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TNO report

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A high resolution European emission data base for the year 2005.

A contribution to UBA-Projekt: “Strategien zur Verminderung der Feinstaubbelastung” – PAREST: Partikelreduktionsstrategien – Particle Reduction Strategies

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Summary

A transparent and consistent emission inventory is a prerequisite for (predictive) modelling of air quality. TNO has been asked to prepare a European emission inventory to support UBA in its ambitions to develop strategies to reduce the particulate matter exposure of the German Population. One objective of the PAREST project was to prepare a significantly improved, high resolution (~ 7 x 8 km^2) European emission database for the substances NOx, SO_2, NMVOC, CH_4, NH_3, CO and primary PM10 and PM2.5 for the year 2005. The emission data are subsequently to be used as European background data to facilitate the modelling of Air Quality over Germany. By determining and describing the present situation, emission reductions due to policies, technological improvements, etc. can be evaluated and (autonomous) changes and trends can be identified.
The TNO 2005 base year emission inventory was set up using, as much as possible, official reported emissions at the source sector level. This ensures incorporation of national expertise as well as staying close to what is accepted by policy makers in Europe. The emissions were downloaded from the European Environment Agency (EEA, 2008). However, the reported emissions by individual countries may contain gaps and/or errors. Therefore, various consistency checks were made and in some cases alternative expert emission data from the IIASA RAINS model (http://www.iiasa.ac.at/~rains) or TNO defaults were used. In the final emission grids the emission data were aggregated again to 10 so-called SNAP97 source categories e.g., energy production and conversion (SNAP1), residential combustion (SNAP2) or road transport (SNAP7).
When critically reviewing previous inventories it was concluded that the distribution patterns used for many of the sources may be out dated and/or no longer suitable to be used at the currently desired resolution. For each source category a split was made between emissions from point sources and area sources. Examples of point sources are e.g. power plants, refineries and major industries such as iron and steel plants. Examples of area sources are road transport, animal husbandry and residential combustion. For the point sources a new highly detailed database was compiled whereas for the area sources new geographical distribution maps were compiled to be used as proxies (e.g. population density is used to distribute emissions from residential combustion).

Compared to previous high resolution emission databases for Europe such as the UBA year 2000 inventory (Visschedijk and Denier van der Gon, 2005) and the year 2003 high resolution European emission data base for the EU integrated project GEMS (Visschedijk et al., 2007) the difference is only partly the total amount of emitted substances. The major improvement made in the TNO PAREST emission database is the spatial distribution of the emissions which is more realistic by linking sources better to their origin and/or preparation of proxies that closer resemble the nature of the emissions.
Overall the activity has resulted in a consistent set of high resolution emission maps for Europe for the base year 2005. In the PAREST project the German emission estimate is replaced by the improved emission maps for Germany prepared by IER, consistent with the German specific emissions for 2005 and reference scenarios for 2010, 2015 and 2020 used in the PAREST project. The base year 2005 set is also instrumental in preparing projected European emissions for the period 2010-2020.

Table of contents

1 Introduction

A transparent and consistent emission inventory is a prerequisite for (predictive) modelling of air quality. It allows identification of the (relative) importance of sources for (further) reducing the release of pollutants to the environment. By determining and describing the present situation, emission reductions due to policies, technological improvements, etc. can be evaluated and (autonomous) changes and trends can be identified. The emission inventory is a starting point to explore further options for emission reductions including costs of measures.

TNO has been asked to prepare a European emission inventory to support UBA in its ambitions to develop strategies to reduce the particulate matter exposure of the German Population (Forschungsvorhaben des Umweltbundesamtes UFOPLAN 206 43 200/01 „Strategien zur Verminderung der Feinstaubbelastung“). This project is referred to as PAREST (Particle Reduction Strategies)

The new emission database is partly a follow-up from a previous UBA project, where TNO prepared a gridded European anthropogenic emission database for the year 2000 (Visschedijk and Denier van der Gon (2005) and the derived high resolution emission inventory prepared for the EU FP6 project GEMS (Visschedijk et al., 2007). When critically reviewing these previous inventories it was concluded that the distribution patterns used for many of the sources may be out dated and/or no longer suitable to be used at the currently desired resolution. This was not surprising since the resolution of the emission maps has increased from 50 x 50 km^2 to ~ 7 x 8 km^2 in about 5 years time. The ambition of the endeavour described in this report is 1) to present a new base year 2005 for modelling and 2) to make a major quality improvement, review and overhaul of the functions and spatial patterns necessary to distribute emissions on a ~ 7 x 8 km^2 resolution.

In the overall PAREST project TNO contributes to several work packages. The work described in this report describes the TNO contribution to work package 1 (Arbeitspaket I: “Erstellung der Emissionsdatenbasis”) of the PAREST project.

1.1 Objective and Approach

One objective of the PAREST project was to prepare a significantly improved, high resolution European emission database for the substances NOx, SO_2, NMVOC, CH_4, NH_3, PM10, PM2.5 and CO for the year 2005 to be used in the UBA PAREST project. To fulfil this objective the work was split into the following tasks

1. Collection, selection and processing of the emission data to be gridded
2. Collection, processing and updating of point source information
3. Collection, selection and processing of geographical information maps to be used as proxies for diffuse and /or area sources distributions.
4. Distribution of the emission data by source sector using the proxy maps and point source data.

The work done under task 1 is described in chapters 2 and 3. The updating of the point source data is described in chapter 4, whereas the compilation of data to distribute the area sources is discussed in chapter 5. The final result of emission compilation and gridding is discussed in chapter 6.

1.2 Base year, resolution and domain of study

The base year of the inventory is 2005. The base year emission data will be scaled to the projection years 2010, 2015 and 2020. The emission data and gridded maps for the projection years are documented elsewhere (Denier van der Gon et al., 2009).

The domain of study is presented in Figure 1. The study area extends well beyond the EU boundaries and encompasses over 40 countries (see Table 1 for a listing of the included countries and marine areas). The resolution of the gridded emission data is 1/8 ° x 1/16 ° longitude-latitude, which is about 7 x 8 km^2.

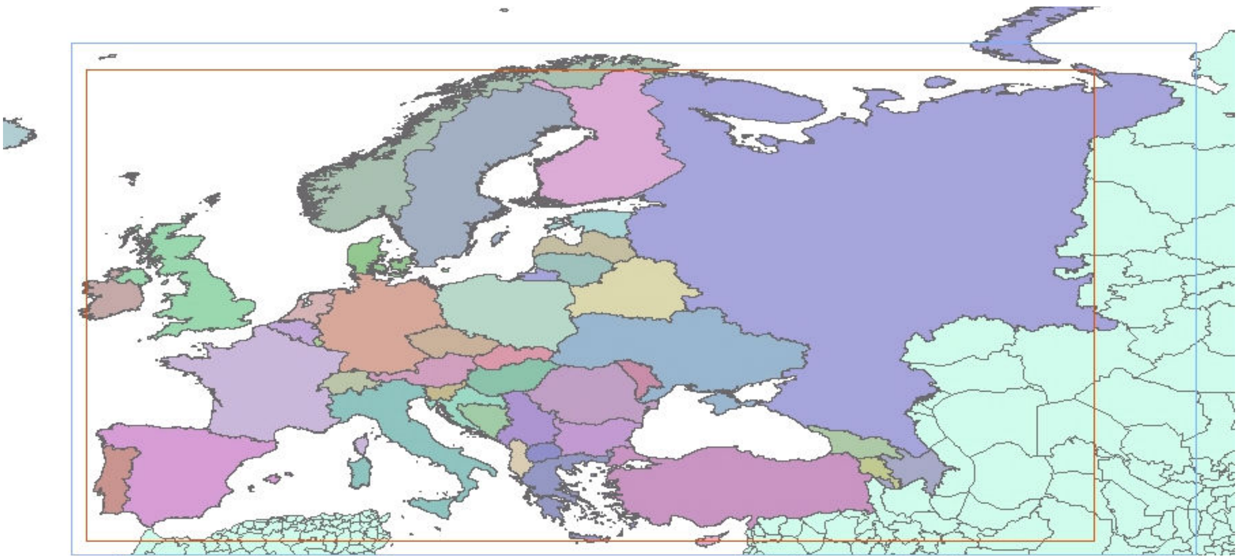

Figure 1 Countries included in the Pan-European emission inventory

As a part of the approach described in this report the emission data for Germany were collected and processed along with other countries. However, to prepare the final emission grids, the default TNO Germany estimates were replaced by high resolution emission grids for Germany prepared as part of the PAREST project by IER, Stuttgart in collaboration with other German partners (see PAREST project description). Therefore, the final step in preparing the emission grids to be used as model input was the nesting of these detailed German emission grids in the overall European emission map. This step is described in chapter 7.

Table 1. Countries and seas included in the European emission database and their respective ISO3 abbreviation

Country	ISO3	Country	ISO3	Sea	ISO3
Albania	ALB	Kyrgyzstan [a]	KGZ	Baltic Sea	BAS
Armenia	ARM	Latvia	LVA	Black Sea	BLS
Austria	AUT	Liechtenstein	LIE	Mediterranean Sea	MED
Azerbaijan	AZE	Lithuania	LTU	North Sea	NOS
Belarus	BLR	Luxembourg	LUX	Remaining North-East Atlantic Ocean	ATL
Belgium	BEL	Malta	MLT	EMEP-external Remaining North-East Atlantic Ocean	ATX
Bosnia & Herzegovina	BIH	Monaco	MCO		
Bulgaria	BGR	Netherlands	NLD		
Croatia	HRV	Norway	NOR		
Cyprus	CYP	Poland	POL		
Czech Republic	CZE	Portugal [b]	PRT		
Denmark	DNK	Republic of Moldova	MDA		
Estonia	EST	Romania	ROM		
Finland	FIN	Russian Federation	RUS		
France	FRA	Serbia and Montenegro	YUG		
FYR of Macedonia	MKD	Slovakia	SVK		
Georgia	GEO	Slovenia	SVN		
Germany	DEU	Spain [b]	ESP		
Greece	GRC	Sweden	SWE		
Hungary	HUN	Switzerland	CHE		
Iceland [a]	ISL	Turkey	TUR		
Ireland	IRL	Turkmenistan [a]	TKM		
Italy	ITA	Ukraine	UKR		
Kazakhstan [a]	KAZ	United Kingdom	GBR		

[a] outside of the domain of the gridded map.

[b] partly outside the gridded map: Russian Federation up to 60^o longitude, Spain excluding the Canary Islands; Portugal excluding Madeira and the Azores.

2 Methodology and selection of emission data

2.1 Air Pollutants and classification of sectors

The substances taken into consideration in the inventory are SO_2, NO_x, NH_3, CO, NMVOC, CH_4, PM10 and PM2.5. The emissions by substance will be given at the SNAP 97 (Selected Nomenclature of Air Pollutants) 1st level that consists of 11 source categories which is the grouping of sources as commonly adopted in modelling of Air Quality (Table 2).

Table 2. Description of source categories

SNAP		Description
1		Public electricity and other energy transformation
2		Small combustion plants
3		Industrial combustion and processes with contact
4		Industrial process emission
5		Fossil fuel production
6		Solvent and product use
7		Road Transport
	7.1	Road transport Gasoline
	7.2	Road transport Diesel
	7.3	Road transport LPG
	7.4	Non-exhaust (volatilization)
	7.5	Non-exhaust (brake wear, tyre wear, road wear)
8		Other (non-road) transport and mobile machinery
9		Waste disposal
10		Agriculture
11*		Nature

* Note: Emissions for SNAP 11 (nature) were not prepared.

2.2 Selection of emission data to be gridded

The basic input data needed in order to create gridded emission data is emission by country and by sector.
For the substances CO, CH_4, NMVOC, NH_3, NO_x and SO_2 countries have been obliged to submit official emission data for many years now. During this period the quality of the official emission data has risen to a generally high level with many country-specific factors being taken into account. Therefore, data submitted by individual countries are often more accurate than estimates obtained by using a generic method, based on emission factors that have only limited regional or technological differentiation. For PM emission data reporting obligations are of a more recent date, and country coverage is still far from complete. For PM emissions we have therefore relied on other information sources to a much greater extent.

For all substances reporting errors and other inconsistencies in the submitted data occur. For example; country emission estimates may be off by orders of magnitude for unknown reasons; sector data may show large discrepancies to the reported national total when summed. Therefore, we have submitted all official sectoral emission data to a consistency check and assessed whether the order of magnitude of the national total is within, at least in our view, reasonable boundaries. In case we suspected errors, the official country data were rejected in favour of a default TNO emission estimate or data from the IIASA RAINS model. When official data were unavailable for 2005 or a near-by year, again default TNO or IIASA estimates were used.

2.2.1 *Official country-reported emission data for 2005*

Emission data for the substances CO, CH_4, NMVOC, NH_3, NO_x, SO_2, PM10 and PM2.5 as officially submitted by parties to EMEP/CLRTAP are available from the European Environmental Agency (EEA) (Wagner et al., 2007). The EEA dataset is mainly based on the following data sources:

- CH_4:Country reports submitted in 2007 under the EU Monitoring Mechanism and to UNFCCC (excl. LULUCF)
- CO, NH_3, NO_x, NMVOC, SO_2, PM10 and PM2.5: Officially reported data to EMEP/LRTAP by 15 March 2007. The reported data is available from http://webdab.emep.int/

The EEA distinguishes eight emission source categories in its dataset. The gridded emission data produced in this project will be at the level of SNAP97 source categories. The link between the EEA sectors and SNAP97 can be approximated based on source sector knowledge. The assumed links are listed in Table 3.

Table 3. The EEA sectors and the approximate link with SNAP97

EEA_sector	SNAP
National Totals (Excluding Natural sources)	-
Energy Industries	01
Fugitive Emissions	05
Industry (Energy)	03
Agriculture	10
Waste	09
Other (Energy)	02
Road Transport	07
Other Transport	08
Industry (Processes)	04
Other (Non Energy)	06
Unallocated[a)]	-

[a)] Difference between National Total and sum of reported sectors

2.2.2 *Missing data in the officially reported emissions*

For the year 2005 official emission data was 70-80% complete on average. As an approximation for missing 2005 data EEA has used data obtained through a "gap-filling" routine (Wagner et al., 2007b). Where countries have not reported data for 2005, emission values have been considered to equal the last reported emission (e.g. 2004 or earlier). No further gap-filling was attempted by the EEA, if no data had been reported by Parties in any (recent) year. The coverage obtained in the EEA dataset increased to about 90% as a result of this gap-filling, leaving 10% to be filled in by other data sources. Primary source for completing the EEA gap-filled dataset has been IIASA's RAINS model (2005 CLE projections) for the substances CH_4, NH_3, NO_x, NMVOC, SO_2, PM10 and PM2.5. For CO, data for the year 2000 from the TNO reference database has been used to complement the EEA data (Visschedijk & Denier van der Gon, 2005). When no RAINS or TNO data was available, it has been attempted to complete the emission data based on data extracted from the latest available UNFCCC National Communications. PM emissions are not covered by the National Communications, and where this compound was not covered by RAINS, we have used the CEPMEIP 1995 data (Visschedijk et al., 2004) as a default.
Table 4 indicates the data origin for each country-substance combination for the final version of the 2005 dataset. Those cases where the EEA gap-filled data have been completed using other information sources are indicated by the data reference numbers 1 (reported by country), 2 (EEA data) 6, 10, 13 (RAINS or TNO data), 17, 18, 19 and 20 (National Communications).

2.2.3 *General quality and consistency checks performed on the official emission data*

As has been mentioned before, the gap-filled EEA data may contain reporting and estimation errors. If these remain unrecognized the overall quality of the data might be severely affected. We have therefore performed several consistency and quality checks with the aim to eliminate most of these errors.

A confusing issue in making choices is that the separately reported national emission total is often a more reliable indicator of the actual total emission by a country than the sum of the sector contributions. Ideally these should be equal. This is mentioned because in quite a few cases the EEA emission by sector for a specific country and substance does not add up to the separately reported EEA national total for that country and substance for no apparent reason. The EEA has marked those cases by introducing an "Unallocated Contribution", defined as the difference between the national total and the sector sum. According to (Adams, 2006) there is a number of cases in the EEA dataset where a reported sector contribution should in fact be zero but has for particular reasons not been updated. These cases are recognized by the Unallocated Contribution being of a negative sign and exactly the opposite of a certain sector's contribution (which has somehow survived updates). Our solution has been to delete this value for that specific sector. This has occurred in only a few cases with relatively low contributions. In case a discrepancy between the sector sum and the national total cannot be explained easily and, in addition, this discrepancy is significant (exceeding 10% of the national total), all emission data for that particular substance and country is regarded as unreliable and hence rejected in favour of default values.

We have used the IIASA RAINS 2005 data as default (Amann et al. 2005) for all sources except CO, for which TNO default data for 2000 as described in (Visschedijk and Denier van der Gon, 2005) has been used.

When the difference between the reported national total and the sum of the sector contributions does not match, but the Unallocated Contribution is smaller than 10% of the national total, no correction has taken place and the sum of the sector contributions is regarded as to sufficiently approximate the national total.

The next general quality check that has been performed on the official country data involves a test, whether in the country data all expected sector contributions are in fact present. For each substance there is one or more sectors for which the contribution is almost always significant, the so-called "key sectors". Per substance these key sectors are (Olivier et al., 2001):

- CH_4: "Agriculture", "Waste"
- CO: "Road Transport", "Other (Energy)"
- NH_3: "Agriculture"
- NMVOC: "Other (Non-Energy)", "Road Transport"
- NO_x: "Energy Industries", "Industry (Energy)", "Road Transport"
- SO_2: "Energy Industries"

If for a country the contribution of at least one of the above mentioned sectors is missing or insignificant in the official data, without a valid reason, all emission data for that country and substance have been rejected in favour of 2005 IIASA or, in case of CO, 2000 TNO default estimates. For Kyrgyzstan NH_3 from agriculture seemed lacking but this number appeared to be mixed up with the 'Unallocated contribution' in the EEA dataset. This could easily be corrected. A valid reason for a key sector to be missing can be e.g., SO_2 from Energy Industries in small countries that import all electricity from other countries and hence have no emission.

The final quality check performed on the EEA dataset involves a validation of the order of magnitude of the national total as reported by countries. We have set the criterion that the national total should not differ more than a factor 2 from the IIASA RAINS 2005 emission estimates or, in case of CO, the TNO reference database. Country emission data for which the total deviates more than a factor 2 are rejected and replaced by RAINS 2005 estimates and, for CO, TNO estimates.

As a result of the above described tests for several country-substance combinations the EEA gap-filled data have been replaced.
Table 4 indicates the data origin for each country-substance combination for the final version of the 2005 dataset. The data reference number list at the bottom of the table refers to the different tests described above (numbers 7, 8, 9, 11 and 12).

2.2.4 *Data shortcomings for specific country – substance – sector combinations*

In analyzing the EEA emission data we have also come across several isolated (non-systematic) issues for specific country – substance – sector combinations. These are not always indicated in Table 4 because Table 4 only refers to country totals with the sectors aggregated.

First of all, for Italy no PM2.5 data was available. Here we have estimated PM2.5 by taking 70% of Italy's PM10 emissions (indicated in Table 4 by data reference number 16). Secondly, for Cyprus, Kazakhstan and Kyrgyzstan only country totals were available (no sector split) for some substances.

In these cases we have subdivided the country total according to a sector contribution profile of a nearby country (which were Turkey and Russia respectively). This is indicated in Table 4 by the data reference numbers 14 and 15. For France, in sector SNAP 05 the PM2.5 emission exceeded the PM10 emission. PM2.5 has been re-calculated here by taking 70% of PM10. For Denmark, for sector SNAP 04 no PM10 was available. PM10 emission for this sector was estimated based on PM2.5 (which was available) by assuming PM2.5 to be 70% of PM10.

In spite of all our efforts to complete the emission inventory for the whole of Europe, there were some instances, where we could not provide an alternative data source, as data were lacking. This was the case for Kazakhstan (NH_3, NMVOC and PM), Kyrgyzstan (CH_4 and PM), Turkmenistan (all except CH_4), Monaco (PM) and Malta (CO). These cases concerned either relatively remote or small areas and will not affect modelling results very much.

2.2.5 *Summary of the emission data*

An overview of the final set of emission data to be gridded by country and source sectors is given in Table 5. The various consistency and quality checks to the EEA country data have been presented in the previous sections as well as the approach towards lacking data. The corresponding origin of the emission data by country and source sector can be found in Table 4. For 52% of the country substance combinations, directly reported emissions were used. For 11%, EEA gap filled data were used, while for the remaining 37% of the country substance combinations other data sources were used.

Table 4. Origin of the emission data to be gridded

ISO3	name	CH4	CO	NH3	NMVOC	NOx	PM10	PM2_5	SOx
ALB	Albania	6	10	6	6	6	6	6	6
ARM	Armenia	10	12	2	12	12	13	13	2
AUT	Austria	1	1	1	1	1	1	1	1
AZE	Azerbaijan	20	20	10	20	20	13	13	11
BEL	Belgium	1	1	1	1	1	1	1	1
BGR	Bulgaria	1	1	1	1	1	6	6	1
BIH	Bosnia and Herzegovina	6	10	6	6	6	6	6	6
BLR	Belarus	6	1	1	1	1	1	1	1
CHE	Switzerland	1	1	1	1	1	1	1	1
CYP	Cyprus	1	15	1	1	1	9	9	9
CZE	Czech Republic	1	1	1	1	1	1	1	1
DEU	Germany	1	1	1	1	1	1	1	1
DNK	Denmark	1	1	1	1	1	1	1	1
ESP	Spain	1	2	2	2	2	2	2	2
EST	Estonia	1	1	1	1	1	1	2	2
FIN	Finland	1	1	1	1	1	1	1	1
FRA	France	1	1	1	1	1	1	1	1
GBR	United Kingdom	1	1	1	1	1	1	1	1
GEO	Georgia	19	19	10	10	19	13	13	10
GRC	Greece	1	2	2	2	2	6	6	2
HRV	Croatia	2	2	2	2	2	9	9	2
HUN	Hungary	1	1	1	1	1	1	1	9
IRL	Ireland	1	1	1	1	1	1	1	1
ISL	Iceland	17	17	10	17	17	13	13	17
ITA	Italy	1	2	2	2	2	2	16	2
KAZ	Kazakhstan	18	14	N/A	N/A	14	N/A	N/A	14
KGZ	Kyrgyzstan	N/A	14	2	14	14	N/A	N/A	14
LIE	Liechtenstein	1	2	2	2	2	2	5	2
LTU	Lithuania	1	1	1	1	1	1	1	1
LUX	Luxembourg	1	2	2	2	2	6	6	2
LVA	Latvia	1	1	1	1	1	1	1	9
MCO	Monaco	17	1	2	1	1	N/A	N/A	1
MDA	Republic of Moldova	6	1	1	1	9	9	9	9
MKD	FYR of Macedonia	6	1	1	1	7	6	6	1
MLT	Malta	2	N/A	1	1	1	8	8	9
NLD	Netherlands	1	1	1	1	1	1	1	1
NOR	Norway	1	1	1	1	1	1	1	1
POL	Poland	1	1	1	1	7	1	1	1
PRT	Portugal	1	1	1	1	1	9	9	1
ROM	Romania	1	1	1	7	2	6	6	7
RUS	Russian Federation	6	12	8	7	7	9	9	7
SVK	Slovakia	1	1	1	1	1	1	1	1
SVN	Slovenia	1	1	1	1	1	1	1	1
SWE	Sweden	1	1	1	1	1	1	1	1
TKM	Turkmenistan	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TUR	Turkey	1	11	9	9	9	6	6	9
UKR	Ukraine	6	1	9	9	9	9	9	1
YUG	Serbia	6	10	6	6	9	6	6	1

Legend to Table

N/A	No data available
1	Reported by country
2	Gapfilled by EEA: Emission value considered to equal the first (or last) reported emission value
6	RAINS 2005 data used: No (gapfilled) country data available from EEA
7	RAINS 2005 data used: Unallocated contribution > 10% national total in EEA data; uncorrectable
8	RAINS 2005 data used: Key source contribution lacking in EEA data
9	RAINS 2005 data used: EEA data more than factor 2 difference with RAINS total
10	TNO 2000 data used: No (gapfilled) country data available from EEA
11	TNO 2000 data used: Unallocated contribution > 10% national total in EEA data; uncorrectable
12	TNO 2000 data used: Key source contribution lacking in EEA data
13	TNO 1995 data used: No (gapfilled) country data available from EEA
16	Calculated as 70% of PM10: No PM2.5 available in EEA data
14	2005 Country total redistributed according to sector contribution profile for Russia
15	2005 Country total redistributed according to sector contribution profile for Turkey
17	2005 Data taken from latest National Communication
18	2004 Data taken from latest National Communication
19	1997 Data, extracted from latest National Communication
20	1994 Data scaled from 1990 which is extracted from latest National Communication

Table 5. Summary of the 2005 emission data to be gridded by country and substance (Mg)

