC[1)]	CH_4
					(tons)				
ALB	21625	32296	29390	22393	102000	9032	6483	1349	101840
ARM	8642	6851	25988	1549	74400	5847	4455		106280
AUT	191648	37981	190573	53549	858745	48544	36497	9039	448140
AZE	90431	185366	103225	50751	228895	26945	18224		443000
BEL	333251	187300	241706	81089	1099620	68485	42208	10129	518000
BGR	190612	1312916	136158	91840	667270	92345	56600	8351	484000
BIH	52780	420031	40347	17309	193000	48139	20280	2922	68730
BLR	247760	351271	228676	128106	717500	55967	36488		588510
CHE	97141	20276	146929	66057	393811	15076	10119	2830	215440
CZE	320197	250741	243754	73691	648000	109262	71411	13960	508000
DEU	1656612	641199	1521574	638233	4768005	254960	167395	48783	2884000
DNK	206943	28412	127883	90815	578570	31869	21876	6513	274000
ESP	1327976	1486140	1115822	394220	2774002	228943	165290	46411	1826000
EST	37381	91170	37010	9608	201660	41649	21650		118000
FIN	212960	79410	169298	34697	526300	42552	35705	10053	186080
FRA	1443731	646379	1540796	728409	6639583	367676	285801	76322	2771000
GBR	1749579	1188703	1457164	314725	4025043	196889	125225	35171	2427000
GEO	43626	14357	51003	38146	180742	10051	7000		157900
GRC	321252	477501	280241	55014	1531000	65176	48658	12345	501000
HRV	87373	107658	101872	32544	402100	28558	18707	4319	147400
HUN	187650	487418	150970	77762	633041	85940	59622	9913	552750
IRL	129441	132373	87646	126777	279571	20892	13738	4278	609000
ITA	1387833	755306	1728347	433843	5207199	270433	207341	59453	1801000
LTU	49053	43359	63239	50003	281500	20136	16880		176020
LUX	33036	4109	13226	6507	48939	4176	3243	979	22900
LVA	35246	16779	32781	12199	272926	9799	7405		118000
MDA	18362	7588	54608	33066	120315	16409	9851		107890
MKD	38437	90193	26063	14693	76940	20867	9453	1658	65890
NLD	401582	85001	264486	156796	676479	56004	34819	11393	981000
NOR	210719	27110	373825	25598	568180	31900	26516	7174	324860
POL	843117	1514779	581723	309249	3463003	299117	211513	47193	2182000
PRT	264845	231619	261184	68373	674999	58490	46200	12803	626340
ROM	330876	838488	378514	223444	2325000	161220	106469	17023	1461000
RUS	1890764	1611003	1908679	1079084	8300570	1363194	675359		18144000
SVK	106393	124133	86365	31593	290139	28450	17982	3572	214000
SVN	57963	96768	54241	18358	68000	20692	14985	3194	178000
SWE	251893	57561	305038	53472	832962	78161	66694	15791	279250
TUR	942405	2121891	773793	274978	3778193	414066	302242	57100	1205730
UKR	848894	1262863	929279	466701	3521279	609459	282366		6456000
YUG	166438	396258	142375	66036	553000	91646	44427	8059	455670
Total (GG) [1)]	***16836***	***17471***	***16006***	***6451***	***58582***	***5409***	***3357***	***548***	***50736***

[1)] Black Carbon, no estimate is made for the Former Soviet Union (FSU) states.

[2)] Malta, Cyprus and Monaco are not covered for all species and therefore not included in this overview table.