ISO3	name	CH4	CO	NH3	NMVOC	NOx	PM10	PM2_5	SOx
ALB	Albania	177753	112643	24086	31544	24942	9280	6655	31613
ARM	Armenia	153280	74400	14557	26030	8642	6586	4766	10307
AUT	Austria	336052	720311	63941	154136	225063	45533	26119	26410
AZE	Azerbaijan	442000	174468	50751	280177	113274	26940	18235	185366
BEL	Belgium	372991	875540	74168	201809	293090	43036	29184	146578
BGR	Bulgaria	488553	740271	57006	147012	233447	91647	55771	900267
BIH	Bosnia & Herzegovina	155367	182253	17313	41801	51867	44754	19241	426826
BLR	Belarus	736506	531756	135498	188513	158648	35664	24996	76979
CHE	Switzerland	167535	334931	55010	101135	86447	19495	9137	17396
CYP	Cyprus	46543	41070	5270	11460	17300	2902	2111	14477
CZE	Czech Republic	521445	510768	68419	181811	277846	34346	20863	218633
DEU[1)]	Germany	2268192	4034502	619418	1253290	1443097	193468	110854	560074
DNK	Denmark	268368	611163	92541	118305	185844	39243	27903	21864
ESP	Spain	1774696	2384102	436345	1118707	1534609	213168	143834	1359576
EST	Estonia	89305	158110	9270	36200	32070	26791	20427	77230
FIN	Finland	214343	521950	36220	131500	177407	51287	34083	69151
FRA	France	2681140	5676626	735320	1439096	1206939	508163	328777	465489
GBR	United Kingdom	2356741	2416504	317582	977169	1626930	150130	95059	706237
GEO	Georgia	150800	347470	38146	51600	52191	10034	7012	14357
GRC	Greece	404371	637220	73000	360760	317250	71293	53713	536820
HRV	Croatia	150139	311113	44164	91975	68903	24084	16714	60350
HUN	Hungary	370306	586999	80116	177461	203073	51574	30973	485364
IRL	Ireland	623920	222273	112697	61865	115988	12396	10232	70152
ISL	Iceland	19820	19580	3352	8300	27780	2038	1623	8150
ITA	Italy	1905074	4207000	426012	1262703	1172968	165844	116089	496884
KAZ	Kazakhstan	1480790	1114271	N/A	N/A	200894	N/A	N/A	947986
KGZ	Kyrgyzstan	N/A	3680	59114	2320	2380	N/A	N/A	8720
LIE	Liechtenstein	665	1586	176	638	303	54	38	51
LTU	Lithuania	159724	190348	39442	84102	57630	10759	8705	43727
LUX	Luxembourg	16630	41327	5311	9987	14915	3537	2614	2933
LVA	Latvia	85706	336563	13943	62991	41468	15545	13506	10317
MCO	Monaco	30	1308	6	373	339	N/A	N/A	56
MDA	Republic of Moldova	218540	140309	26681	38303	65882	45820	25038	123776
MKD	FYR of Macedonia	90779	103880	7360	25090	39073	19210	9032	104950
MLT	Malta	17464	N/A	1009	5419	11846	668	448	8259
NLD	Netherlands	795745	598916	135244	176215	344168	39690	22940	62257
NOR	Norway	219042	446292	23030	221668	196860	56271	49623	24080
POL	Poland	1824196	3333450	326480	885650	720464	289135	137713	1222140
PRT	Portugal	530817	652487	73097	301945	275130	48913	38831	214921
ROM	Romania	1226167	1405075	194059	404314	307236	151856	103190	685754
RUS	Russian Federation	22855157	13017583	764452	2730722	2726741	1515589	947055	2743460
SVK	Slovakia	197197	299444	26927	78940	98030	45216	36152	89007
SVN	Slovenia	100266	82546	18274	43320	57741	9319	7100	41757
SWE	Sweden	267277	602066	52378	198839	204865	53065	32885	39690
TKM	Turkmenistan	968000	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TUR	Turkey	2350218	2825033	410077	787787	931719	372263	267536	1792167
UKR	Ukraine	5140401	2923350	552695	703261	1175434	506260	304224	1192369
YUG	Serbia	527447	314745	67612	146741	163835	85823	42679	375050

N/A = No data available [1)] To be replaced by data delivered through project partners (IER, IZT) see also chapter 1

2.3 International sea shipping

Emission from ships is an important source of air pollutants like SO_2, NO_x and PM. Emission from sea shipping takes place on international waters and is therefore not included in any national emission data reporting. To make the PAREST emission data complete, an additional emission estimate for sea shipping had to be added to the country reported emission data discussed earlier in this chapter.

A comparison was made from various sources reporting international shipping emissions (TNO, IIASA, EMEP). It was found that for 2005 there was good agreement between the various information sources for SO_2 and NO_x as well as PM (Table 6). It was decided to use the EMEP shipping estimates for 2005. The EMEP emission totals per substance are given by Table 7.

Sea shipping is the most important form of shipping in terms of emission but we also distinguish inland and coastal shipping. Emission from coastal and inland shipping is, at least partly, reported by countries but it was necessary to make a correction for international inland shipping, this is described in appendix 1.

Table 6: Sea Shipping emissions PM10 (Gg/year)

Reference	TNO (2005)	IIASA (2007)	IIASA (2007)	EMEP (2008)
Year	2000	2000	2005	2005
Baltic Sea	22.8	24.7	25.3	26.6
Black Sea	5.7	7.6	7.5	7.5
Mediterranean Sea	118.9	146.3	144.6	146.8
North Sea	57.9	58.0	60.0	59.4
North-East Atlantic Ocean	90.1	64.6	66.5	68.0
Total	295.4	301.2	303.9	308.2

Table 7: Emission totals for international sea shipping as used in this study (Gg/year)

Pollutant	CO	NMVOC	NO_x	SO_x	PM2.5	PM10
Baltic Sea	35	12	343	245	25	27
Black Sea	9.3	3.2	90	65	7.1	7.5
Mediterranean Sea	182	61	1810	1259	139	147
North Sea	75	26	739	526	56	59
Remaining North-East Atlantic Ocean	80	27	819	557	64	68
Total	381	129	3802	2652	292	308

3 Attribution of emissions to detailed source sectors.

The emission data that serve as input for the final year 2005 emission database have been presented in Chapter 2. These data are available for ten SNAP sectors (Table 2). Each sector is an aggregation of a larger number of emission sources. For example, SNAP sector 4 includes all industrial process emissions. However, to properly distribute the emissions for this source sectors it is necessary to know how much of these emissions should be allocated to e.g., iron and steel industry, non-ferro industry, fertilizer industry etc. Only when this level of detail is reached we can properly distribute the emission for a country to the specific plants causing the emission. A similar story holds for all other aggregated source sectors. Within one SNAP sector there are always multiple proxies relevant. For instance, within SNAP 4 the locations of e.g. oil refineries, coke ovens, steel plants and aluminium smelters all determine the spatial distribution. From our input data however, we only know the summed emissions for SNAP 4. So, in order to make the emission data compatible with the proxy data a further sub-division of the SNAP emissions is necessary. In subsequent chapters the updated proxy information for point sources (chapter 4) and area sources (chapter 5), used to make the final distribution of emissions on the grid level, are presented.

3.1 Further sector disaggregation of SNAP emissions using the IIASA RAINS model

We have subdivided the SNAP-based emission input into individual source contributions based on IIASA's RAINS model (Amann et al., 2005). RAINS is a bottom-up emission inventory for all substances included in this report except CO. The detailed RAINS results as emission per country, per substance, per source are available online for 2005 (http://www.iiasa.ac.at/web-apps/tap/RainsWeb/). A link of the RAINS source categories to SNAP is provided. Our set of proxy data is based on knowledge on which sources are relevant for each substance, and the sources distinguished in a bottom-up inventory such as RAINS correspond to a reasonable extent to this set. At the time the emission data were processed in this report, RAINS provided the most recent, consistent and complete bottom-up emission inventory for Europe.
Our approach has been to scale the detailed RAINS results according to the ratio of the aggregated emissions per SNAP in RAINS versus the set of input data discussed in Chapter 2. In other words, we make a further source split in the SNAP-based emission input data, per substance, per country, based on the relative share of each source category within a specific SNAP code according to RAINS. Consequently RAINS is only used to estimate how strong the contributing sources are in relation to each other, not to set the absolute levels. The results of the RAINS model needed to be extended on certain aspects.

3.1.1 Addition of the Caucasus countries

The PAREST inventory includes the Caucasus region (Azerbaijan AZE, Armenia ARM and Georgia GEO), whereas these countries are not included in RAINS. Since these are relatively small countries, far from Germany we have opted for a simple approach to obtain similar results as RAINS produces for other countries. The emission inventories for the Caucasus countries are based on the RAINS results for Russia. The same profiles of mutual shares of source contributions per SNAP as for Russia were assumed. As explained in this chapter, the emissions will later be scaled to the earlier obtained SNAP totals for AZE, ARM and GEO, so we only use a relative share of source contributions comparable to Russia. The point source database (see Chapter 4) was used to determine which industrial processes take place in the three Caucasus countries. Processes that do not occur have been deleted from the Caucasus inventory before the emissions are scaled.

3.1.2 *Addition of a CO emission inventory*

RAINS (Amann et al., 2005) does not include CO. In order to sub-divide the SNAP-based CO emissions into contributions that can be gridded as it was done for the other substances, a bottom-up emission inventory for CO has been created for this purpose. For CO nearly all emissions are caused by transport and stationary combustion, so we have only regarded these sources. All activity data have been taken from the IEA International Energy Statistics and Balances (IEA). All emission factors for stationary combustion and non-road transport (SNAP 1 to 4 and 8) have been taken from the LOTOS/EDGAR inventories (Visschedijk et al., 2005 and references therein). Emission factors for road transport (SNAP 7) have been taken from the Dutch Emission Registration under the assumption that the average vehicle fleet in Europe in 2005 is comparable to the Dutch fleet in 2000. The CO emission per energy unit (PJ) of a passenger car on gasoline is about 10 times higher than from a diesel fuelled passenger car. Therefore, gasoline fuelled vehicles will dominate the CO emission from road transport. Since the CO emission per unit of energy from the average diesel passenger car engine does not differ much from a truck engine, we used only one emission factor for diesel in road transport (140 kg CO/PJ). Please note that per vehicle km the emission factors will differ substantially because a truck uses more fuel per km than a passenger car. Table 8 lists all emission factors used for CO per fuel type. Also indicated in Table 8 is the link with SNAP codes. The set of emission factors given in Table 8 results in a good indication of the relative source contributions within a specific country.

Table 8: Emission factors used in the CO inventory (kg CO/PJ)

Combustion sector	SNAP	Coal	Gaseous fuels	Heavy oil	Medium distillates	Light fuels*	Wood	Peat	Waste
Power plants	1	20	20	15	100*	5000	100	10	20
Oil refineries	1	150	20	15	100*	5000			
Coke ovens	1		20		100*	5000			
Residential combustion	2	5000	70	15	1000	5000	6000	1500	5000
Agriculture	2	5000	70	15	100*	5000	6000	1500	5000
Chemical industry	3 / 4	150	20	15	100*	5000		100	150
Iron and steel	3 / 4	150	20	15	100*	5000		100	150
Non-ferrous metals	3 / 4	150	20	15	100*	5000		100	150
Non-metallic minerals	3 / 4	150	20	15	100*	5000	1200	100	150
Other industry	3 / 4	150	20	15	100*	5000	1200	100	150
Road transport	7		530		140*	1600			
Rail transport	8				100*	5000			
Internal navigation	8				100*	5000			
Aerial transport	8				100*	5000			
Other non-road transp.	8				100*	5000			

* Engine application assumed

It is important to stress that the CO inventory has only been used to estimate relative importance of the various CO emission sources, as the absolute levels are dictated by the SNAP-based emissions discussed in Chapter 2.

3.2 Further processing of RAINS results for harmonisation with proxy data

In order to make an optimal spatial distribution of the emissions, some additional processing of the RAINS data is required. The RAINS fuel data contained more detail than we could accommodate. Therefore the fuels in RAINS have been aggregated to one of the following fuel types; Coal, Gaseous fuels, Heavy oil, Light fuels, Medium distillates, Peat, Waste or Wood. Furthermore, the RAINS source sectors for electric power production are aggregated to one sector "Power plants". Some more detailed modifications are discussed below.

3.2.1 Sub-division of industrial combustion in point source categories

In RAINS industrial combustion is classified as either combustion in boilers or in furnaces. For the spatial distribution this sub-division is irrelevant and boilers and furnaces have been summed. A significant part of the industrial combustion takes place in sectors that are treated as point sources in this report (see section 3.4). RAINS does however not specify combustion by industrial sector, and distribution as point source is not possible without further classification. We have sub-divided the industrial combustion in RAINS into the following industrial sectors:

- Chemical industry (point source)
- Iron and steel industry (point source)
- Non-ferrous metals industry (point source)
- Non-metallic minerals industry (point source)
- Other industry (area source)

3.2.2 Correction of the deviant structure of the RAINS SO_2 emissions for non-road transport

In RAINS non-road transport emissions are split into:
- Aerial transport
- Transport in agriculture
- Rail transport
- Inland waterways
- Coastal waterways
- Other non-road transport,

except for SO_2 for which the non-road transport emissions are less specified. SO_2 emission from non-road transport is divided into:
- Aerial transport
- Coastal waterways
- Other non-road transport

For spatial distribution we need the more extensive classification as available for NOx, so the SO_2 emissions from "Other non-road transport" have been split up. This has been achieved by taking the fuel consumption data used by RAINS to calculate NO_x and applying default SO_2 emission factors by fuel type, also taken from RAINS.

3.2.3 Further classification of CH_4 emission from natural gas distribution and processing

Transport and distribution losses of natural gas are a significant source of CH_4 emission, for instance in Russia. Transport and distribution losses mainly occur during production and first processing of natural gas, during longer range transport via the high pressure network and as distribution losses in cities that have an older cast iron distribution network. The IPCC Guidelines for estimating greenhouse gas emissions (IPCC, 2006) provided emission factors for these activities, including an uncertainty range (Table 9).

Table 9. Range of emission factors for transport losses of natural gas (Gg/bcm) (IPCC, 2006)

Activity	Low	Medium (log. mean)	High
Processing	0.051	0.33	2.1
Transmission and storage	0.042	0.56	7.6
Distribution	0.18	1.6	15

Emission from gas processing, transmission and storage is estimated based on the amount of gas produced whereas emission due to gas distribution is estimated based on the amount of gas consumed. Production and consumption of natural gas by each country is available from the IEA Energy Statistics and Balances. By selecting the appropriate emission factor from Table 9 and taking the 2005 activity data from the IEA, CH_4 emission from transport and distribution losses of natural gas have been calculated. The results are in reasonable agreement with the PAREST estimate for these activities and the following source contribution profile has been derived (Table 10):

Table 10. Relative share of the CH_4 emission contribution by processing, transmission and distribution of natural gas to total transport losses, per country

ISO3	Processing	Transmission	Distribution	
ALB	21%	79%	0%	2)
ARM	0%	0%	100%	2)
AUT	5%	8%	87%	1)
AZE	10%	37%	52%	2)
BEL	0%	0%	100%	1)
BGR	3%	10%	87%	2)
BLR	1%	2%	97%	2)
CHE	0%	0%	100%	1)
CYP	0%	0%	100%	1)
CZE	0%	1%	99%	1)
DEU	4%	7%	89%	1)
DNK	27%	47%	25%	1)
ESP	0%	0%	100%	1)
FIN	0%	0%	100%	1)
FRA	0%	1%	99%	1)
GBR	17%	29%	54%	1)
GRC	0%	1%	99%	1)
HRV	9%	33%	57%	2)
HUN	5%	9%	87%	1)
IRL	6%	10%	84%	1)
ITA	4%	7%	89%	1)
LUX	0%	0%	100%	1)
NLD	21%	36%	43%	1)
NOR	36%	62%	2%	1)
POL	6%	11%	83%	1)
PRT	0%	0%	100%	1)
ROU	9%	34%	57%	2)
RUS	15%	57%	28%	2)
SVK	1%	1%	98%	1)
SWE	0%	0%	100%	1)
TUR	1%	4%	95%	2)
UKR	5%	19%	76%	2)
YUG	2%	8%	90%	2)

1) 'Medium' emission factors assumed to apply
2) 'High' emission factors assumed to apply

From Table 10 it can be observed that in general most losses occur during final distribution of gas. There are however a few countries with high indigenous production where gas transport is at least equally important. Based on Table 10 the PAREST CH_4 emission due to loss during transport of natural gas has been divided into contributions by processing, transmission and distribution activities. The spatial distribution of processing is discussed in section 3.3 and transmission and distribution in section 3.4.

3.3 Allocation of emissions to point sources

A significant part of the emissions has been allocated to point sources. A point source is a source that emits at a discrete and specific location in reference to the grid cell size (e.g. a stack). In this project a major update of the existing point source information has been made and also several new point source categories have been added (see Chapter 4 for details). The link between the TNO point source database and the RAINS / PAREST emission source categories is documented in an internal TNO report (Visschedijk et al., 2010). The linkage is a technical selection and does not affect the absolute emission totals. An example of such a linkage table is given in Table 11 for the source sector energy transformation (SNAP 01).

In the case of SNAP 1 almost all emission is allocated to point sources, and so is a large part of SNAP 3, 4 and 5. Only minor parts of the emission under SNAP 6, 8 (airports) and 9 were distributed based on point source information. No emissions under SNAP 2, 7 and 10 were distributed based on point source information.

Table 11 illustrates that for power and heat plants the TNO point source database has a differentiation in fuel types (e.g. gas or coal power plants). Emission is in this case distributed per fuel type. For all other point source types this information is not available in the TNO point source database (e.g. we have no information on whether a certain iron and steel plant is specifically gas- or coal-fired).

All point sources belonging to a specific sector and country in this case have an identical fuel usage profile.

In order to estimate how much emission is to be allocated to a particular point source, its capacity is used as a key. The capacity of each point source is for that reason expressed in a relative unit. This is the ratio of the point source capacity to the total capacity for that source in a specific country. The emission to be allocated is calculated by multiplication of this ratio with the total emission of a sector in a country.

Table 11 Example of the relation between the RAINS / PAREST point source categories and the TNO point source database for the source sector energy transformation (SNAP 01)

SNAP Sector	PAREST / RAINS sector	PAREST / RAINS fuel type	Point source category	Fuel type
1: Energy trans-formation	Power plants	Coal	Electricity and heat production	Hard coal
		Coal		Brown coal
		Coal		Coal water mix
		Coal		Oil shale
		Coal		Petroleum coke
		Peat		Peat
		Heavy liquid fuels		Residual oil
		Heavy liquid fuels		Black liquor
		Medium distillate fuels		Gasoil
		Light liquid fuels		Other light liquid fuels
		Gas		Natural gas
		Gas		Coal syngas
		Gas		Refinery gas
		Gas		Blast furnace gas
		Gas		Coke oven gas
		Gas		Biogas
		Gas		LPG
		Gas		Other gaseous fuels
		Wood		Wood
		Waste		Other solid fuels
		Waste		Paper mill waste
	Other transformation	Gas	Oil refineries	-
		Heavy liquid fuels		
		Medium distillate fuels		
		Coal		
	Briquettes production	-	Coke ovens	
	CO emission coke ovens			

3.3.1 *Usage of the EPER database*

The European Pollutant Emission Register (EPER) is a Europe-wide (EU-27) centrally managed database that contains key environmental data from industrial facilities in European Union Member States plus Iceland (ISL) and Norway (NOR). EPER was established in 2000 as a result of European Commission Decision 2000/479/EC. It contains self-reported data by a selection of industrial facilities that fulfil a number of criteria, such as capacity or emissions exceeding a certain threshold. For each facility in EPER, information is provided concerning, among others, the amounts of pollutants released into air. Facility data in EPER comprise the summed emissions per economic sector of individual installations belonging to that sector. EPER contains no information on plant characteristics such as capacities. At the time our research for the PAREST project took place the most recent year available was 2004.

Many of the point source categories in the TNO point source database fall under the economic sectors that are obliged to report to EPER. For the spatial distribution of point source emissions a register like EPER can therefore be very useful, provided that the data contained are complete and accurate. We have attempted to assess the accuracy and completeness of the EPER database, based on a comparison of the summed EPER emissions per substance, activity and country with the equivalent RAINS / PAREST emissions. The thought behind this is that the EPER emissions should be consistent with the nationally reported emissions. Our conclusion is that the NO_x and SO_2 emissions as reported for power plants and oil refineries in EPER are in reasonable agreement with the PAREST / RAINS emissions. Both sectors fall under SNAP 1. For other substances and other categories however there is an unacceptable difference between EPER and PAREST, which is partly caused by incompleteness of EPER. In addition, there is the problem that the EPER information is often too aggregated since emissions are summed for economic activities (e.g. the iron and steel industry as a whole while our approach requires process differentiation).

For use of EPER in PAREST we have linked the majority of the power plants and oil refineries in the TNO point source database on an individual basis to the corresponding facility in EPER (see Chapter 4). This enables us to compare the PAREST point source emissions with EPER on a plant by plant basis. Many power plants in Europe are equipped with flue-gas desulfurization (FGD) and/or Denox, which are two techniques that control SO_2 and NO_x emissions, respectively. In addition, there are several oil refineries that have substituted natural gas for residual oil as primary fuel used. In principle this information is not included in the TNO point source database as it is used in PAREST but can result in comparable installations of similar size having a totally different SO_2/ NO_x emission. For instance, if three out of five coal-fired power plants in a country have FGD, then the SO_2 emission of these three plants will be far less than either of the other two, in spite of similar capacity. Moreover, differences in the sulphur content of the coal used are not accounted for in the TNO point source database. However, it is expected that in EPER all of these important plant characteristics were taken into account.

The major drawback of simply replacing the PAREST NO_x and SO_2 point source emissions for refineries and power plants by EPER is however that this would introduce an inconsistency with the nationally reported totals. As this is considered undesirable, we have chosen to merely redistribute the PAREST point source emission according to the emission ratio between plants in EPER. Large differences in installed emission control within a country will thus be accounted for, while consistency with nationally reported emission is still maintained.
While research for the PAREST project was carried out, the EPER has been replaced by the E-PRTR regulation (see http://prtr.ec.europa.eu/Home.aspx for further details). The European Pollutant Release and Transfer Register (E-PRTR) is the new Europe-wide register that provides easily accessible key environmental data from industrial facilities in European Union Member States and in Iceland, Liechtenstein and Norway. It replaces and improves the previous European Pollutant Emission Register (EPER). However, at the time of the PAREST project, EPER was a more complete set than E-PRTR, and it was decided to use EPER for the PAREST project.

3.4 Allocation of emissions to area sources

All emission sources that are not classified as point sources are regarded as area sources in this report. An area source is a two-dimensional source of diffuse air pollutant emissions that emits over a surface with dimensions exceeding the grid cell size (e.g. diffuse emissions by households, animal husbandry). Strictly speaking, the emission by vehicular traffic along a road, highway or ships on a river would be a line source, a one-dimensional source of air pollutant emissions. However, in our approach the line source is transferred to the grid, with the share of the line source defined by the length of the line or node in the particular grid cell and the intensity of the activity. The emission allocated to the particular stretch of line in a grid cell is equally distributed in the grid cell. So, effectively the line sources are transferred to a grid and treated as area sources. For almost all area sources the exact dimension and location of the source are principally unknown. Area sources are therefore spatially distributed according to a proxy, which is a parameter that is used as a key to approximate the actual spatial distribution of the source. As described in Chapter 5, this project has brought about a major update of proxy information. This has resulted in a new road, rail, inland waterway and gas distribution network and new maps of urban and rural population, farm animals and arable land. Table 12 presents an example of the link between the RAINS / PAREST area emission source categories and the available proxy information for the transport sector.

Table 12: Example of the relation between the RAINS / PAREST area source categories and the proxy data for the transport sector (SNAP 7 and 8)

SNAP sector	PAREST / RAINS sector	Proxy
71: Road transport, gasoline	Light duty vehicles; exhaust; gasoline-fuelled 2-Wheeled vehicles; exhaust Heavy duty vehicles; exhaust; gasoline-fuelled	Partly road network and partly population[a)]
72: Road transport, diesel	Light duty vehicles; exhaust; diesel-fuelled Heavy duty vehicles; exhaust; diesel-fuelled	
73: Road transport, LPGs	Light duty vehicles; exhaust; gas and LPG-fuelled Heavy duty vehicles; exhaust; gas and LPG-fuelled	
74: Road transport evaporation	Stationary evaporation from gasoline vehicles	Population
75: Road transport, wear	Light duty vehicles; brake, tyre and road wear Heavy duty vehicles; brake, tyre and road wear 2-Wheeled vehicles; brake, tyre and road wear	Partly road network and partly population[a)]
8: Non-road transport	Mobile sources in agriculture	Arable land
	Rail transport	Rail network
	Inland waterways	Inland waterways
	Coastal waterways	Coastal waterways
	Other mobile sources and machinery	Population
	Livestock – other cattle	
	Livestock – pigs	Distribution of pigs
	Livestock – poultry	Distribution of poultry
	Livestock – other animals (sheep, horses)	Distribution of other animals
	Fugitive emission due to ploughing, tilling and harvesting Fertilizer use Storage and handling of agricultural products (crops) Agricultural waste burning	Arable land

[a)] See section 3.4.2

The different proxies for area sources are discussed in more detail in Chapter 5. For two important sources (road transport and wood combustion by households) emission is distributed according to two proxies with the balance varying for one source (road transport). The following sections will describe the approach followed for these two sources.

3.4.1 *Spatial distribution of emission due to wood combustion by households*

In principle, population density is used as a spatial proxy in order to distribute wood combustion emissions. However, without any adjustment the result would be that too much emission is allocated to densely populated areas. Many high-rise apartment buildings in urban environments are less likely to be fitted with a fireplace, stove or a wood boiler, for various reasons.

For both Sweden and the Netherlands spatially distributed emission data for domestic wood combustion is available from the national emission registrations (Segersson and Johansson, 2008 and ER, 2008). The Swedish and Dutch methodologies to distribute emissions take into consideration regional statistical information on the type of housing (availability of district heating, low- or high-rise, year of construction, free standing detached or not etc.) as well as regional information (on a city or county level) on wood use that is based on among others questionnaires to users. Our population map comprises an urban and rural part (see Chapter 5) and we have overlaid the spatially distributed wood use data available for Sweden and the Netherlands with both the urban and the rural population map respectively. It appears that on a per capita basis urban regions consume on average about half the amount of wood compared to rural regions. This in line with expectations and for the spatial distribution over Europe we assume rural regions having twice the weight in distributing emissions.

3.4.2 *Spatial distribution of road transport emissions*

For the spatial distribution of road transport emission two proxies are available, the Trans-tools traffic flow map and population.

TRANS-TOOLS is a European transport network model covering both passenger and freight transport, as well as intermodal transport (Trans-tools Final Report). One of the outputs of Trans-tools is the traffic flow map that is based on modeled transport demand and network loads. The traffic flow map comprises a network of major rural roads and highways that covers the whole of Europe. Except for Turkey, for which only the European part is included, and Ukraine and Russia that also have only partial coverage. As explained in section 5.2 we have extended the Trans-tools network to cover the whole of Turkey, Ukraine and Russia. Based on among others the earlier ETIS database (http://www.iccr-international.org/etis/index.html) and the VACLAV model (http://www.iww.uni-karlsruhe.de/reddot/288.php), for every road section Trans-tools gives a traffic intensity for light and for heavy duty vehicles. Trans-tools focuses on inter-urban transport and only regards motorways and other main roads. Urban roads are associated with shorter ranges and are disregarded by the model.

The Trans-tools model offers a valuable tool for the spatial distribution and the modified traffic flow map used in this project for the spatial distribution of long and medium range road transport emissions. For short range transport population is used.

The percentage of the total road network that is covered by the Trans-tools map varies from country to country, so a varying percentage of the emissions was allocated to the Trans-tools network. The first step in estimating this percentage is estimating the amount of vehicle kilometres (vKm) driven on the Trans-tools network versus the total amount of vKm driven in a country. Estimates for the total amount of vKm per country and vehicle type are taken from the models TREMOVE (http://www.tremove.org/) and RAINS (http://www.iiasa.ac.at/web-apps/tap/RainsWeb/).

For each country the fraction of the total vKm allocated to the modified Transtools network was established for light duty vehicles, heavy duty vehicles and motor cycles (including 2-stroke vehicles). The share not allocated to transtools is distributed by population density.

In the above section the fraction of the activity data (vKm) allocated to the Trans-tools network was derived. However, to be able to estimate the fraction of the emission per substance that has to be allocated to the Trans-tools network, the differences in emission factors for highway/non-urban versus urban driving must be taken into account. For example, an average car emits per kilometre more CO on urban roads than on highways. Specific emission factors are available from the TREMOVE inventory as composite emission factors for cars, trucks and motorcycles that vary per country due to differences in vehicle fleets (fuel type, age etc.). For countries lacking in TREMOVE, emission factors from comparable countries are assumed to be applicable. The ratio of the emission allocated to the Trans-tools network versus population is estimated according to:

Emission fraction Trans-tools network = (vKm fraction * Highway emission factor) / (vKm fraction * Highway emission factor + (1 - vKm fraction) * Non-highway emission factor)

This results in allocation fractions per substance and vehicle type per country.

3.5 Residual emission that can not be allocated to RAINS / PAREST categories or point sources

Regarding the disaggregation of the emission input data into RAINS / PAREST categories some final remarks should be made about so-called ‘residual or left over’ emissions. As has been explained in chapter 2, the country data have been checked for missing or unexpected SNAP contributions, and for major and obvious cases emission data is either corrected or rejected (as long as a better alternative is available). Nevertheless in some cases there are source contributions that can not be distributed over RAINS categories. In a number of cases countries report emission data under a certain SNAP sector for which there is no equivalent emission in RAINS. Or in other words; country data say there is an emission for this category while RAINS says there is none. In most cases this is the result of countries allocating an emission under a different SNAP sector than RAINS does. So, it is often a matter of “reported elsewhere”. But since it is unclear where exactly, we have to find a pragmatic solution. These residual emissions have been gridded separately and are in most cases spatially distributed according to population density.

There is also a second category of residual emissions related to point sources. Occasionally, there is a point source emission for a certain country-sector combination while there are no point source records for this country-sector combination in our point source data base. A surrogate proxy (mostly population) is then used to distribute the emissions for that country-sector combination.

The percentage per country and substance that both types of "left over" emission make up of the national total for that country and substance have been listed in the TNO internal documentation (Visschedijk et al., 2010). In rare cases a substantial (10-30%) fraction of the emissions of a particular substance in a country may be qualified as "left over". This means that for that country the spatial distribution is sub-optimal for the particular pollutant. Since population is most often used as the proxy for leftover emission, a relatively large share of the leftover emissions is allocated to highly populated areas such as cities. Below we briefly comment on some of the more important consequences.

- In Armenia (ARM) the majority of SO_2 emission from industrial processes (SNAP 4) could not be allocated to point sources. In the RAINS / PAREST database there are four potential sources of SO_2 under SNAP 4: coke ovens, paper mills, oil refineries and sulphuric acid production. None of these processes occurs in Armenia according to our information and it is unknown what the country-reported emission for SNAP 4 represents. Population is used as a proxy.
- In Azerbaijan more than a quarter of the CO emissions could not be allocated. This concerns emission from SNAP 5 and SNAP 8. In our simple CO inventory there are no CO emissions from oil and gas production whereas Azerbaijan is a major oil producer and some CO might be emitted. Furthermore in the IEA energy statistics there is no record of any energy consumed (and hence no emission) by off-road mobile sources in Azerbaijan. All transport-related fuel consumption is lumped into one category "road transport".
- A third of the SO_2 emission from Belarus and 15% of the SO_2 emissions from France could not be allocated. Both countries reported a high contribution for SNAP 5, which is the production and distribution of fossil fuels. Since there is hardly any fossil fuel production in either country it is unknown what this figure stands for and why it is so high. Population is used as a substitute proxy.

- In Poland almost one quarter of the CO emission could not be allocated. This turns out to be country submitted data for SNAP 9, waste treatment and disposal. Our simple CO inventory does however not include CO emission from waste disposal. Possibly this concerns the uncontrolled combustion of waste by households, in which case population that is used as a surrogate proxy is an adequate distribution key.

4 Updating of point source data

A point source is a source that emits at a discrete and specific location, within a surface smaller than the grid cell size (e.g., a stack). Point sources are static and have indefinitely small dimensions, contrary to mobile sources that emit along a line or over a larger surface. In the emission inventory point sources are defined by a geographic coordinate and an emission, together with characteristics such as height and heat output. In principle all stationary sources could be regarded as a point source, but in practice only those which are relatively large in size and small in number are. Processing certain emissions as point sources requires specific knowledge on characteristics like location and size. In this study many industrial activities are regarded as point sources:

- Electricity and large heat production plants using coal, peat, oil-shale, gas, heating oil, motor fuels, biomass and solid, liquid and gaseous wastes
- Oil refineries
- Coke ovens
- Fossil fuel production covering crude oil production, natural gas production and coal mining sites
- Iron and steel production plants including sintering, pellet plants, blast furnaces, open hearth furnaces, basic oxygen furnaces and electric arc furnaces
- Production of non-ferrous metals including primary and secondary aluminium, copper, zinc and lead, and primary nickel
- Cement production
- Chemical industry
- Airports
- Harbours

When critically reviewing previous inventories (e.g. Visschedijk and Denier van der Gon, 2005) it was concluded that the distribution patterns used for many of the sources may be out dated and/or no longer suitable to be used at the currently desired resolution. For usage in PAREST a major update of point source information has been made and several new point source categories have been added.

4.1 Starting point for the point source update

The starting point for the PAREST / TNO point source database is the collection of point sources as used in e.g. the gridded emission data prepared for UBA for the year 2000 (Visschedijk and Denier van der Gon, 2005). Table 13 presents an overview of the starting point for updating.

Table 13: Number of points sources in the previous TNO point source database and the updated point source database for PAREST

Branch	Number of facilities as database entries	
	Year 2000 inventory[a)]	PAREST (this study)
Thermal power generation; all fuels	1276	1823
Oil refineries	195	190
Iron and steel; all integrated plants and EAFs	510	590
Non-ferrous metals; all plants primary & recycling	278	291
Cement clinker production	302	439
Sea harbours	-	1212
Fossil fuel production; crude oil, natural gas and coal	353	353[b)]
Chemical industry	763	763[b)]
International airports	272	272[b)]

[a)] Visschedijk and Denier van der Gon (2005)
[b)] Not updated

Many different literature sources have been consulted to update the year 2000 point source database. Some of these sources provided updated data for 2005 but for most categories new literature information had to be gathered to update point source information to 2005. Our procedure for updating the TNO point source database consisted of:

- Checking whether each individual installation active in 2000 was still in use in 2005
- Checking for each individual installation if the recorded characteristics like location and capacity were correct for 2005
- Adding installations that were active in 2005 but not present in the 2000 database and for which capacity was above a certain threshold
- Adding a new category of point sources (harbours)
- Linking, when possible, each individual point source in our database with the EPER central register of point source emissions for 2004

Based on the significance of the source for the PAREST substances, as well as on the availability of new information the following categories were updated to 2005:
- Power generation (all fuels)
- Refineries
- Iron and Steel production (all processes)
- Non-ferro industry (all processes)
- Cement production
- Larger sea harbours

The chemical industry has not been updated to 2005 due to a lack of data and source significance. Fossil fuel production sites are not expected to have changed much since 2000 and have also not been updated. Airports have not been updated from 2000 to 2005 as well.

In previous TNO studies municipal waste incineration was sometimes regarded as a point source as well. However in 2005 the controlled incineration of municipal waste was not a significant source for any of the substances under consideration. In all of the EU(15) extensive emission control equipment is used. Waste incineration in Central and Eastern Europe is takes place since a few years on a limited scale only. Usable new data on individual incinerators in Europe seems to be unavailable as well. In this report waste incineration is not regarded as a point source anymore.

In the next sections we describe the improvements and underlying data by source category.

4.2 Power Generation

Power generation is the most important point source category for the substances under consideration, especially NO_x and SO_2. Two literature databases have been used for the update:

- World Electric Power Plants Database (WEPP; see http://www.platts.com/)
- EPER, European Pollutant Emission Register (http://prtr.ec.europa.eu/)

4.2.1 Usage of WEPP

The UDI World Electric Power Plants Data Base (WEPP, 2008) is a global inventory of electric power generating units. It contains design data for plants of all sizes and technologies operated by regulated utilities, private power companies, and industrial auto producers. The WEPP database is an almost complete register of stationary electricity plants, as there is no capacity threshold for inclusion in WEPP. WEPP provides many plant characteristics of which fuel type and capacity are our primary interest. Most power plants in WEPP are boiler-type, but also gas turbines and engines have been considered. We have used a 20 MWe (roughly comparable to 50MWth) capacity threshold for inclusion in the PAREST point source database. Table 14 shows the total capacity in Europe of small (<20 MWe) plants versus large (>20 MWe) plants in WEPP. The 20 MWth threshold results in about 95% of the installed capacity being covered.
Fuel types covered in WEPP are hard coal, brown coal, coal water mix, oil shale, petroleum coke, peat, residual oil, black liquor and paper mill wastes, gasoil and other light liquid fuels, natural gas, coal syngas, refinery gas, blast furnace gas, coke oven gas, biogas, LPG and other gaseous fuels, wood and other biofuels. Wind, hydro, solar, geothermal and nuclear energy production have been disregarded by us. There is a difference in the fuel usage profile between the larger and the small power plants. Coal is much more used in large plants than in small plants (Table 14).

Table 14. Installed capacity and fuel consumed by smaller power plants and larger power plants in Europe (WEPP, 2008)

	Small plants (<20 MWe)		Large plants (>20 MWe)	
	Total Capacity (Gwe)	%	Total Capacity (GWe)	%
Gas	15	36	252	37
Oil	11	28	81	12
Coal	4.3	11	291	43
Other	10	25	51	7.6
Total	40	100	676	100

For a number of countries we have attempted to verify the completeness of the WEPP database. All plants in the year 2000 point source database were included in WEPP, as it also covers closed facilities. But WEPP provided a significant number of additional plants. The WEPP database appears to contain almost all large plants in Europe (which are our primary interest). It can therefore directly replace the old TNO point source database for power plants. Especially coverage for Eastern European countries was improved by this update.

For non-EU(15) countries the old TNO point sources file contained only 389 point sources for power generation. The new point sources file contains 575 power plants for these countries. For Europe as a whole, the 2005 PAREST point source list for electricity generation comprises 5157 units in 1823 plants with a total capacity of 676 GWe. Unfortunately WEPP provides no geographical coordinates. Later in this section it will be discussed how plant coordinates have been determined.

4.2.2 *Usage of EPER*

EPER (http://eper.ec.europa.eu/eper/) is the European Pollutant Emission Register, a European-wide register of industrial emissions into air and water, which was established by European Commission Decision 2000/479/EC. EPER contains self-reported emission data by among others larger electricity generating plants. EPER gives the summed emissions per plant and the geographical coordinates but contains no further information on plant characteristics such as capacities. At the time our research for the PAREST project took place the most recent year available was 2004.

We compared WEPP with EPER, but because of the large amount of companies, we did not compare each plant. Instead we selected the plants in WEPP with the highest capacity (with a minimum of 400 MWe) and we selected the plants in EPER with the largest emission of CO_2 (as a proxy for fuel use), NO_x and SO_2 (with a minimum of 100 times the reporting limit for these three substances together). Of the 1248 WEPP plants located in the European Union and Norway we managed to find the equivalent plant in the EPER database for 605 plants. In some situations, we connected two EPER plants to one WEPP plant or we connected two WEPP plants to one EPER plant. This was necessary because sometimes different units of the same plant were entered individually in EPER or in WEPP for some reason. The degree to which we have been able to establish a link between WEPP and EPER is illustrated by Table 15 and Table 16.
It is concluded that 85% of the total capacity in Platts (in the EU + Norway) is represented in the EPER database (Table 15) and that 85% - 89% of the emissions in EPER are connected to the Platts database (Table 16).

Table 15. Connection of WEPP plants to EPER plants for the European Union and Norway (capacity in MWe)

	Plants	**Capacity**
Connected to EPER	605	332
Not connected to EPER	643	58
Total	1248	390

Table 16 Connection of EPER plants to WEPP (2008) plants (Emissions in Mtonnes)

	Plants	**CO_2**	**NO_x**	**SO_2**
Connected to WEPP	616	1164	1.76	3.56
Not connected to WEPP	671	141	0.31	0.42
Total	1287	1305	2.07	3.98

As mentioned, WEPP contains no geographical coordinates of the plants, so these had to be determined separately. If a connection between EPER plants and WEPP plants was possible, then we used the EPER coordinates for defining the location of the plant. For the other 1218 WEPP power plants in Europe we used Google Maps (see http://maps.google.com) to find the coordinates manually. When it was not possible to find the exact plant location we used the coordinates of the city where the plant is located. These coordinates were found using the Getty Thesaurus (see http://www.getty.edu/research/conducting_research/vocabularies/tgn/) or again Google Maps.

The 2005 PAREST point source database for power generation contains 1823 point sources versus 1276 in the 2000 database. Coverage of smaller sized (e.g. 20 – 100 MWe) facilities (among which CHP engines) and plants in Eastern Europe has improved significantly. We have added new companies that recently entered service and removed closed installations. Thus the new point sources file is up to date and contains more detail than the old point sources file (expansion of 50% in spite of a similar capacity threshold).

4.3 Oil Refineries

Refineries are important sources of SO2 (due to residual-oil fired boilers and incidental H_2S flaring), NMVOC (from fugitive sources), and PM and NOx (from combustion and FCC catalyst regeneration). Other substances are emitted as well. Two databases have been used to update the refineries in the 2000 point source dataset:

- World Refinery Survey, 2006 (WRS, ref Oil & Gas Journal Online Research Centre)
- EPER, European Pollutant Emission Register (http://eper.ec.europa.eu/eper/)

The WRS claims to be a complete survey that includes every oil refinery in Europe. Information for Eastern Europe and Russia seems to have improved significantly during recent years. We have basically replaced the 2000 point sources for refineries by the WRS data. When comparing the 2000 refinery point sources with the new World Refinery Survey it appears that there were not many large changes in Europe. For the EU(15) the 2000 and 2005 dataset is virtually the same, while for Eastern Europe and Russia coverage appears to be better. The WRS contains in total 190 refineries for Europe but the amount of point sources cannot be compared directly with the old 2000 dataset, because sometimes one plant in the WRS database was entered as three separate plants in the 2000 point sources data. Crude capacity as given by WRS was recorded by us as indication of the size of the refinery.

4.3.1 *Usage of EPER for refineries*

EPER (http://eper.ec.europa.eu/eper/) is the European Pollutant Emission Register, a European-wide register of industrial emissions that contains self-reported emission data by among others oil refineries. EPER contains summed emissions per facility/location but no further information on plant characteristics such as capacities. We compared the WRS with the refineries reporting to EPER and connected these refineries, when we were able to. The result of this comparison is presented in Table 17 and Table 18. Note that one facility in EPER can be linked with multiple facilities in WSP and vice versa.

Table 17. Connection of refineries in WRS (2006) to EPER refineries for the EU and Norway.

	Refineries	**Production**
	(#)	10^6 m^3/year
Connected to EPER	101	866.8
Not connected to EPER	9	19.5
Total	110	886.3

Thus 98% of the total capacity in WRS (in the EU + Norway) is connected to the EPER database.

Table 18 Connection of EPER refineries to WRS refineries (emissions in ktonnes)

	Refineries	**CO_2**	**NO_x**	**SO_2**	**PM10**
Connected to WRS	106	139946	181	597	6.46
Not connected to WRS	62	11464	13	29	0
Total	168	148810	194	625	6.46

Thus 93% - 100% of the emissions in EPER are connected to the WRS database.

If a connection between EPER plants and WRS plants was possible, then we used the EPER coordinates for defining the location of the plant. Thus, there were 96 refineries left without coordinates in the whole of Europe. We used three methods to define these coordinates, being the old 2000 dataset, the Getty Thesaurus (for the coordinates of the city; see http://www.getty.edu/research/conducting_research/vocabularies/tgn/) and Google Maps (only if Getty Thesaurus could not provide the coordinates, for the coordinates of the city; see http://maps.google.com).

4.4 Non-ferrous metals production

The non-ferrous metals industry is a modest source for the substances considered in this report. Especially since SO_2 emission is mostly abated to a fairly high degree in Europe. The production and location of primary and secondary aluminium, copper, zinc and lead, and primary nickel has been reviewed. A combination of literature and branch organisation information (e.g. International Zinc Association, World Nonferrous Smelter Surveys, Metal Bulletin Directories) was used to completely update the Non-ferrous metals production. A detailed internal documentation is described in Visschedijk et al. (2010). Starting point for the update was the 2000 point source dataset used in Visschedijk and Denier van der Gon (2005). We have revised this dataset by updating capacity, coordinates (if available) and company names (if necessary). Furthermore, we added new information on the type of process used (if available). If there were multiple data sources available, then we favoured to use the most recent. We used the older data sources only to fill the gaps. When plants in the 2000 overview could not be linked to new information, we checked for name changes. If there had been changes in the name of a company, we used this new name for updating the 2000 dataset. For plants with unknown coordinates we used Getty Thesaurus or Google Maps to find the coordinates of the nearby city. After these steps, the list of non-ferrous metal smelters had only been partly updated. None of the information sources used provided all the information needed. Table 19 presents the results for non-ferrous metal smelters in 2005. Under 'Maintained' all smelters that could not be updated are listed. Note that for the majority of lead smelters no new information could be found.

Table 19: Results of the update of point source information for non-ferrous metal production in Europe

	Total	New	Updated	Deleted	Maintained
Zinc	48	9	28	3	11
Lead	91	2	5	0	84
Nickel	7	6	0	0	1
Copper	69	6	33	5	30
Aluminium	76	2	53	4	21

Total = All point sources in the new point sources file
New = New point sources
Updated = Old point sources with new information
Deleted = Closed companies, deleted from the new point sources file
Maintained = Point sources without new information, but probably still open and maintained in the point sources file

4.5 Iron and steel industry

The iron and steel industry is an important source of PM. Also NO_x and SO_2 are emitted in considerable amounts. The update of the 2000 point source list for the iron and steel industry has been based on the Iron & Steel Works of the World Directory 2007 (MBD, 2007). It includes details of the world's producers of iron, raw, rolled, stainless, alloy, carbon and coated steel.
One of the shortcomings of the MBD is that data on capacities (annual or batch) often lack. In case we used the MBD for updating data on plants that were already present in the 2000 point sources file, we assumed no changes in capacity. If the plants were not yet present an estimate had to be made, when the MBD did not provide the plant's capacity. In some cases the batch capacity of the unit was given (in tons or m^3), which was used to estimate the annual capacity. Factors used to convert batch capacity to annual capacity are listed in Table 20 (2nd column). In case batch capacity was also unknown, we used a default capacity as per Table 20 (3rd column). Table 20 has been based on averages observed for other plants for which characteristics were known.

Table 20. Default process capacities used for estimating missing capacity data in the iron and steel industry

	Conversion factor for batch to annual capacity	**Average annual capacity per installation (ktonnes/unit/year)**
Electric arc furnace	5.5 ktonnes/tonne	550
Blast furnace	0.7 ktonnes/m^3	1250
Oxygen converters	6.3 ktonnes/tonne	1500
Open heart furnaces	0.94 ktonnes/tonne	330
Sinter Plant	10.5 ktonnes/m^2	1900
Coke ovens	8 ktonnes/oven	510

We used the Getty Thesaurus (for the coordinates of the city) and Google Maps (if Getty Thesaurus failed to provide the coordinates of the city) to find the coordinates for the new point sources.

The 2005 PAREST point source list for the iron and steel industry is, in spite of our attempt to update, still largely based on pre-2000 data. However, especially for Turkey, Russia and Eastern European countries a significant improvement could be made. The amount of electric arc furnaces has grown considerably as well.

4.6 Cement production

The cement industry is a source of PM emission. NO_x and, depending on the fuel used, SO_2 may be emitted in significant quantities as well. We have assumed that the bulk of the emission from cement production is caused by clinker production (cement kilns), rather than by cement mills. The point source information therefore only comprises kilns used for clinker production.

The primary information source has been the World Cement Directory 2002 (WCD, 2002). This directory encompasses a worldwide overview of cement production plants. It also includes worldwide maps showing plant locations. WCD (2002) provided kiln capacities as well as the number of kilns per plant.
It has been assumed that the WCD gives a complete list of cement production plants for Europe and it has been used for a major update of this point source category. Compared to the year 2000 cement point source list we have added 224 new plants, updated 215 plants and we have removed 87 plants. The removed plants can be divided in closed plants (2), plants with only mills (10), duplicate plants (5) and plants which were not present in the World Cement Directory (70). For some plants, the annual production capacity was unknown and had to be estimated. Average capacity per kiln varied between 450 and 600 for four countries (Germany, Spain, United Kingdom and Turkey). Therefore an average capacity of 500 kton/kiln was assumed. In some cases only the total annual capacity of the cement mill was given, which we used as an estimate for the total kiln capacity. We assumed 500 ktonnes/year units. The point source list has been expanded with many new plants, especially in the western European countries (Table 21). Finally, we checked some of the removed cement plants that were present in the older year 2000 dataset, but no longer appeared in the WCD (2002). This occurred especially in Switzerland. It was not possible to find specific information about these plants on the Internet, nor were they present in the EPER database. These plants have been excluded from the 2005 dataset but it is not fully clear whether they have been shut down.

Table 21. Result of the point source list update for cement production

	Number of plants	Capacity (ktonnes/year)
TNO 2000 point source dataset	302	324000
TNO PAREST 2005 point source list	439	373000

4.7 Sea harbours

In this study sea ports have been added to the point source dataset for 2005. In harbours storage and handling of bulk goods takes place. Depending on the product this can be a moderate source of PM emission. Harbours are furthermore centres for maritime coastal transport. For sea harbours we used two information sources:

- World Port Index 2008 (WPI 2008)
- Port capacity in the EU(27), Eurostat Maritime transport statistics for goods (gross weight), Annual data for all ports 2008, Eurostat

The WPI contains the location and physical characteristics of and the facilities and services offered by major ports and terminals world-wide (approximately 4300 entries), in a tabular format. All ports in this dataset are given a four-class characterisation of the harbour size. The WPI also provides coordinates of all ports covered. To convert the WPI capacity classification to physical units we used Eurostat data. Eurostat provides detailed turnover data for more than 1200 sea and inland harbours in the EU(27). Eurostat does however not provide geographical coordinates. We have linked the ports in the WPI with the Eurostat data in order to be able to compare these four classes with gross turnover data as recorded by Eurostat. We derived the following relation (Table 22):

Table 22: Relation between WPI (2008) capacity classes and approximated capacity.

WPI capacity class	Description	Approximate capacity (1000 tonnes/year)
L	Large	50000
M	Medium	10000
S	Small	5000
V	Very small	1000

The physical units (tonnes/yr) are necessary for distributing emissions. 1212 Ports are added to the 2005 dataset.

4.8 Coal mining, oil and gas production, chemical industry and airports

No update of point sources was made for:

- Coal mining, oil and gas production: These activities are significant sources of PM, CH_4 and NMVOC. A first screening revealed that the locations of coal mines, oil fields and gas fields have not changed substantially during the last decade. Therefore these point sources will not be updated.
- Chemical Industry: This industry is a moderate source of fugitive NMVOC emission. The point source list available for 2000 provides only a rough indication of the spatial distribution. In this report the chemical industry is regarded as a whole because so many different activities usually take place on the same location. Furthermore we were not able to find any useful new information about recent changes in plant locations across Europe. Locations are not expected to have changed drastically.
- International airports: Airports are a source of NO_x, CO and to a lesser extent NMVOC and PM. Locations and capacities are not expected to have changed much during 2000 to 2005, so no update has been made for airports.

5 Area Sources

An area source is a source that emits along a line or over a surface that is larger than the grid cell size. Area sources usually consist of a large number of small sources that are collectively processed. In this report all emission sources that are not regarded a point source are treated as an area source. All mobile emission sources are for instance regarded as area sources, just like emission by households and emission in agriculture. Area sources are spatially distributed based on a proxy. This is a parameter with a known spatial distribution that is used to approximate the source actual distribution.

All area sources in this study are spatially distributed based on the distributions of one or more of the following parameters:

- Urban population
- Rural population
- Total population
- Highways and other main roads
- High-pressure gas network
- Railroads
- Shipping:
  - Sea
  - Coastal
  - Inland
- Arable land
- Farm animals (livestock):
  - Chicken and poultry
  - Cattle
  - Pigs
  - Other animals

The PAREST project has brought about a major update and expansion of proxy data. A detailed documentation for internal use is given in Visschedijk et al. (2010). The major area source categories are briefly discussed in this chapter.

5.1 Distribution of urban, rural and total population

Population distribution is a major component in gridding emissions, as many anthropogenic sources of emission are allocated with total population per raster cell as a proxy. Population is also used as a default proxy for anthropogenic sources that are expected to follow population distribution but for which we do not have specific data . In the PAREST project population distribution is based on two related datasets from the Center for International Earth Science Information Network (CIESIN, http://sedac.ciesin.columbia.edu/gpw/).

1. Gridded Population of the World (GPW, version 3) (CIESIN 2008a) depicts the spatial distribution of human population across the entire globe for the year 2005. Population count is gleaned from various levels of official administrative data and transformed with a simple areal weighting scheme in a longitude-latitude grid format of 2.5 arc minute resolution (or 1/24th of a degree). This corresponds with approximately 5 kilometers at the equator. The result is a spatially uniform and consistent worldwide dataset.
2. For a select number of emission types an additional distinction between urban and rural population is necessary. The second dataset, GRUMP (Global Rural-Urban Mapping Project alpha version, for the year 2000) (CIESIN 2008b), is used to make this distinction. GRUMP may be viewed as an extension of GPWv3 where the resolution is higher (30 arc seconds or 1/120th of a degree) and urban extents are systematically taken into account. Population and spatial data from a human settlements database and satellite imagery (night-time-lights, where necessary supplemented by other geographic datasets) are used in conjunction to determine which areas and subsequently which part of the population may be classified as urban. It is the urban extent "mask", basically an urban-rural label for each grid cell, that is used in the gridding database.

The related CIESIN urban-rural population data as provided by CIESIN is not used because of gaps in the coverage. After various processing steps we have constructed urban and rural population maps (Figure 2 and Figure 3) on the PAREST resolution. Total population (not shown) is defined and calculated as the sum of rural and urban population.

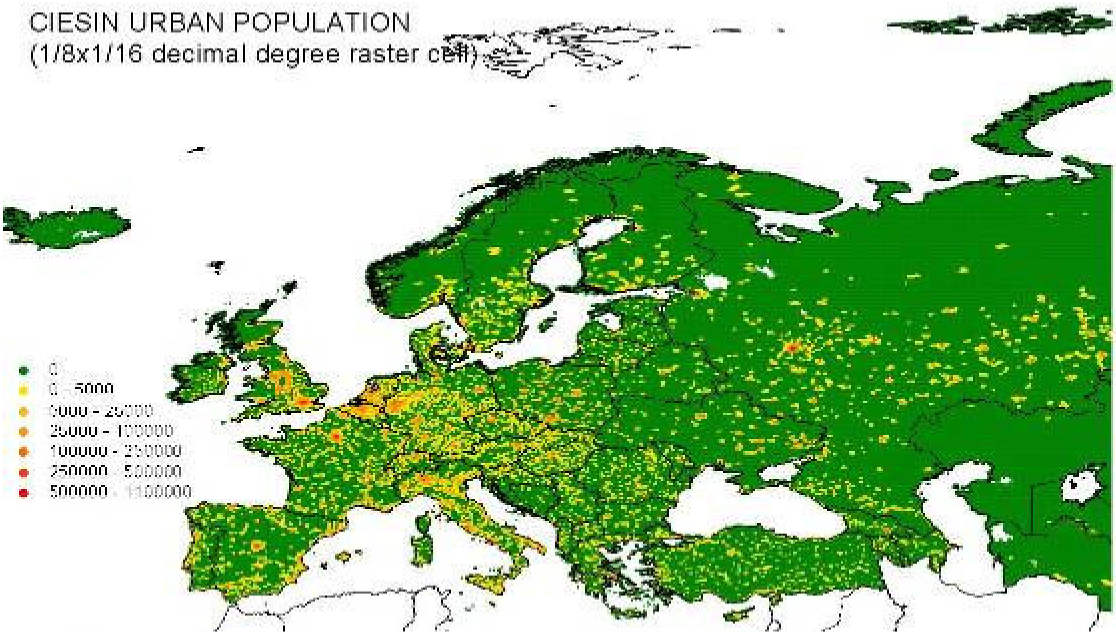

Figure 2: Derived "urban" population map on 1/8 x 1/16th degree resolution

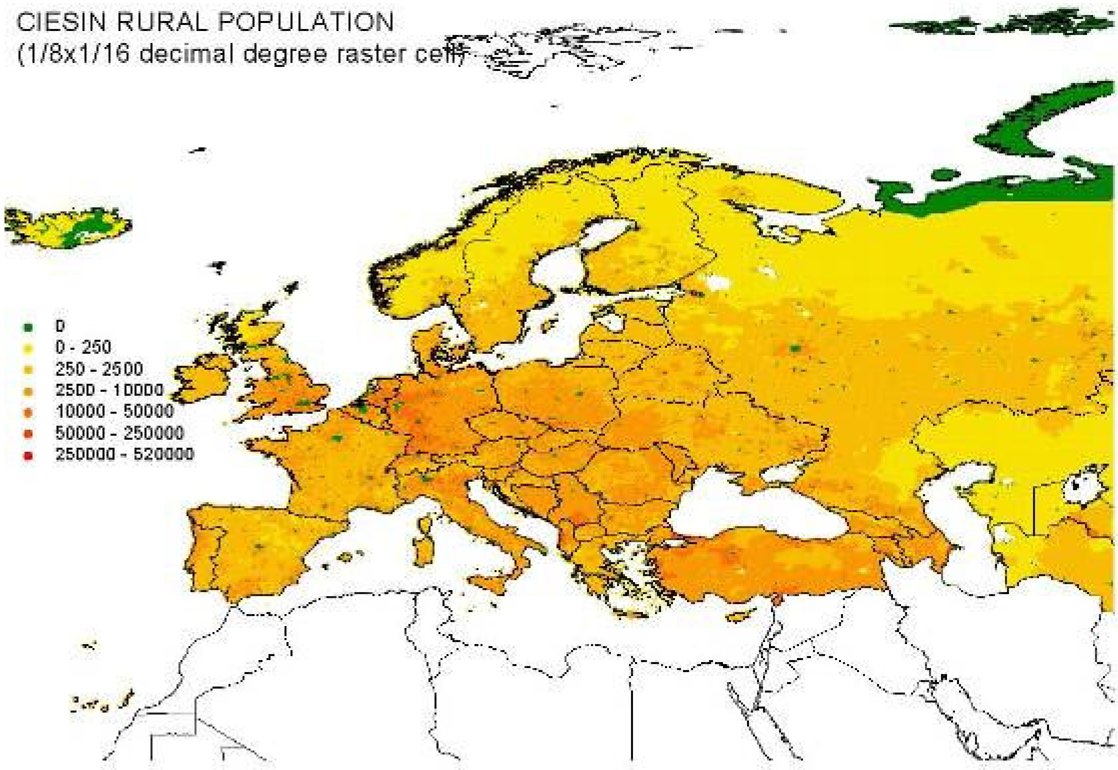

Figure 3: Derived "rural" population map on 1/8 x 16th degree resolution

5.2 Road transport

Road transport is one the biggest sources of emission of NO_x, CO, NMVOC and PM. It is imperative that for this source emissions are distributed as accurately as possible. Key components in the spatial distribution are the locations and traffic intensities of major roads. Both these parameters are available from the Trans-tools project, in which TNO Automotive is a partner. Trans-tools is a European transport network model covering both passenger and freight transport, as well as intermodal transport (Ref Trans-tools Final Report) (see also section 3.5.2). One of the outputs of Trans-tools is the Traffic Flow Map that is based on modelled transport demand and network loads. Based on among others the earlier ETIS database (http://www.iccr-international.org/etis/index.html) and the VACLAV model (http://www.iww.uni-karlsruhe.de/reddot/288.php), Trans-tools gives a traffic intensity for light and for heavy duty vehicles, for every road section. Trans-tools is intended for modelling inter-urban transport and only regards motorways and other main roads. Urban roads that are principally used for shorter ranges are disregarded by the model. The Trans-tools model offers a valuable tool for the distribution of road traffic emission, and the Traffic Flow Map forms the basis for the spatial distribution of long and medium range road transport emissions. For short range transport population is used as a proxy.

The Traffic Flow Map comprises a network of highways and major rural roads that covers Europe, except Turkey, for which only the European part is included, Ukraine en Russia that also have only partial coverage and the Caucasus countries (Armenia, Azerbaijan and Georgia) plus Cyprus and Malta that are not covered at all (see Figure 4 for coverage of the Traffic Flow Map). We have extended the Traffic Flow Map to cover the whole of Turkey, Ukraine, Russia and the Caucasus countries. This has been done manually using GIS, based on the UNECE European road map (http://www.unece.org/stats/trends2005/transport.htm) that has a level of detail comparable to Trans-tools but covers in full the countries mentioned above. In this operation Turkey and Russia are completely replaced by the UNECE map, whereas for Ukraine the Trans-tools network is extended. For Cyprus and Malta we have no data on major roads. The result of the network extension except Ukraine is shown in Figure 5.

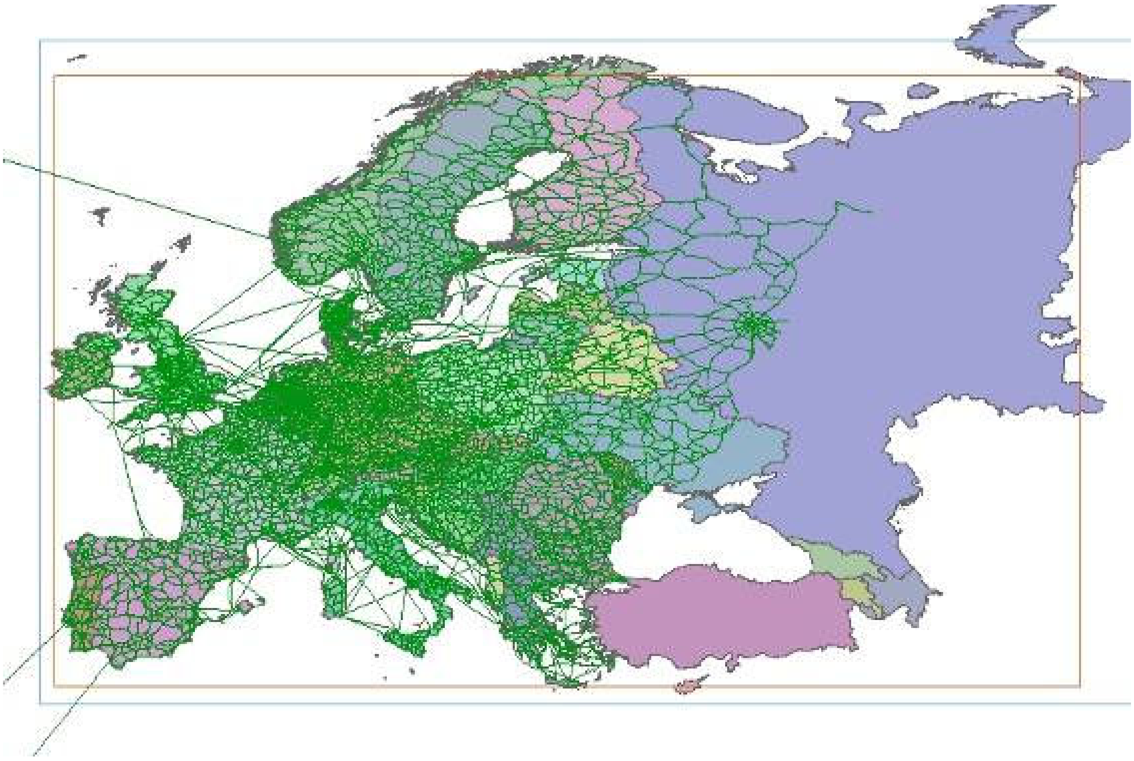

Figure 4 Road map for Europe from the EU Trans-tools project to be used for non-urban traffic (Sea ferries are also shown but not used in PAREST)

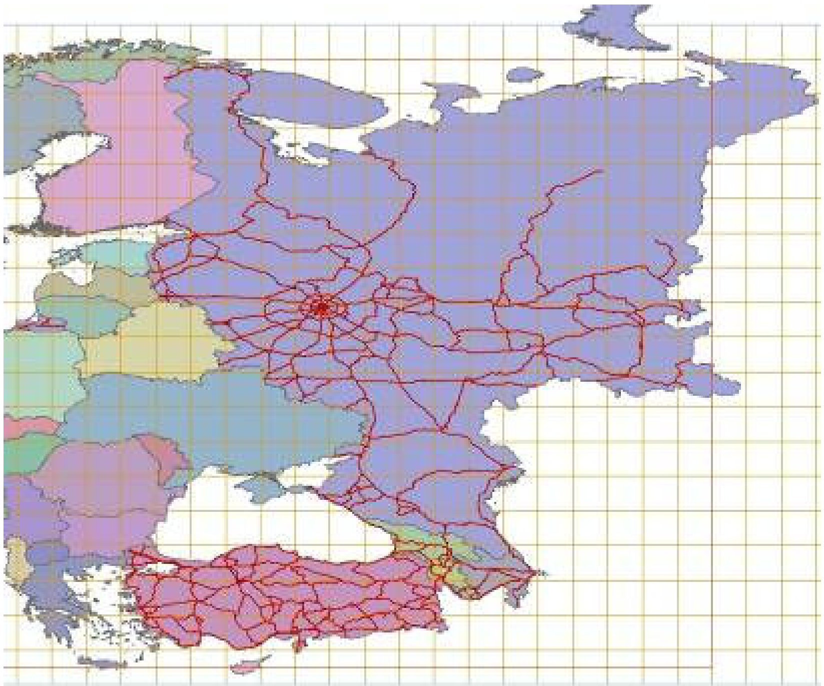

Figure 5. The modified road map for major roads for Turkey, Ukraine, Russia and the Caucasus countries, manually drawn based on UNECE European road map (http://www.unece.org/stats/trends2005/transport.htm)

The Trans-tools Traffic Flow Map includes car and truck traffic intensities per road section. We have calculated the total vehicle kilometres driven per country by multiplication of the intensity with the length of the road section. The calculated vehicle kilometres have been compared to highway and rural vehicle kilometres as derived from other literature sources and appear to show a reasonable consistency with other information. The vehicle kilometres driven on the road sections that we have added have been estimated by overlying those road sections in GIS with population. We have assumed that the inter-urban transport is proportional with population, provided that the population resolution is lowered to 1 x 1 degree lon-lat. So within each 1 x 1 degree cell the distribution of traffic intensity is uniform. For Ukraine we have extended the existing Trans-tools network instead of replacing it and have again assumed that for the new roads the traffic intensity is proportional to population on a 1 x 1 degree lon-lat grid. Furthermore we assumed that based on the ratio between the total population in the covered area versus the non-covered area, the amount of vehicle kilometres in the area covered by Trans-tools makes up 50% of the total vehicle kilometres driven in the Ukraine.

5.3 High pressure natural gas transportation

In certain areas in Europe CH_4 emission from loss during transportation of natural gas can be considerable (see section 2.2). Population might serve as a proxy for the low pressure network, but it is unsuitable to distribute emission from the high pressure network since locations of gas fields and human settlements are not primarily related. The location of the high pressure natural gas transport network has been derived from a map developed within the European INOGATE project. INOGATE[1] is an international energy co-operation programme between the European Union (EU), Turkey and countries of the NIS, with the exceptions of the Baltic States and the Russian Federation..The INOGATE map of natural gas pipelines after we have converted it to the longitude – latitude based PAREST grid is shown in Figure 6.

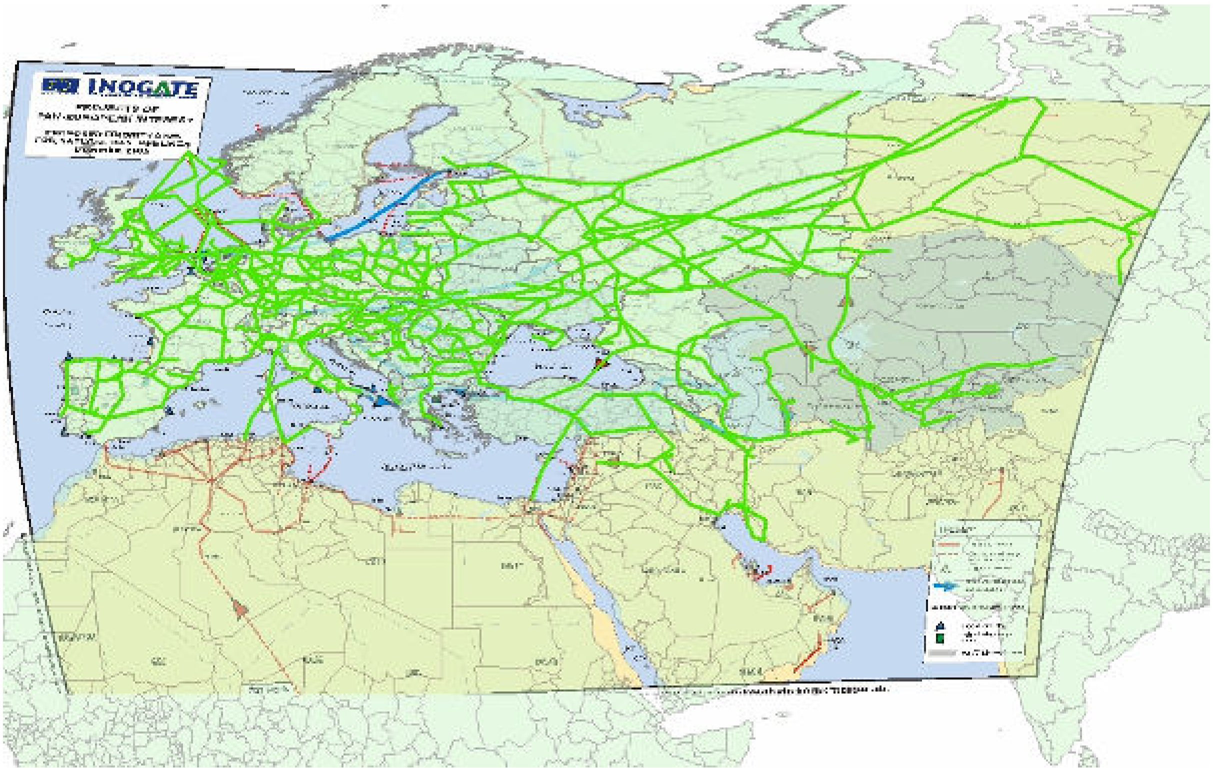

Figure 6 The INOGATE map of natural high pressure natural gas pipelines, converted to the PAREST lon-lat raster in WG84 projection

[1] For more information we refer to http://www.inogate.org/

5.4 Agriculture

5.4.1 Distribution of livestock

Emissions from farm animals through enteric fermentation and manure are very important CH_4 and NH_3 sources. Livestock quantities are used for allocation of these emissions. The Gridded Livestock of the World (GLW) dataset from the Food and Agriculture Organization (FAO) is used as input. This dataset is based on national census data and the corresponding administrative boundaries from the year 2000. Livestock numbers are converted into livestock densities per square kilometre, taking into account areas unsuitable for (different types of) animals and environmental variables. The results are available from the FAO on a raster format of 1/20*1/20th degree lon-lat and completely cover the PAREST study area.

For usage in PAREST we have selected the densities for cattle, sheep, goats, pigs and poultry. In conjunction with the area of each cell (in square kilometers) the livestock density is converted back into the total number of animals per cell. This result is subsequently aggregated to 1/8*1/16 degrees, and the fraction of each animal per cell per country is determined. As an example Figure 7 shows a part of the spatially distributed NH_3 emission from farm animals.

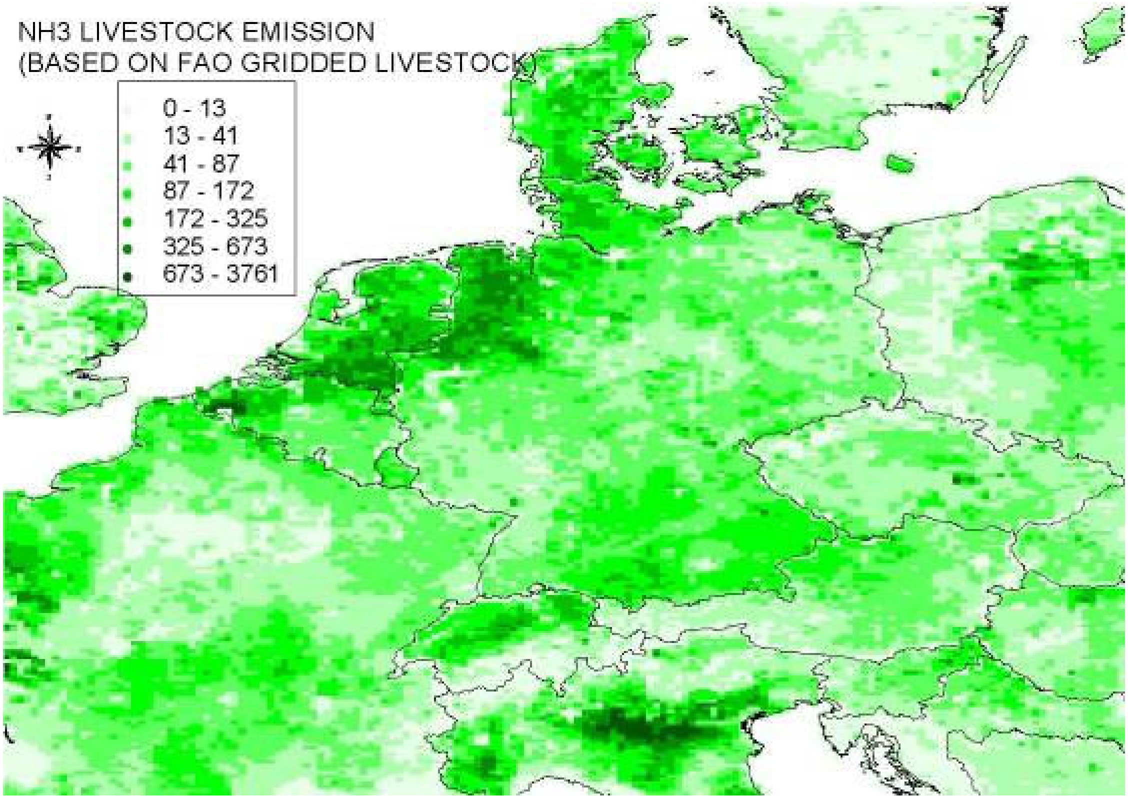

Figure 7: Detail of gridded 2005 NH_3 emission due to livestock (tonne/cell/yr)

5.4.2 Distribution of arable land

In PAREST, land use data such as the distribution of arable land, are used to allocate certain types of agricultural emission. The premier dataset used for this purpose is CORINE land use (part of the "Coordination of Information on the Environment" programme; http://dataservice.eea.europa.eu/dataservice/.), currently under the auspices of the European Environment Agency (EEA). CORINE is supplemented by the PELINDA dataset (de Boer et al., 2000) and a global land cover data base (Wilson and Henderson-Sellers, 1985) for two different areas outside the EU27. The need for combining land use data arises from incomplete coverage for the total model domain by the preferred CORINE data set (Figure 8) The land use datasets and processing by TNO is discussed in more detail in an internal documentation report by Visschedijk et al. (2010).

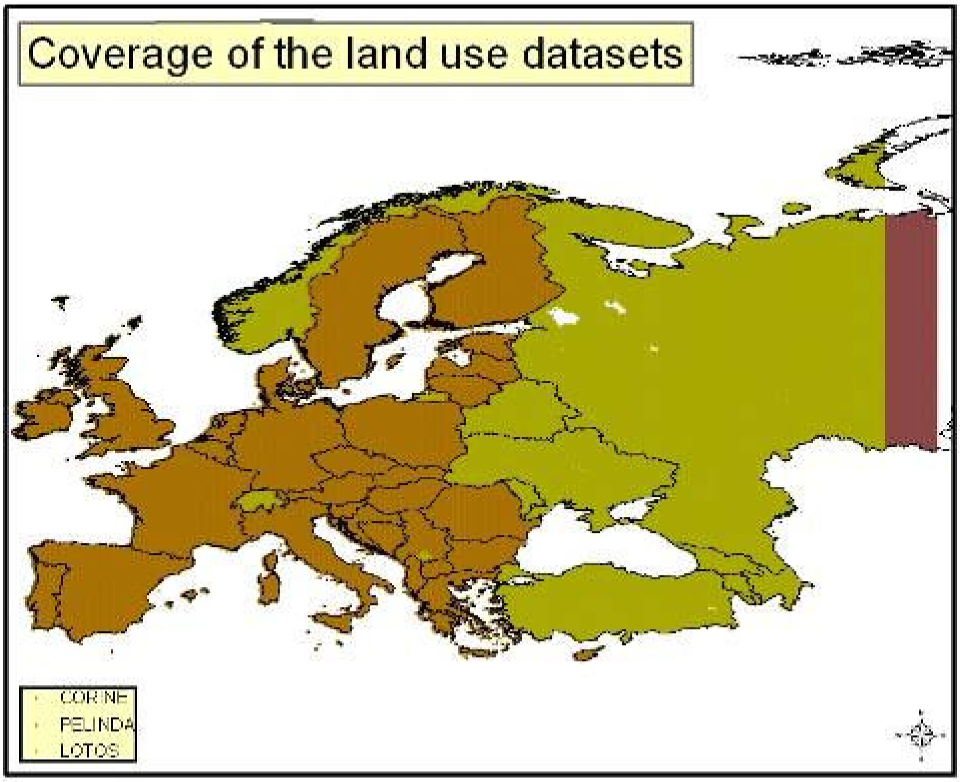

Figure 8 The various datasets used in PAREST for different areas in Europe (brown = CORINE, tan = PELINDA and purple = Wilson and Henderson-Sellers, 1985)

5.5 International shipping

International sea shipping is a very important source of air pollutants, especially SO_2, NO_x and PM. These emissions take place on international waters and are not included in country-submitted emission data.

For the spatial distribution of emissions from sea shipping we have used gridded data of sea shipping tracks from EMEP (Vestreng et al., 2003, Entec, 2002). The data is available on EMEP's 50 x 50 km grid (see http://www.emep.int/index_model.html) and covers the Baltic Sea, Black Sea, Mediterranean Sea, North-East Atlantic Ocean and North Sea. The EMEP 50x50 km grid has been converted with a Fortran programme to 1/8 x 1/16 degrees longitude-latitude (lo-lat). To achieve this, each 50 x 50 km cell was first disaggregated onto much smaller cells and than re-aggregated in lon-lat coordinates to 1/8 x 1/16 degrees.

For the North Sea only, the 50 x 50 km emissions have been redistributed on a finer grid based on a detailed map of shipping traffic on the North Sea, which roughly reaches from -4 to 13 degrees longitude and 44 to 60 degrees latitude (MARIN, 2003). This map has been converted from the original 8 x 8 GENO grid to the PAREST resolution, once more by disaggregation and subsequent re-aggregation. 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 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) due to the coarse 50 x 50 km grid, total emission from shipping will be conserved. The detailed map for the North Sea contains intensity of total sea traffic (sea miles travelled summed for all vessels, not fuel use) that however provides an acceptable base for allocating the shipping emission. Figure 9 shows the spatially distributed emission of sea ships for a part of Europe centred around the North Sea. There are major routes visible in the Mediterranean and Atlantic with local maxima around Gibraltar and in the Channel. There is furthermore heavy traffic along the Dutch coast, in the channel between the North Sea – Eastern Sea and along the Danish North East coast.

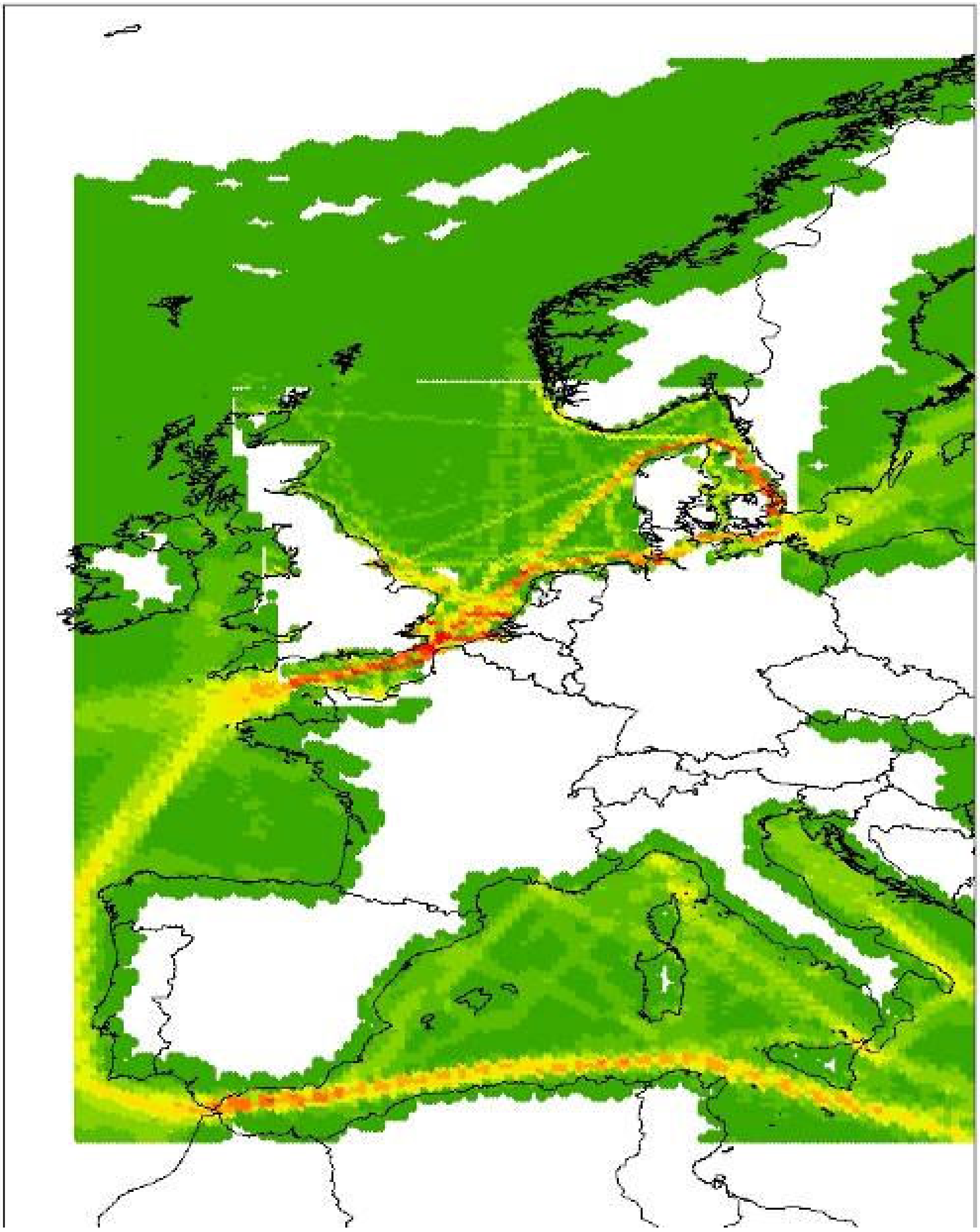

Figure 9: Example of shipping tracks and intensity of emissions for part of the domain

5.6 Rail ways

Diesel-powered rail transport is a moderate source of NO_x and PM. In the PAREST project this emission has been distributed over the European rail network (Visschedijk et al., 2010). The emissions are distributed on a country basis and equally distributed over the rail network. A more detailed split is unreliable as we lack information of train kms on the individual tracks by electric rail transport vs diesel rail transport. For countries where the rail network was incomplete or missing, the emissions have been gridded by population.

6 Results

The sequential steps described in the previous sectors result in high resolution gridded emission maps for the year 2005 that can be used to model air quality. First we discuss the emission maps by substance. Next a comparison for the point source representation in the TNO PAREST maps is compared with the European Pollutant Emission Register (EPER).

6.1 Emission maps by substance for 2005

6.1.1 NO_x

PAREST spatially distributed NO_x emission from all source categories on the 1/8th x 1/16th grid is shown in Figure 10. The various major area sources for NO_x can clearly be distinguished in Figure 10: the road network, population centres with also high emission from road transport and mobile machinery (in e.g. construction), inland waterways and sea shipping routes. For shipping it is easy to see the difference in available resolution in the underlying data for the North Sea and the other international waters (e.g. compare the Norwegian South coast with the North-West coast) because two different resolution maps were used as discussed in 5.5.

The 1/8th x 1/16th degree (~ 7 x 8 km2) is a high resolution that is desirable for modelling but has certain disadvantages for visual presentation of emissions for the whole study area. This way of presenting can be misleading because e.g., road locations can appear as lines so thin that they are hardly distinguishable anymore. Furthermore, point sources become very small spots on the map and despite their high emissions in one grid cell cannot be seen in the map due to limitations of the pixel and printing resolution. This problem can be by-passed by making a coarser grid map for presentation purposes. This is achieved by deliberately increasing the grid cell size to a resolution of ½ x ¼ degree (Figure 11).

The NO_x emissions as depicted in Figure 11 give a more clear and objective presentation of the emissions because grid cells with high emission in absolute terms are clearly visible. Important point sources can now be seen as red squares, while the resolution is still high enough for major roads to be seen as important area sources. Especially emissions in the Rhein-Ruhr area, the Netherlands and Belgium are high. However, Figure 11 does not give the real resolution and when comparing with Figure 10 it can be seen that especially line sources like the shipping tracks in the North sea are in fact more accurate than they appear in Figure 11. Since also for other substances it is important to properly represent the point sources we will show the emission grids on ½ x ¼ degree lon-lat grid (~25 x 25 km^2). However, it should be kept in mind that this is not the resolution that is available for modelling.

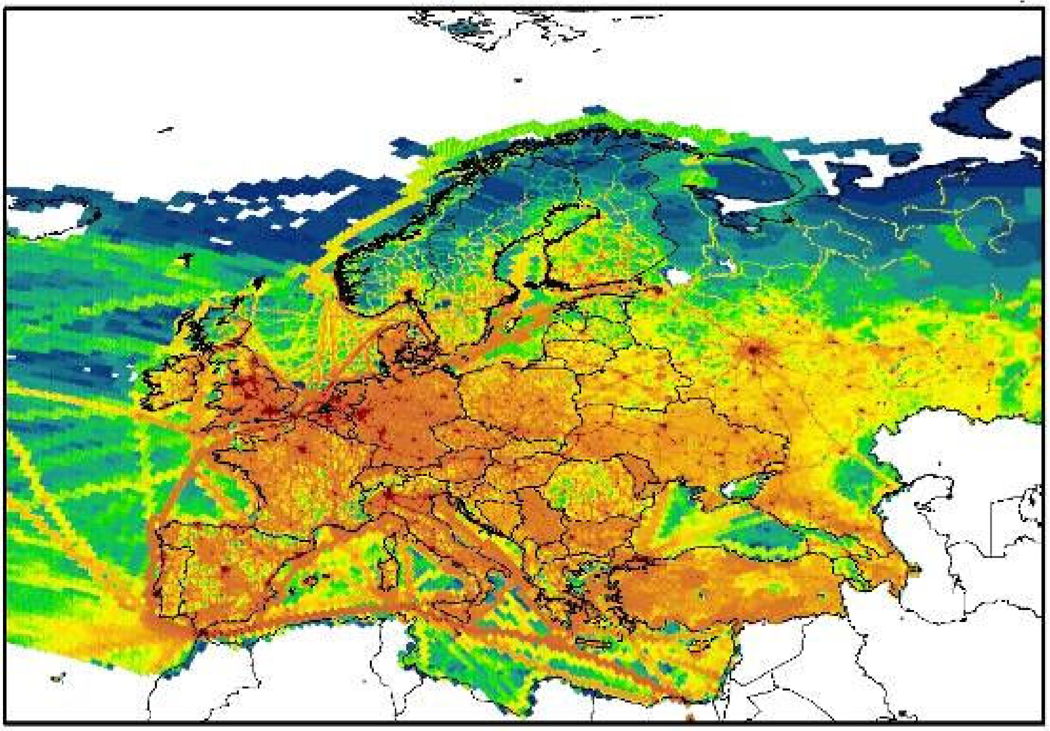

Figure 10 TNO PAREST spatial distribution pattern for NOx emission on the 1/8th x 1/16th degree lon-lat PAREST grid

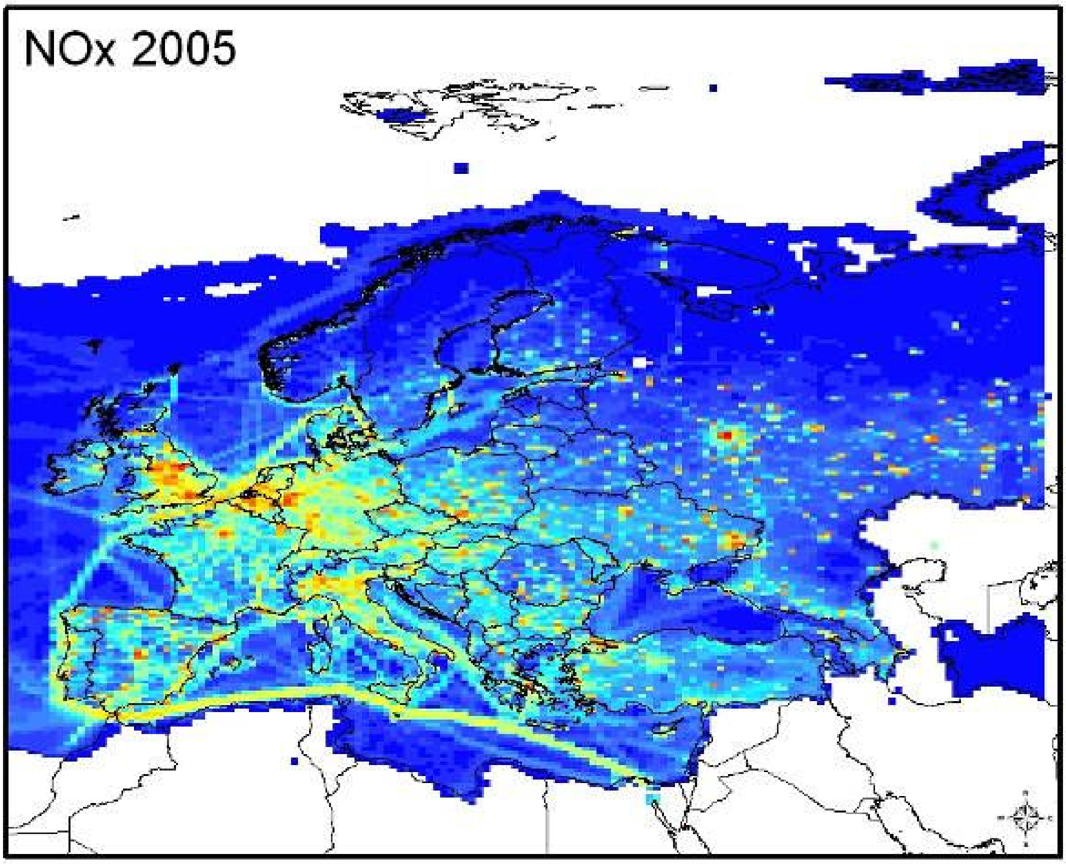

Figure 11 TNO PAREST spatial distribution pattern for NOx emission on the coarser 1/2 x 1/4 degree lon-lat grid

6.1.2 *PM2.5*

PM2.5 encompasses the particulate matter that is most prone to long range transport. PM2.5 from surrounding regions can significantly contribute to ambient PM concentrations in Germany. Point sources and area sources can be distinguished in the emission distribution map (Figure 12). The map illustrates the road densities in Western Europe and population and point sources in Central and Eastern Europe. Previously we saw the highest NO_x emission in and around Germany, for PM2.5 the emission seems to have other hotspots however. Central and Eastern Europe are more important (mostly due to residential coal use and high point source emissions). France has a relatively high PM2.5 emission that is related to the reported high PM2.5 emission from residential wood combustion. Besides France, the Western European countries do not stand out as much as they do for NO_x (compare Figure 11 and Figure 12).

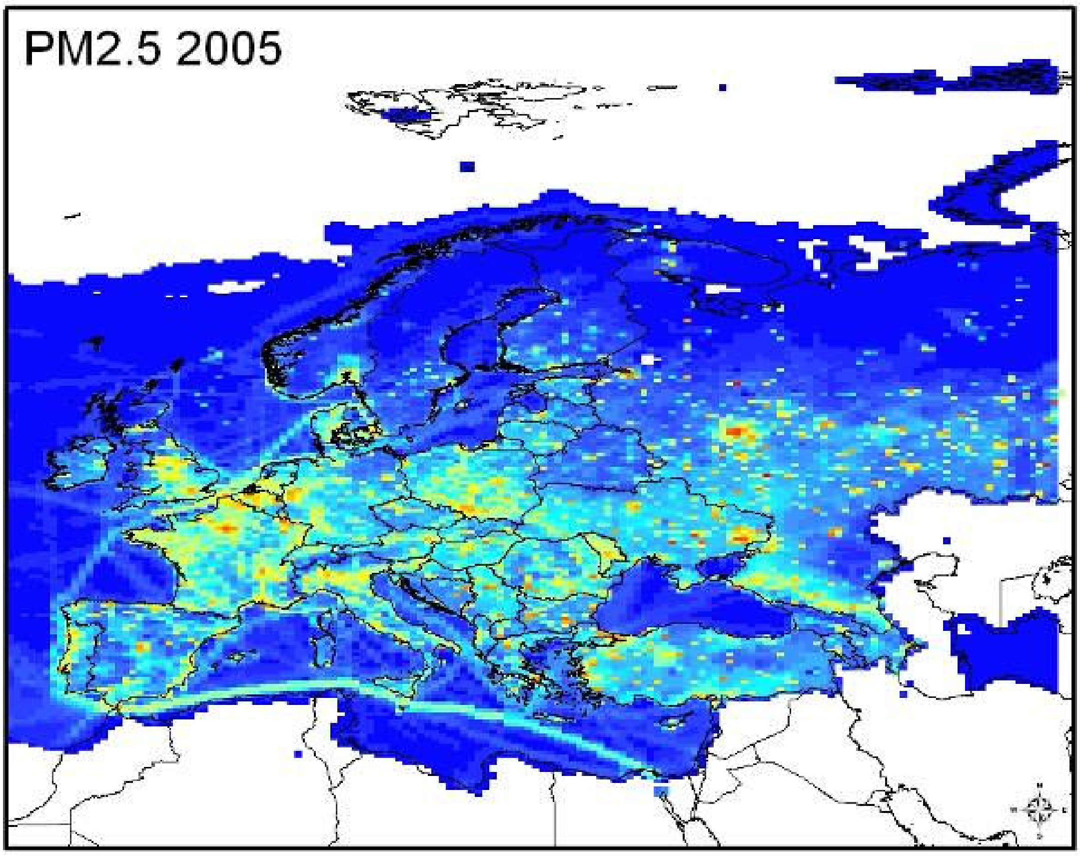

Figure 12 TNO PAREST spatial distribution pattern for PM2.5 emission on the coarser ½ x ¼ degree lon-lat grid.

6.1.3 PM10

The distribution of PM10 emission across Europe for 2005 is shown in Figure 13. The PM10 distribution is related to PM2.5, but there are some differences. The transport sector is less dominating in the PM10 map compared to the PM2.5 map (Figure 12). This is because other sources contribute significantly to the coarse fraction of PM10 (PM2.5-10). Especially important agricultural (animal husbandry) regions such as Brittany can be recognised. When comparing the maps for PM2.5 and PM10, one may get the impression that PM10 emission is lower but it should be noted that maps only show the spatial distribution pattern. So overall the PM10 emission is higher than PM2.5 but PM2.5 has less gradients than PM10 because it is more combustion related, which is omnipresent in road transport and residential combustion.

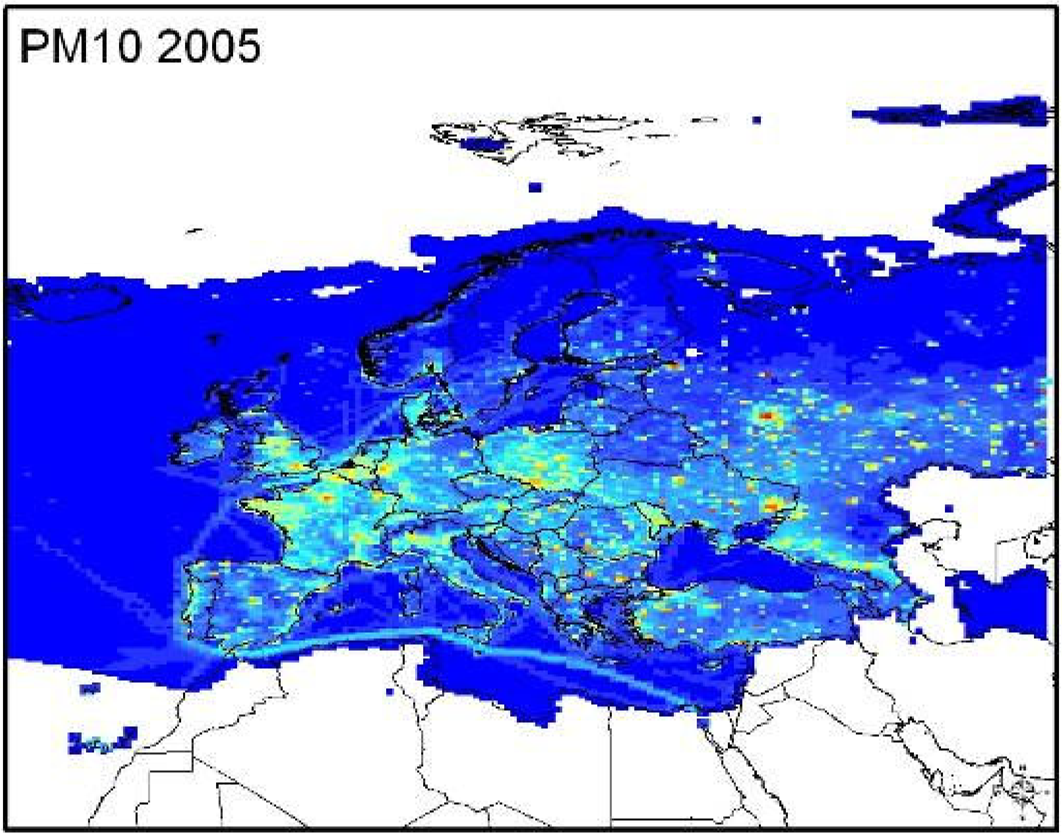

Figure 13 TNO PAREST spatial distribution pattern for PM10 emission on the coarser ½ x ¼ degree lon-lat grid

6.1.4 SO_2

SO_2 is an example of a substance which is dominated by point source emissions, especially the combustion of coal and residual oil (Figure 14). These fuels are primarily used in large combustion plants and in sea shipping. Large combustion plants in this respect are oil refineries and power plants, both of which are treated as a point source in the emission data base. The dominance of point sources is clear in Figure 14, and sea shipping routes also stand out clearly. Diffuse emission patterns due to area sources are limited and occur only in some countries (e.g. Poland, Turkey) where coal is also used in households.

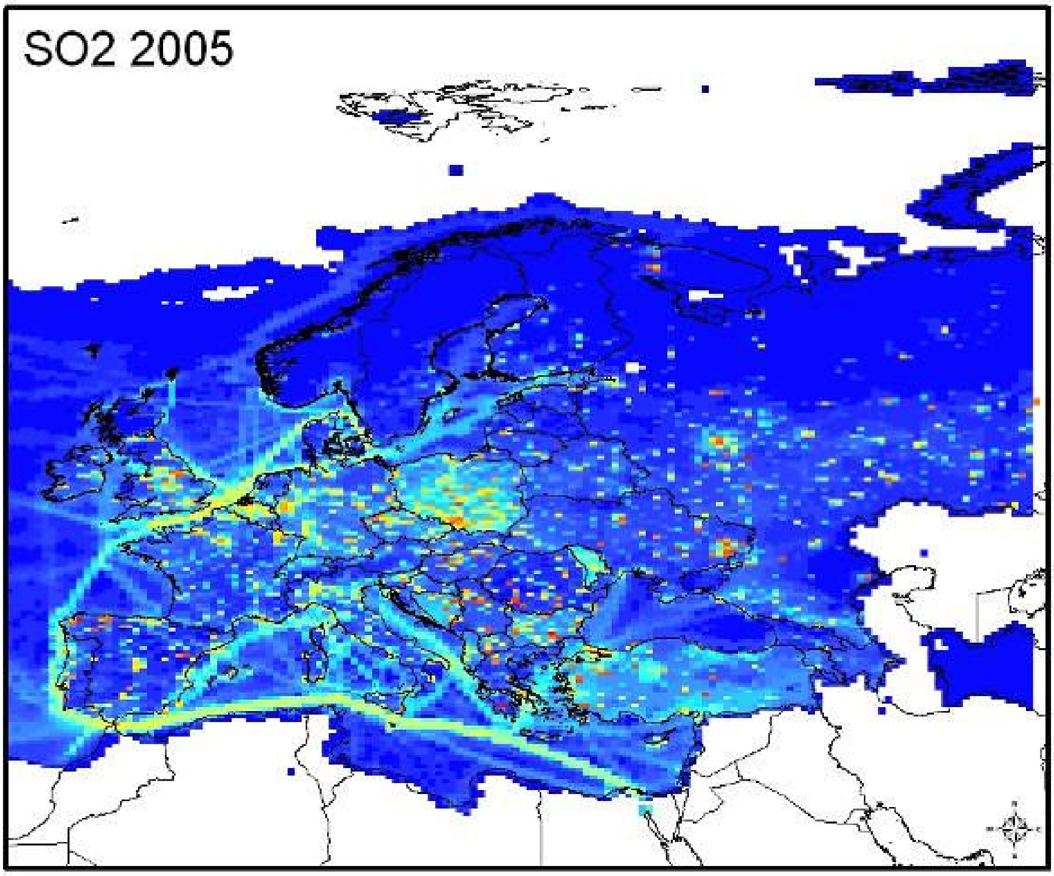

Figure 14 TNO PAREST spatial distribution pattern for SO_2 emission on the coarser ½ x ¼ degree lon-lat grid

6.1.5 *NMVOC*

The spatial distribution of fugitive NMVOC sources (e.g. solvent use and gasoline evaporation) is strongly related to population (Figure 15). Another NMVOC source with the diffuse distribution pattern of population is residential combustion of wood and coal. Point sources for NMVOC are for instance oil production sites in the North Sea and in Western Siberia.

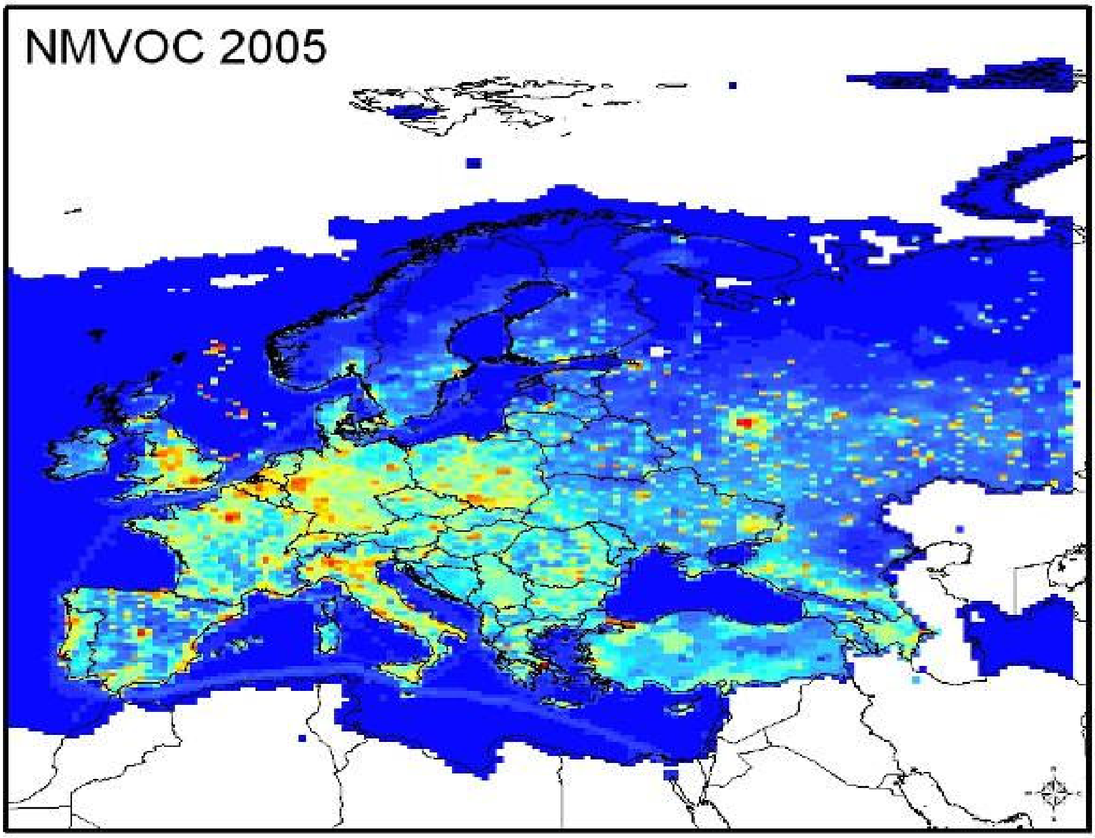

Figure 15 TNO PAREST spatial distribution pattern for NMVOC emission on the coarser ½ x ¼ degree lon-lat grid

6.1.6 CO

CO emission is largely caused by residential combustion of wood and coal and therefore a strong link with population can be observed in Figure 16. Another important CO source is road transport but the location of major roads like highways is not obvious in Figure 16.. CO emission is highest under urban driving conditions and urban traffic emission is distributed according to population.

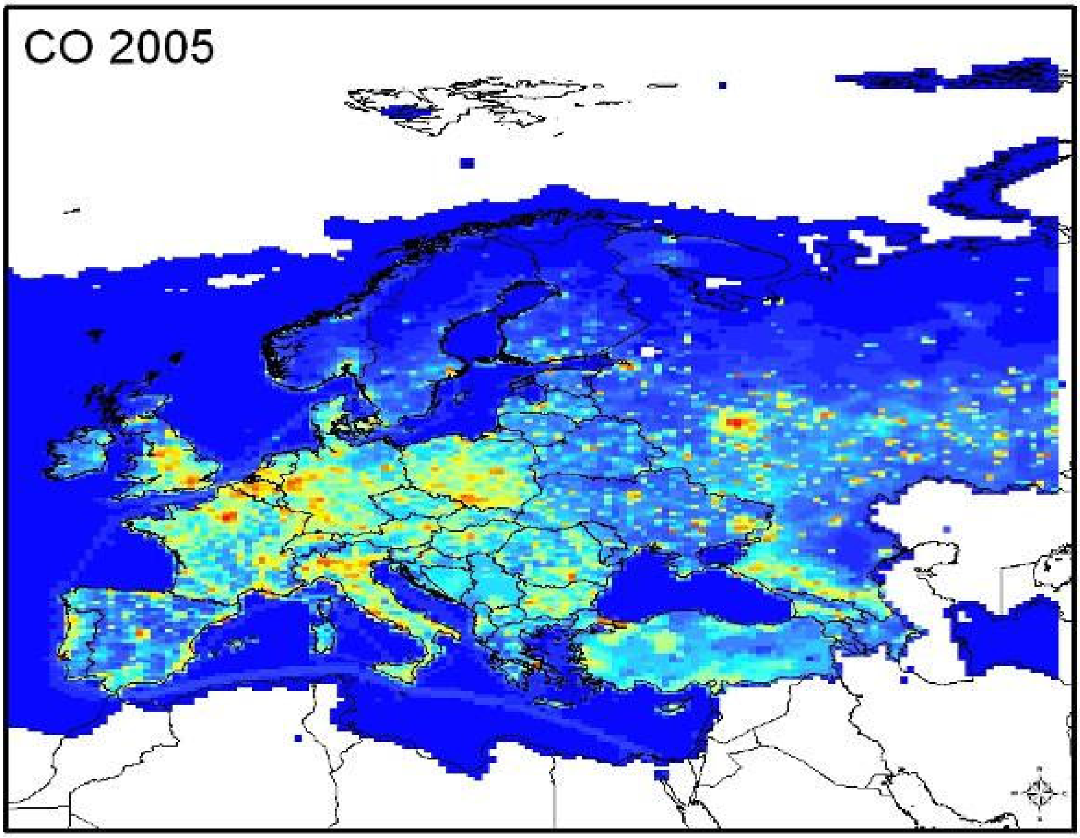

Figure 16 TNO PAREST spatial distribution pattern for CO emission on the coarser ½ x ¼ degree lon-lat grid

6.1.7 *CH_4*

For CH_4 the link to population is much weaker compared to some previous pollutants like NOx or PM. The only significant CH_4 source that is distributed by population (in absence of better data) are landfills. In Figure 17 a link with farm animal population can be observed instead: the Netherlands' South-East, the Po Valley in Italy and Brittany in France stand out. Fossil fuel production sites like underground hard coal mines and oil production facilities are a third major source of CH_4. Both sources can be distinguished as point sources. Especially in Central and Eastern Europe and Russia leakage from the low pressure natural gas distribution network is a major CH_4 source as well. This source follows urban population and appears as a point source in Figure 17. In Russia, there is also significant leakage from the high pressure natural gas transportation network as well. This emission is distributed according to the high pressure gas network that can be seen as line shaped patterns.

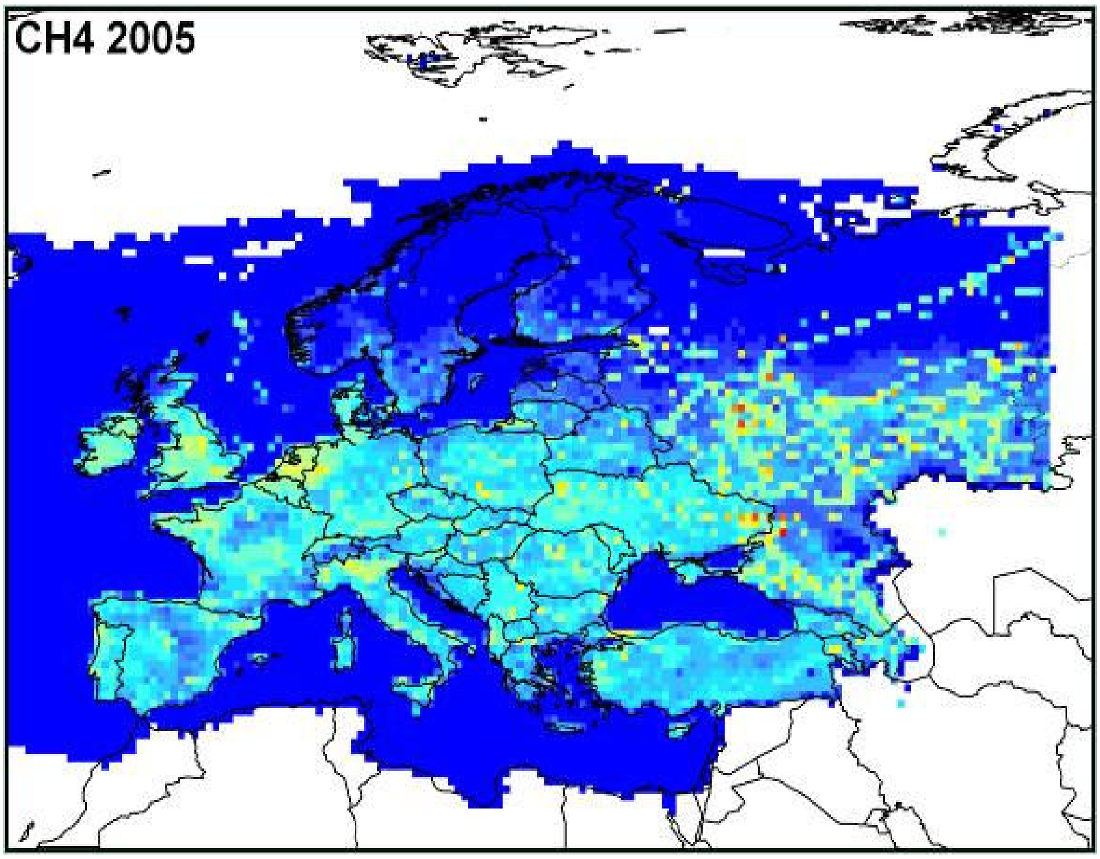

Figure 17 TNO PAREST spatial distribution pattern for CH_4 emission on the coarser 1/2 x 1/4 degree lon-lat grid

6.1.8 *NH_3*

NH_3 emission is dominated by animal farming and important regions in this respect are the Netherlands' South-East and the adjacent area in North West Germany across the Dutch-German border, the Po Valley in Italy and Brittany in France (Figure 18). There is no link with population, shipping routes, major roads or point sources of any kind.

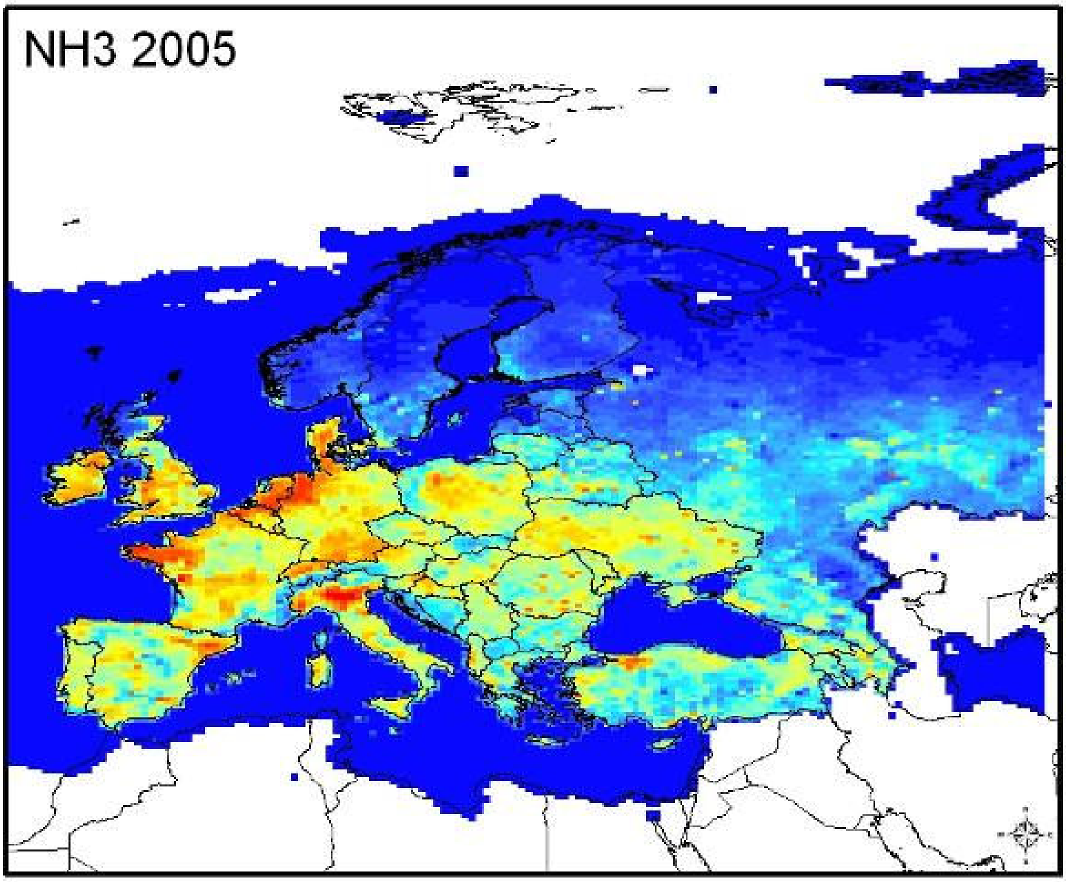

Figure 18 TNO PAREST spatial distribution pattern for NH_3 emission on the coarser 1/2 x 1/4 degree lon-lat grid

6.2 Comparison with the European Pollutant Emission Register (EPER)

TNO has updated and overhauled its point source emission and allocation data. For part of the domain another source of point source information exists; the European Pollutant Emission Register (EPER). EPER was the first European-wide register of industrial emissions into air and water, which was established by a Commission Decision of 17 July 2000.

The first reporting year of EPER was 2001 and information was collected on the annual emissions of approximately 9200 industrial facilities in the EU-15 and in Hungary and Norway. The second reporting year was 2004 and includes data from approximately 12 000 industrial facilities in the EU-25. The EPER data has been published on a website (http://eper.ec.europa.eu/) which is hosted by the European Environment Agency (EEA). EPER is the predecessor of The European Pollutant Release and Transfer Register (E-PRTR). Although E-PRTR is the new Europe-wide register and replaces EPER some initial checks showed that it was (at the time when this comparison was made: 2008-2009) less complete than the EPER reporting in 2004. Therefore, the comparison with the TNO-PAREST point source emissions is made with EPER and not with the E-PRTR.

The comparison is made for SO_2 and PM10. SO_2 is truly dominated by point sources emissions while PM10 has an important point source component.

6.2.1 *SO_2*

SO_2 emission in Europe is dominated by point sources such as coal/residual oil-fired combustion plants (in power plants and oil refineries) and H_2S flaring (in oil refineries). The sector Energy transformation (power stations and combustion in oil refineries; SNAP1) is therefore one of the most important sectors of SO_2 emission. The SO_2 emission by power stations and oil refineries according to EPER is shown in Figure 19. High emission can be observed in Spain, UK, Greece and in the Central European countries Poland, Slovak Republic and Hungary. However, a big section of Europe is missing in EPER (Figure 19).

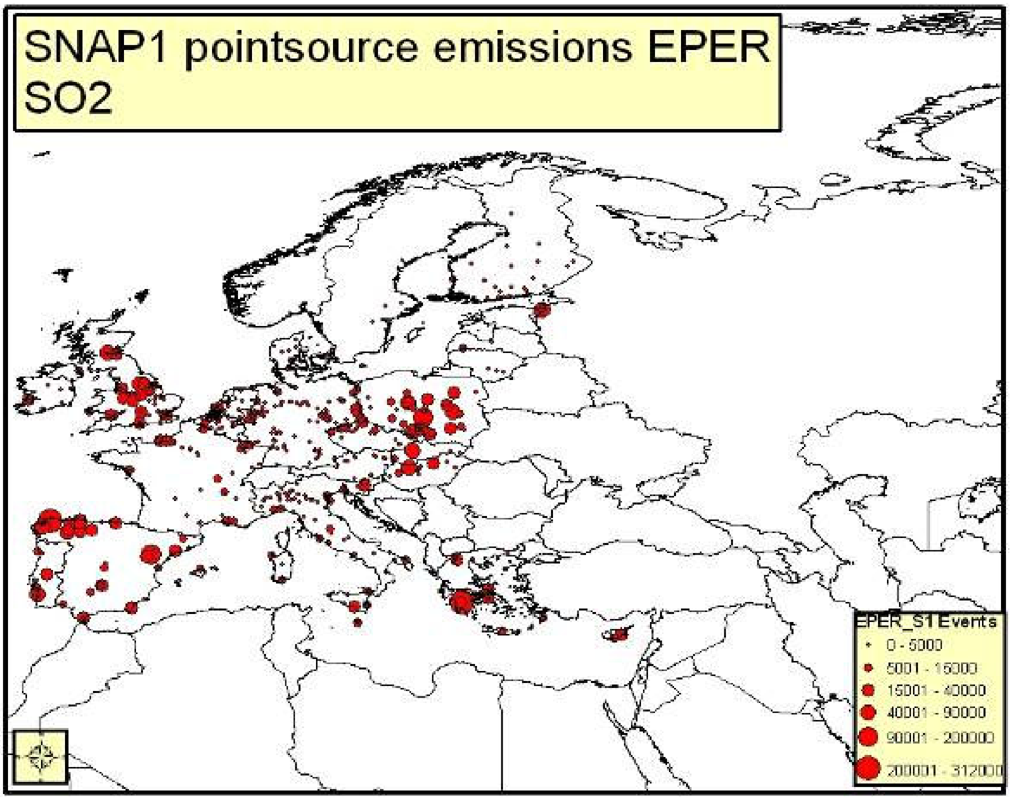

Figure 19 SNAP 1 point source emission for SO_2 according to EPER (tonnes/yr)

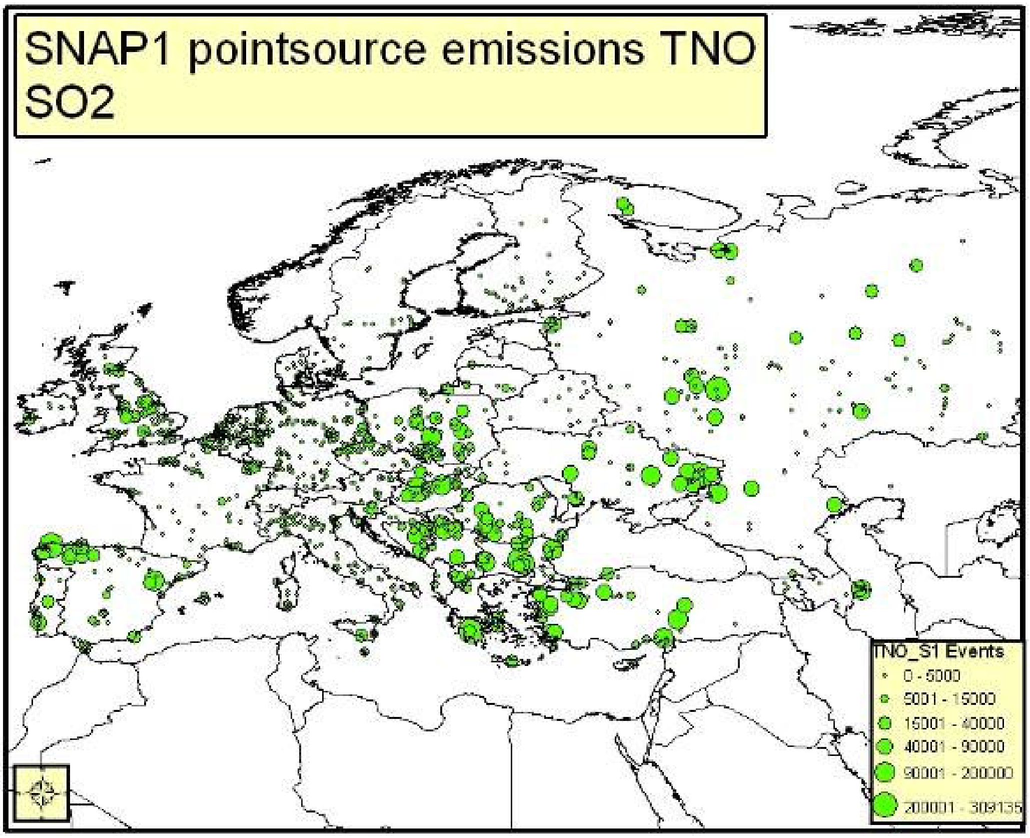

Figure 20 SNAP 1 point source emission for SO_2 according to TNO-PAREST ((tonnes/yr)

The TNO-PAREST point source emissions for SO_2 (SNAP1) completely cover Europe (Figure 20). The TNO data confirm the maxima indicated by EPER for Spain, UK, Greece, Poland, Slovak Republic and Hungary. But many countries in Central and Eastern Europe that are lacking in EPER are represented in the TNO PAREST distribution. For example, Ukraine, Turkey, Bulgaria, Romania and Serbia-Montenegro are among the countries absent from EPER. Important emissions close to Germany take place along the Czech North East and Polish border (moderate source strength) and in Central Poland and Hungary (high source strength). It is interesting to note that a vertical band over Germany amid the UK and Central Poland that stretches from the South of France and Italy to Northern Scandinavia shows only little SO_2 point source emissions. These low emissions have several causes, varying from little use of high sulphur fuels due to for instance a large share of nuclear power (e.g. France) to very stringent emission limit values that result in extensive application of FGD (e.g. Germany, Netherlands, Scandinavia).

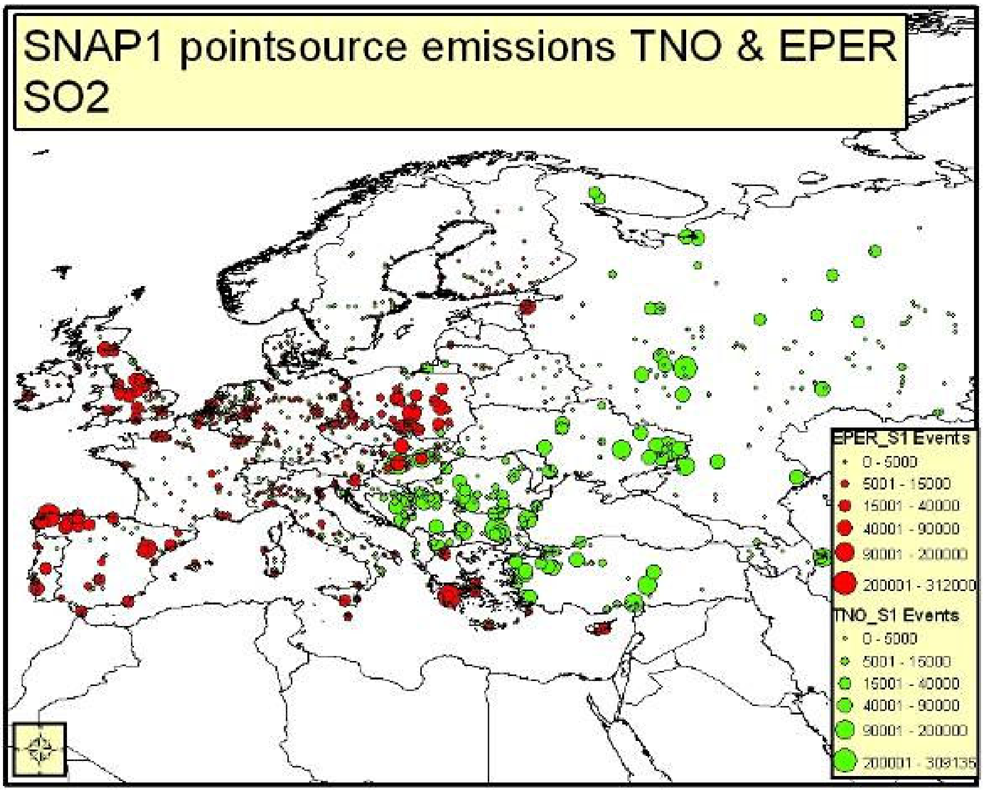

Figure 21 Merged SO_2 emission from SNAP 1 point sources according to EPER and TNO_PAREST (tonnes/yr)

The EPER and TNO PAREST SNAP 1 point source emissions are presented in one figure to further facilitate comparison (Figure 21). For the overlapping countries, the TNO PAREST and EPER emissions were in good agreement despite their different origin. TNO PAREST seems to include more sources for the overlapping countries. This is as expected since we use a lower threshold than EPER. Moreover, Figure 21 nicely illustrates the importance of countries not covered by EPER.

6.2.2 *PM10*

A significant part of the PM10 emission in Europe is caused by point sources, though not to the extent as for SO_2. Analogue to the comparison for SO_2, the following series of figures (Figure 22 to Figure 24) shows PM10 point source emissions for SNAP 1 according to EPER and TNO respectively, followed by both EPER and TNO in the same figure.

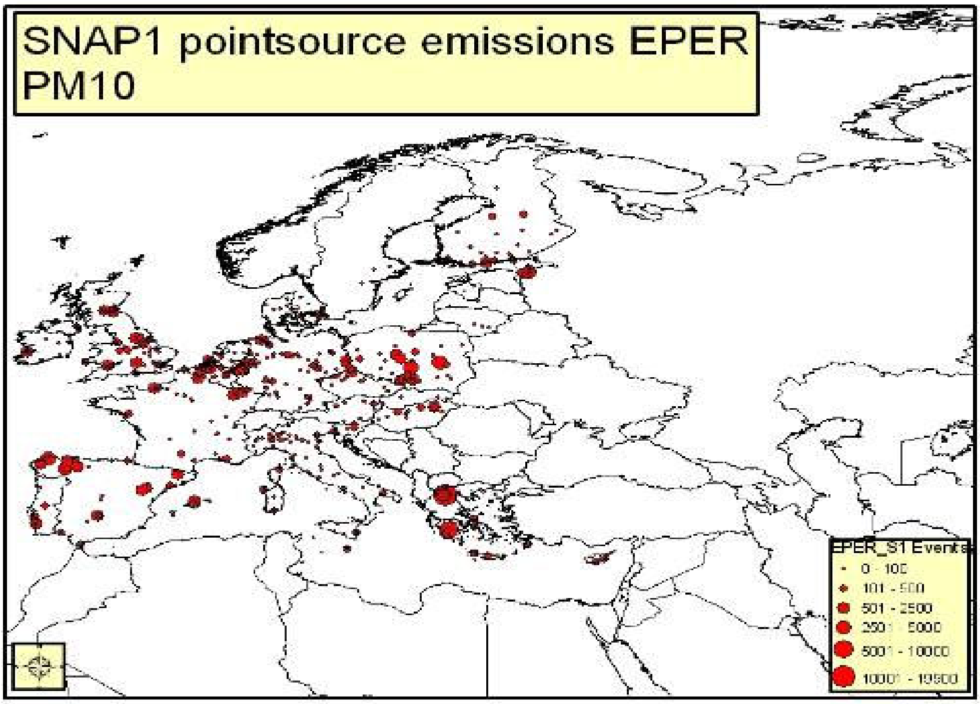

Figure 22 SNAP 1 point source emission for PM10 according to EPER (tonnes/yr)

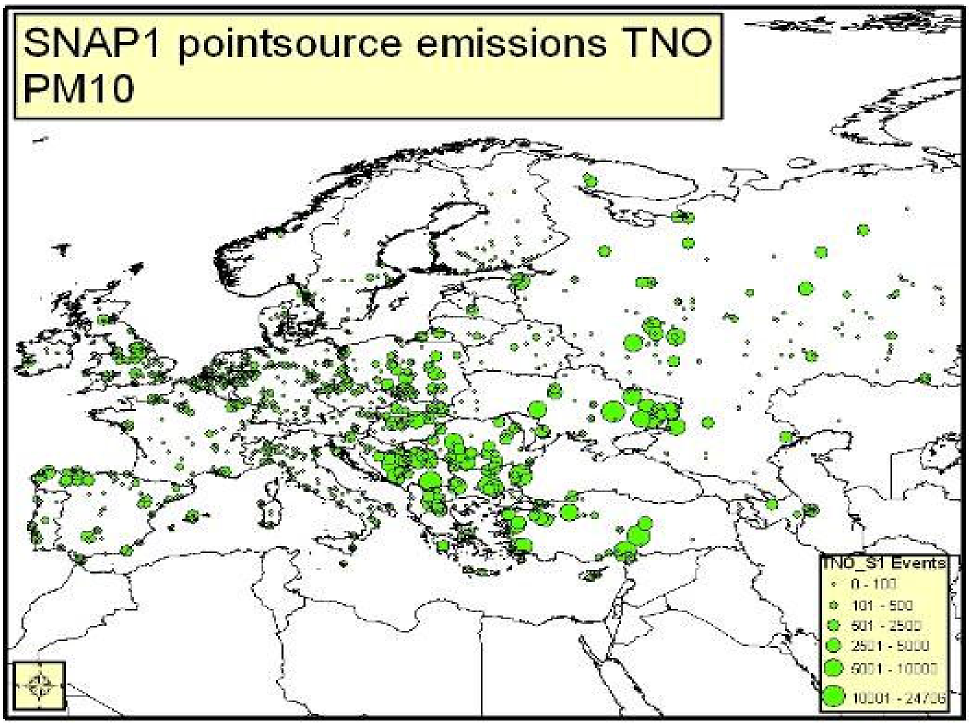

Figure 23 SNAP 1 point source emission for PM10 according to PAREST (tonnes/yr)

For PM10 we have not redistributed the PM10 point source emission totals according to the EPER ratios (contrary to SO_2, see also section 4.2). Nevertheless, the general picture for PM10 is quite similar to SO_2. Apparently SO_2 and PM10 emission often goes hand in hand. When comparing Figure 22 and Figure 23 for overlapping countries it can be observed that TNO PAREST appears more complete. There are far more smaller sources in TNO PAREST (e.g. in the Netherlands and France) compared to EPER but also some larger sources occurring in Poland and in the Czech Republic seem missing in EPER. This is illustrated by Figure 24 where, besides many small sources, in most countries several of the larger TNO PAREST sources seem absent in EPER. Figure 24 overlays the EPER emissions on top of the TNO PAREST emissions, but this approach was also performed vice versa and we did not find sources in EPER that are not in TNO PAREST. It would be interesting to analyze the results in Figure 24 and further interpret these but this is outside the scope of the present project.

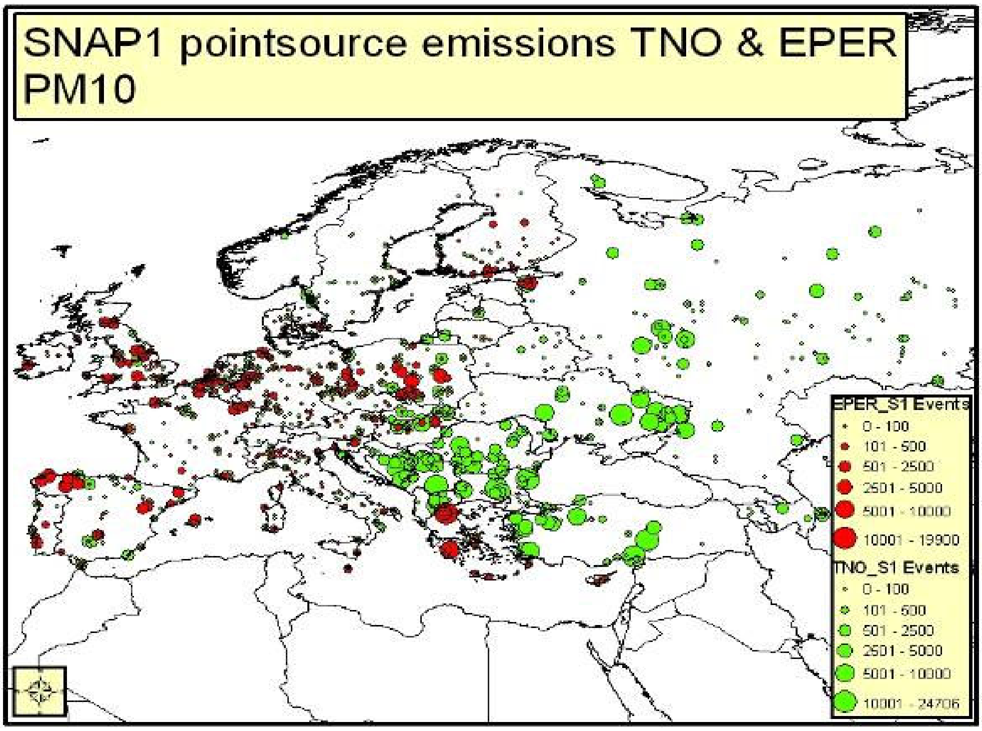

Figure 24 Merged PM10 emission from SNAP 1 point sources according to EPER and PAREST (tonnes/yr)

Earlier it was determined that coverage by EPER for the substances with relevant point source emissions is best for SO_2, followed by NOx and then PM10 (Sections 3.3.1, 4.2). We have discussed SO_2 and PM10. The comparison of EPER and PAREST for NO_x gives a similar outcome as for SO_2 (data not shown). Other substances and/or source categories are not discussed here, because coverage in EPER is relatively poor and/or emission is primarily caused by area sources.

7 Nesting German emissions in European maps

7.1 Substitution of the emission data for Germany with IER data

The previous chapters described the methodology that has been used in PAREST to develop gridded emission data for Europe. The production of the gridded emission data also covered Germany, for which the same methodology as for other countries was followed. In PAREST the emission data TNO prepared for Germany have been replaced by gridded emission data for Germany prepared by Thiruchittampalam et al. (2010) consistent with the German specific emission scenarios used in the PAREST project (Jörß et al., 2010). Therefore, prior to being used as model input, the data for Germany were removed from the gridded emission maps by selecting and deleting all contributions with DEU as country code. International shipping is coded as “INT” in PAREST, and these emissions were not removed. This is illustrated by Figure 25 that shows a “gap” in the CO data where Germany is. International shipping is the only source that can still be seen on the German territory (Nord-Ostsee-Kanal. There is some slight overlap of emission across the German borders, which is caused by cells that are shared by Germany and neighbouring countries. Only the contribution of German origin is deleted.

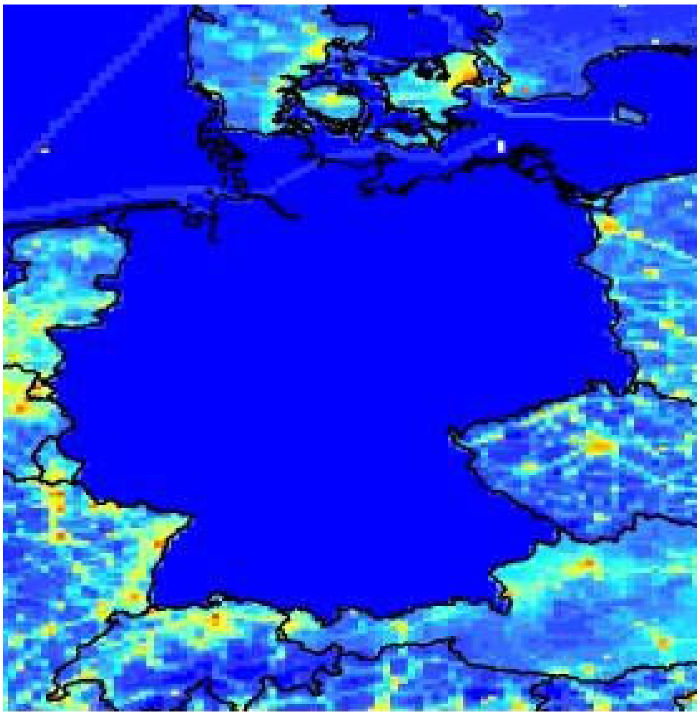

Figure 25 The PAREST emission grid for CO after removal of entries with the landcode "DEU" (Germany)

The gridded emission data for Germany as prepared by Thiruchittampalam et al. (2010) have a spatial resolution of 1/60 x 1/60 degrees. This resolution is aggregated to 1/16 x 1/8 degrees to be compatible with the European emission maps. Then the "new" German emission data were added to the European data, filling in the gap left by the removal of the TNO emissions for Germany. Figure 26 compares NO_x emission in Germany by IER with the TNO default estimate. Both plots use the same scale. The patterns are very similar, despite the fact that TNO and IER use different and independent methodologies. Road locations and emission intensities seem comparable and appear to differ in details only. The location and shape of the maxima caused by high emissions occurring in cities are comparable as well. There is some difference in total emission because IER uses updated national emissions. This causes some slight difference in the gridded emissions as well. Note that the emission data by IER do not include shipping emission on the Nord-Ostsee-Kanal, which occur within Germany but are not regarded as German emissions. Emission on the Nord-Ostsee-Kanal is included in the TNO data for international shipping. It can also be seen in Figure 26 that the IER emission grid by Thiruchittampalam et al. (2010) extends slightly beyond the German border. This is caused by cells that are shared by Germany and another country or by German Islands.

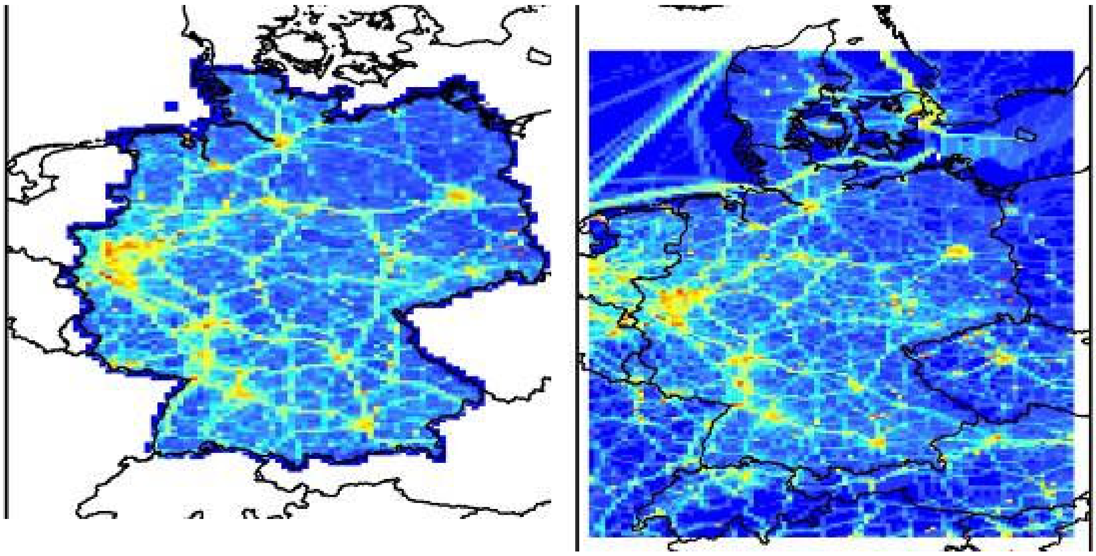

Figure 26 Regridded NOx emissions 2005 Germany by IER / IZT (left) and TNO PAREST default (Right)

Figure 27 shows the gridded NH_3 emission in the final PAREST database, consisting of European emission data with nested emission data for Germany. Important agricultural areas (which are high emitters of NH_3) are easily recognized. Despite their different data origins, regions with high NH_3 emission on both sides of the border connect well to each other without unexpected and/or unrealistic transitions at the border. (e.g., see Dutch – German and the Danish – German border in Figure 27)

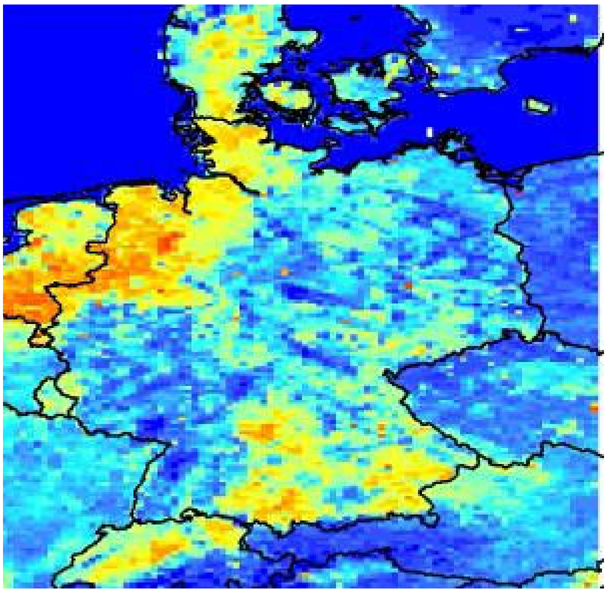

Figure 27 NH_3 emission in final PAREST data base consisting of European emission data with nested emission data for Germany provided by IER.

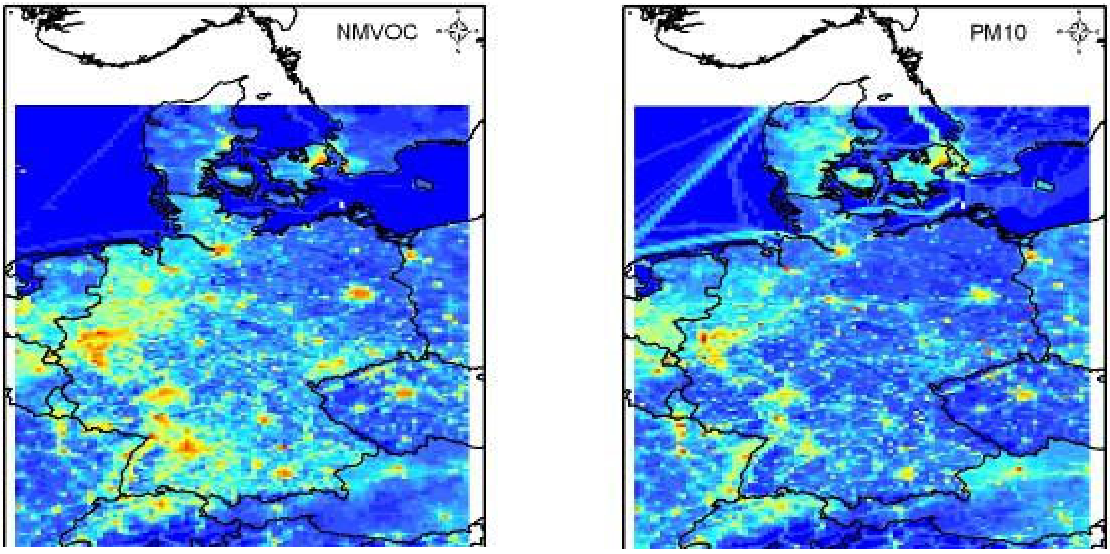

Figure 28 NMVOC and PM10 emission in final PAREST data base consisting of European emission data with nested emission data for Germany provided by IER.

The next two examples of nested German emissions concern NMVOC and PM10 (Figure 28). As mentioned earlier for both substances a strong correlation with population is observed. However, diffuse sources are estimated using different national methodologies. Since these sources are then distributed with e.g. population density they can cause border concentration jumps (see e.g., the jumps in emission levels at the border between Denmark and Germany).

This is a known problem and comparison of implied emission factors can often help in analyzing the causes. However, clarification of such differences is beyond the scope of the present project.

8 PM10 emission due to Resuspension

Not all anthropogenic emissions are covered by the official emission inventories. An example of such emission sources is resuspension of PM by traffic. Clearly the cause for these emissions is anthropogenic. However, from an emission inventory point of view this is often seen as a re-emission and not as a primary emission that needs to be reported. Despite the definition or classification issues, resuspension of dust particles with an aerodynamic diameter smaller than 10 microns due to vehicle-generated turbulence is widely recognised as a significant source of PM_{10}, especially in the urban environment. The material that is being resuspended varies with the nature of the local circumstances. It typically includes particles from vehicle tire wear, road wear, primary exhaust emissions that have settled on road surfaces (perhaps adhering to larger particles), and environmental dust from many sources, such as pollen, sea salt, construction work and wind-blown soils. In addition, the contribution from resuspension to total PM also depends on meteorological conditions; during episodes of rain and when surfaces are wet, resuspension will be much less. The mix of particles with varying chemical composition, and effects from local and climatic conditions make resuspension a difficult source to generalise about and to quantify. Various studies have suggested that emissions from resuspension are of the same order of magnitude as primary emissions from road traffic, relating to vehicle exhaust fumes, tire wear and road wear (e.g., Lenschow *et al.,* 2001; Harrison *et al.,* 2001; Thorpe *et al.,* 2007).
To better approximate observational data and to increase their predictive capacity, models would highly benefit from inclusion of such semi-anthropogenic sources in the emission inventories. As a part of its in-kind contribution to the PAREST project TNO made a first order approximation of the source strength of crustal PM10 from resuspension by traffic (Denier van der Gon et al., 2007). In practice the addition of these estimates enhance the “traffic signal” in PM10 emission maps which seems justified based on measurements of PM10 and the amount of crustal material (soil dust) in PM10. Based on a literature review and interpretation of observational data (Denier van der Gon et al., 2007; 2010) derived emission factors for resuspension expressed in mg/vkm (Table 23). The derived emission factors were applied for the first time in the LOTOS_EUROS model in the frame work of the Dutch policy supporting research programme on PM as described by Schaap et al. (2009). Special correction factors were developed to adjust the emission factors in Table 23 for climate (southern Europe) and for non-skid measures, such as studded tires and road gritting (applicable in Northern Europe) which are known to increase resuspension emissions.

Table 23. $PM_{2.5-10}$ emission factor ($mg.vkm^{-1}$) for traffic-related resuspension as a function of road type for light- and heavy-duty traffic, applied in the LOTOS-EUROS model (Denier van der Gon et al., 2007; Schaap et al., 2009).

	Road type		
	HW	RUR	URB
HDV	198	432	432
LDV	22	48	48

The emission factors and the subsequently derived emission input for the air quality models is a first approximation and needs to be further improved through comparison of model results with observational data. This is discussed in more detail by Denier van der Gon et al. (2010). The resuspension emission maps and emission factors are delivered as a separate “add -on” and are not included in the standard European emission grids.

9 Conclusions

A high resolution European emission database for the substances NO_x, SO_2, NMVOC, CH_4, NH_3, PM and CO for the year 2005 was prepared for application in the air quality modelling foreseen in the UBA PAREST project. Through a strategy that aimed at using as much as possible official reported data, the total emissions by substance and by country stayed close to what is accepted by policy makers and related bodies like the European Commission and EMEP. The selected data were merged with so-called expert estimates for gap filling to obtain a complete set of emissions for all pollutants of interest and for all countries in the model domain.

To be able to distribute the emissions on the desired high resolution of 1/8 x 1/16 degree lon lat (~7 x 8 km^2), the emissions were attributed to a large number of unique source sectors in line with the IIASA RAINS categories[2]. Fore each source category it was determined whether the emission should be treated as a point source or an area source. The gridding tools available at TNO to distribute the point source emissions and area sources were critically reviewed and subsequently updated, improved and/or created. The allocation of the point source emissions to facilities in the point source database in combination with a set of proxy maps to distribute the area source emissions resulted in a new, unique set of emission grids for the year 2005 to be used as input for modelling.
The gridded emissions to be used for Germany in the PAREST project were prepared by IER, consistent with the German specific emission scenarios used in the PAREST project. The German PAREST emission inventory by IER was nested in the European emission grid to produce consistent emission model input data.

The year 2005 emission database constructed and discussed here and its spatial distribution patterns are the basis for distribution maps of future scenarios. TNO prepared projected emissions for 2010, 2015 and 2020 following the possible revision of the NEC directive for the PAREST project using the emission data base described in the present report. The projected emissions are described in a separate TNO PAREST report by Denier van der Gon et al. (2009).

Several checks on the final emission grids were performed. For the source categories and countries where the European Pollutant Emission Register (EPER) provides a good coverage we have made a comparison with the TNO-PAREST approach. The most important outcome of this comparison are the similarities: PAREST is able to reproduce all significant point source emissions that are included in EPER. The new TNO point source data for power and heat production (SNAP 1) shows a (very) good correlation with the EPER data for Western Europe. This builds confidence in the quality of the TNO-PAREST emission data base for point sources for areas outside of the EPER domain as well as the quality of the allocation for point sources in sectors that are less complete in EPER.
Compared to previous high resolution emission databases for Europe by TNO, e.g. the UBA year 2000 inventory (Visschedijk and Denier van der Gon, 2005) and the year 2003 European Emission data base for the EU integrated project GEMS (Visschedijk et al., 2007), the difference is only partly the total amount of emitted substances.

[2] For further documentation we refer to the IIASA RAINS web site http://www.iiasa.ac.at/~rains/home.html.

The major improvement made in the TNO PAREST emission database is the spatial distribution of the emissions. The distribution in the PAREST database is more realistic by linking sources better to their origin and/or by the preparation of proxies that closer resemble the nature of the emissions. This is illustrated in Figure 29 for NOx emissions from Paris and its surroundings. Both emission databases have the same resolution and can directly be compared. The total NO_x emission allocated in the city centre is a factor 2 lower in the TNO-PAREST data base and the importance of roads that connect urban centres can clearly be seen. The cause of this discrepancy is that in the TNO GEMS database the gridding tools available to distribute the emissions were much less sophisticated. The result is that more of the total emission will be distributed with the default proxy population density. Hence an over-allocation in the population centres such as megacities like Paris occurs. Overall, the TNO PAREST database gives a significant improved representation of the spatial emission distribution.

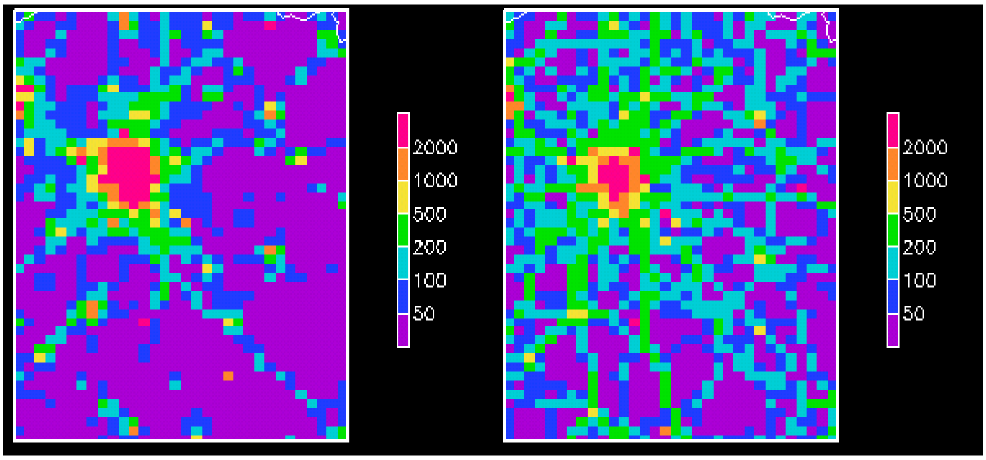

Figure 29 NOx emission from Paris in the TNO GEMS emissions database (left panel; Visschedijk et al., 2007) and the TNO PAREST emissions data base (right panel; this study)

9.1 Outlook

The improvements made in the European emission inventory will most likely receive a warm welcome in the modelling community. The experience with the previous TNO GEMS database is that many modellers are keen to use better model input as soon as it becomes available.

Every project has its limitations in time and budget. There are a few cases where the spatial distribution grids have not been updated although the possibility to do so is essentially there. The most prominent example of this are the international shipping emissions which are still mostly based on a disaggregation of the 50 x 50 km EMEP grids. Furthermore, emissions have in fact a 3^{rd} and 4^{th} dimension being emission height and time, respectively. It is foreseen that as now progress is made in the spatial distribution of the emissions, these two dimensions might become limiting to further progress and may have to be addressed in the future.

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Annex 1 Case study: Emissions from inland shipping in Europe[3]

Inland waterway transport plays an important role in the transportation of goods within Europe. In the EU27 navigable waterways stretching over 43,000 kilometres connect hundreds of cities and industrial regions. In 2007, 141 billion tonne-kilometres of freight were transported over inland waterways in the EU27 (EC, 2009). While 18 out of 25 EU Member States have inland waterways, 10 of which with an interconnected waterway network, the modal share of river transport accounts for only 3.3% of the total inland transport within the EU27.

Emissions from inland shipping in Europe

Emissions from inland shipping are usually reported under the source sector non-road transport. The national reporting of emissions from inland shipping is rather obscured because a part of inland shipping can be international navigation, which does not have to be reported to, for example, EMEP or UNFCCC. A (detailed) description of what part of the total emissions from inland shipping is included in the reporting is usually not required and not present. Hence, it is unclear what countries have exactly selected as their share of inland shipping emissions, and on what basis. This does not necessarily mean that the figures are incorrect; they are simply not transparent and prohibit a proper comparison between countries.
To address the above issues, we made an independent bottom-up calculation for inland shipping per country, following a general methodology. The methodology is by definition less sophisticated than that used by some countries, because it lacks the detailed data that may be available to country experts. However, it is comparable and transparent. This allows inter-country comparisons and gives an overview of total emissions from inland shipping. To more accurately distribute these emissions spatially, a new map with inland waterways and coastal shipping was made.

Activity data

Energy statistics data for inland shipping cannot be used as activity data to accurately calculate emissions that occur within a country because of the mixing of national and international inland shipping. Parts of the fuel bought in a particular country may be used elsewhere or vice versa. The best activity data for navigation on inland waterways are data on tonnes per kilometre (tkm) transported. Such data are reported by e.g. the EU Market Observation for inland shipping 2006 (EC, 2007) (Table 24). It is possible that for a particular country more detailed data than tkm alone are available (e.g. detailed fleet engine compositions) but this will not be the case for most countries. To keep a transparent and comparable approach the activity data of choice are tkms. For Italy, UK and Finland the data in Table 24 have been completed using Eurostat/DGtren data for the year 2000.

It was confirmed that this is consistent based on the available data for the UK from a report on waterborne freight in the UK (Table 25) which presented for total inland waters 0.2 billion tkm which equals the 200 million tkm for this country as presented in Table 24 based on Eurostat. Data for the Russian Federation and Ukraine were taken from EFIN (2004).

[3] This work was done in the framework of the PAREST project in combination with the Dutch policy supporting programme on Particulate matter (BOP). It has also been reported as part of the BOP programme by Denier van der Gon and Hulskotte, 2010.

Table 24 transport services for inland waterways transport in millions of tonne kms for 2005

country	**split**	**Inland transport** [1)] **(10^6 tkm)**
Austria	national	37
Austria	international	1715
Belgium	national	3067
Belgium	international	5651
Bulgaria	national	54
Bulgaria	international	701
Croatia	national	39
Croatia	international	79
Czech	national	60
Czech	international	33
Finland[2)]		460
France	national	4640
France	international	3217
Germany	national	11695
Germany	international	52400
Hungary	national	5
Hungary	international	2105
Italy[2)]		200
Luxembourg	national	0
Luxembourg	international	342
Netherlands	national	10519
Netherlands	international	32548
Poland	national	640
Poland	international	0
Romania	national	2641
Romania	international	2505
Serbia	national	454
Serbia	international	1033
Slovak	national	3
Slovak	international	737
Switzerland	national	1
Switzerland	international	45
UK[2)]		200
Europe	Total	137828
Russia[3)]		71000
Ukraine[3)]		13000

[1)] year 2005 based on EC (2007), unless otherwise indicated

[2)] no data available from EC 2007, data taken from Eurostat for year 2000

[3)] data for year 2000 source UNECE cited in EFIN (2004)

Table 25 **Waterborne freight in the UK (DTLR, 1999)**

	Goods moved (billion tonne-kilometres)		Goods lifted (million tonnes)	
	1989	1999	1989	1999
Seagoing traffic				
At sea				
Coastwise	40.4	40.6	64	73
One-port	15.1	16.2	49	33
Total at sea	55.5	56.8		
Inland waters				
Coastwise	0.3	0.2	12	9
One-port	0.5	0.3	13	7
Foreign	1.3	1.3	36	34
Total inland waters	2.1	1.8		
Total seagoing	57.6	58.6	*149	*140
Internal on inland waters	0.3	0.2	7	4
Total on inland waters	2.4	1.9	68	54
Total waterborne	57.9	58.7	*156	*145

**Tonnages of coastwise traffic and one-port traffic on inland waters are counted both "at sea" and under "inland waters"; these tonnages are therefore included once only in the total. Tonne-kilometres "at sea" and on "inland waters" are additive.*

Emission factors

Emission factors for fuel combustion in inland shipping per unit of fuel consumed are collected from various sources (Table 26). The emission factors need to be converted because we use tonne kilometres (tkm) as the activity data of choice. To recalculate emission factors per unit of fuel consumption to emission per tkm, a data set from the Netherlands was used. The Dutch total emissions from inland shipping (*www.emissieregistratie.nl/*) are divided by its national tonne kilometres (Table 24), resulting in emission factors per tkm (Table 27). Based on the CO_2 data (Table 27 and Rohács & Simongáti (2007)) we can estimate the fuel use per tkm. This was done assuming 3.17 kg CO_2 emitted per kg diesel, resulting in 10 - 12.5 ton marine diesel per million tkm (Table 28). Rohács & Simongáti (2007) directly report an assumed fuel use per tkm, although the origin of their figure is not entirely clear. The amount of fuel used per tkm based on the recalculation of Dutch data is higher than for the average European fleet as derived from Rohács and Simongáti (2007). However, these are rather generic estimates and the estimates from these independent approximations are in line (Table 28). The most remarkable difference is the variation in PM_{10} emission factors (CO varies substantially but is of less interest at present).

Due to the considerable difference in PM10 emission factors (Table 26), the difference between PM10 emissions calculated using the different emission factors is large; amounting to ~ 2200 tons PM10/year for Europe. However, questioning of Dutch experts confirmed that engines installed on barges and ships transporting goods in the Netherlands are relatively new and there was a clear agreement that emission factors of 40-50 kg PM10 per 10^6 tkm were unrealistic for the current Dutch situation. Therefore, we interpret this as the result of a more recent engine park being installed on barges and ships transporting goods over the Rhine as compared to the average European fleet. Hence we have made a rather arbitrary decision to apply the average European emission factors to all countries except the Netherlands and Germany. The calculated emissions from shipping on inland waterways are presented in Table 29.

Table 26 Emission factors for NOx, VOC and PM10 used for inland shipping.

Source/ representation	NO_x	VOC	PM10
	g/kg marine diesel		
average EU situation (Rohács and Simongáti, 2007)	47.02	2.39	3.19
Netherlands (Statistics Netherlands, 2007)	45.90	2.47	1.87
RAINS (IIASA; Amann et al., 1996)	61.78	8.32	4.89
RAINS (IIASA; Amann et al., 1996) v2 [1)]	50.75	6.83	4.01

[1)] corrected for fuel estimate difference

Table 27 Emission factors for inland shipping per million tonne kilometre recalculated from Dutch data by Hulskotte et al. (2003)

Substance	Emission factor ($kg/10^6$ TKM)
PM_{10}	23
NH_3	0.13
N_2O	1.0
CO_2	39770
CO	135
VOC	31
NO_x	576
SO_2	43

Table 28 Fuel consumption and emission factors per tkm for CO2, NOx, VOC, PM10 and CO

emission factors	fuel	CO_2	NO_x	VOC	PM10	CO	reference
	kg/ million tkm						
Average EU	10200	30900	590	30	40	30	Rohács & Simongáti, 2007
NL, DLD, BEL	12550	39770	580	31	23	135	Statistics Netherlands, 2007
RAINS			637	86	50		RAINS PM module (Klimont et al., 2002)

A remarkable feature from Table 28 is that the implied fuel use and the CO_2 emission factor per tkm is higher for the Netherlands than for average EU. The most likely cause is that the use of tkm as activity value leads to an underestimating of emissions because empty ships are not accounted for. In the Dutch methodology also unfreighted ships are included and based on the Dutch data these are responsible for ~25% of the fuel use and emissions. This fits surprisingly with the discrepancy observed in Table 28 which is very close to 25% for both fuel use and CO_2. For the other substances the story is different because the assumed emission factors differ substantially due to built year of engines and installed technologies. Fuel use and CO_2 emission is rather independent of the technologies. The notion that emissions estimated in Table 29 may be underestimated by 25% because empty ships are not accounted for warrants further study.

Table 29 Estimated emissions of VOC, NOx, PM10, CO and SO2 due to inland shipping in 2005.

Country	Emission[1] (tonnes/yr)				
	VOC	NOx	PM10	CO	SO_2[2]
Austria	52.6	1034.0	70.1	52.6	74.7
Belarus	*152*	*880*	*89*		*94*
Belgium	262	5144	349	262	372
Bulgaria	23	445	30	23	32
Croatia	3.6	70	4.7	3.6	5.1
Czech rep.	2.8	55	3.7	2.8	4.0
Denmark					
Estonia					
Finland	14	271	18	14	20
France	236	4636	314	236	335
Germany	1987	37175	1501	8653	2732
Greece					
Hungary	63	1245	84	63	90
Ireland					
Italy	6.0	118	8.0	6.0	
Latvia					
Lithuania	30	186	18		19
Luxembourg	10	202	14	10	15
Netherlands	1335	24979	1009	5814	1836
Norway					
Poland	19	377	26	19	27
Portugal					
Romania	154	3036	206	154	219
Russian Federation	2130	41890	2840	2130	3053
Serbia	45	877	59	45	63
Slovak Rep.	22	437	30	22	32
Spain					
Sweden					
Switzerland	1.4	27	1.9	1.4	2.0
Turkey					
Ukraine	399	7847	532	399	572
United Kingdom	6.0	118	8.0	6.0	8.6
Total	6953	131050	7215	17916	9605

[1] Calculated with an average emission factor except NL, DLD where a Dutch EF was used (Table 26).

[2] For SO_2 only a Dutch emission factor was available as we had no fuel type specification. SO2 may be underestimated.

Spatial Distribution of emissions from shipping on inland waterways

For inland shipping a map is produced using the results of the EU Trans tools project (TNO, 2008) for countries covered by this project. The spatial representation of the inland waterways in the Transtools maps is not very accurate as the project focuses on traffic flows, not on exact location. Inland waterways are represented by lines that intersect at nodes. However, the value of the transtools maps is that the line segments have a traffic intensity which allows a much better spatial allocation of emissions at the national scale. Not all countries of our domain are covered by transtools.

For the remainder of the countries we used a simplified version of the ESRI major waterways map (http://www.esri.com/) or manually added a line segment to the map depicting the waterway that needs to be there based on geographic maps. The map used for distributing emission from shipping on inland water ways is shown in Figure 29 with gridded NOx emissions as an example. Figure 30 is a zoom version of the same map to visualize that indeed intensity differences occur on certain inland waterways. In the near future a foreseen improvement will be the transfer of the intensities from the Transtools map to a better geographical representation of the major rivers.

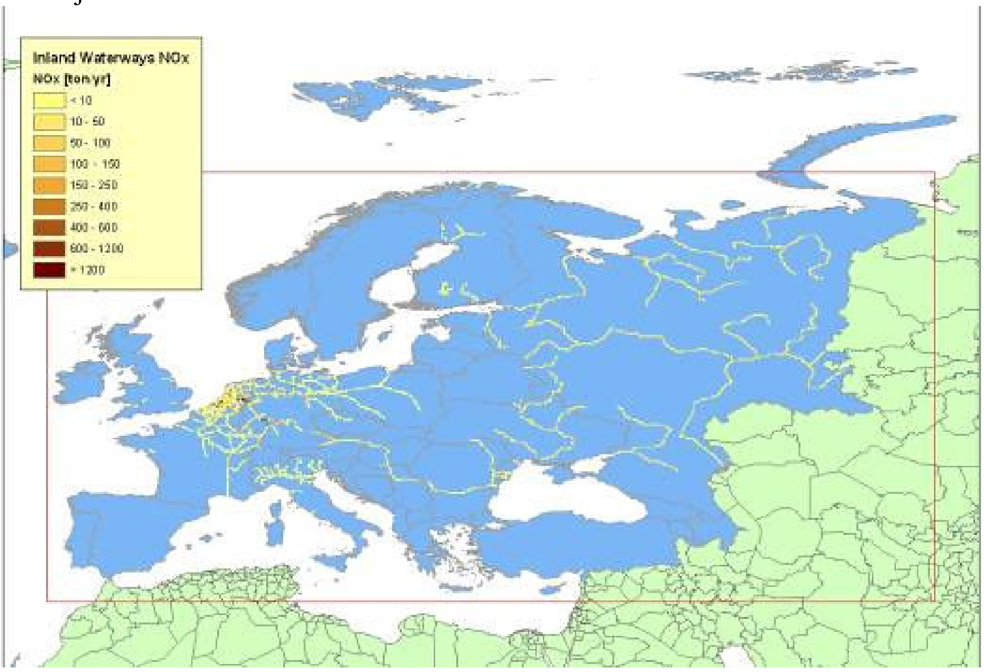

Figure 29 NOx emissions (tonnes/yr) from shipping on inland waterways based on bottom-up estimate (tkm approach; Table 29)

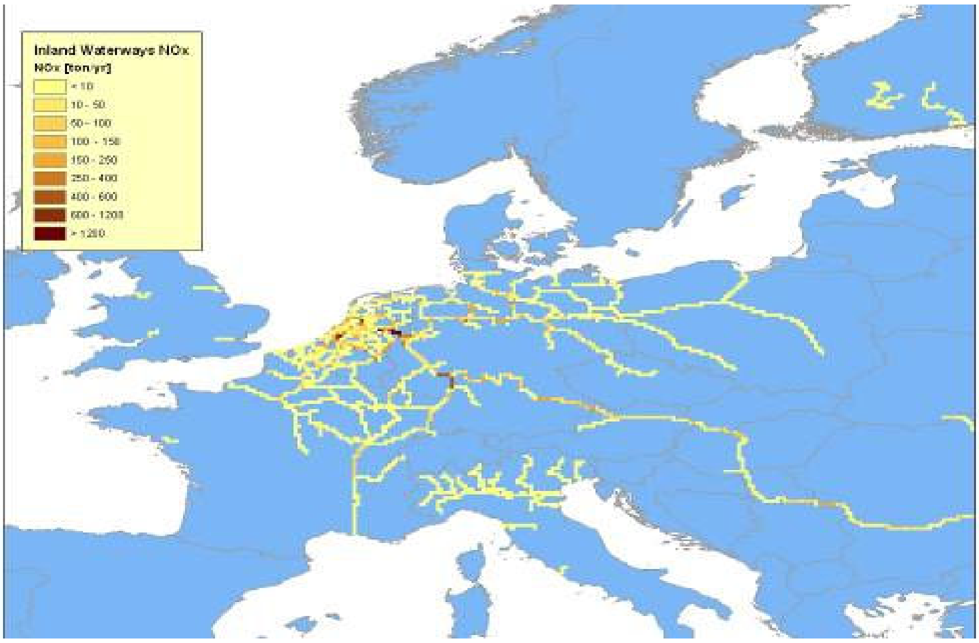

Figure 30 NOx emissions (tonnes/yr) from shipping on inland waterways based on-bottom-up estimate (tkm approach; Table 29 – zoom on N-W.Europe.

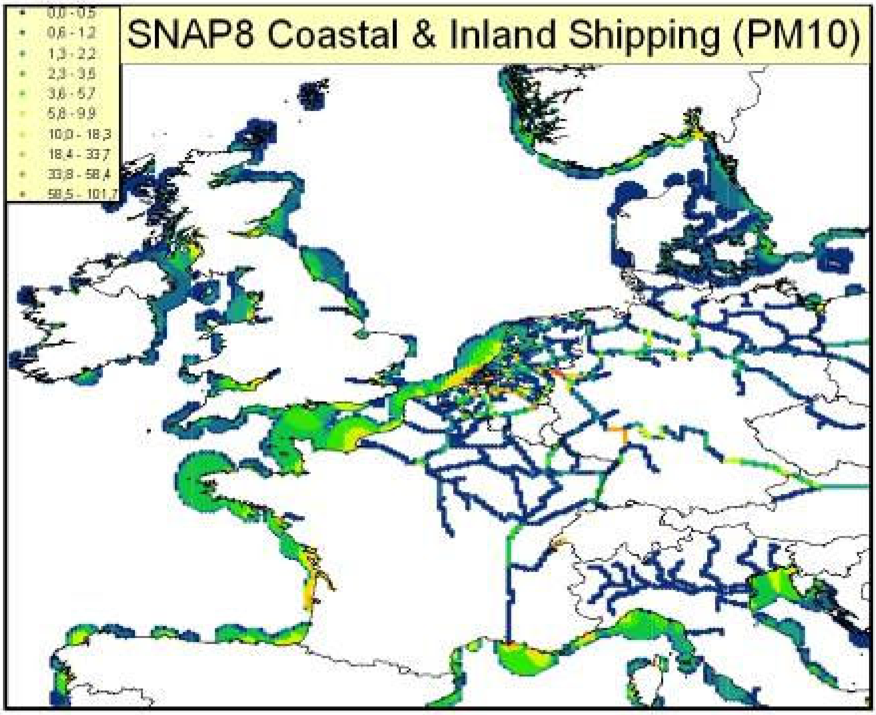

Figure 31 Shipping related PM10 emissions (tonne/yr) under SNAP8 distributed using the gridding tools developed in PAREST.

Finally the inland shipping emission can be combined with other shipping related emissions under the source category non-road transport (SNAP8). An example of such a result is presented in Figure 31.

Conclusions

Inland shipping is an important emission category that may be highly relevant in the vicinity of busy navigation routes or ports. Therefore, a more in-depth assessment, transparent calculation as well as accurate allocation of the emissions is important. The emissions estimated here, and their spatial allocation, allow a better representation of these emissions in models that predict air quality. Moreover, this assessment can be used to further improve the emission estimates by using better national data when available. The activity data that are available for inland shipping are related to the economic activity: tonne kilometre (tkm). It is possible that the emissions estimated based on these activity data are underestimating the total emissions due to inland shipping because empty ships are not accounted for. An indicative estimate is that emissions are 20-25% higher if empty ships are included. It is important to realize the importance of national and international shipping on inland waterways and to report both – even though for certain reporting obligations international traffic may be excluded.

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