**TNO Built Environment and Geosciences**

Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek / Netherlands Organisation for Applied Scientific Research

Laan van Westenenk 501
P.O. Box 342
7300 AH Apeldoorn
The Netherlands

www.tno.nl

T +31 55 549 34 93
F +31 55 541 98 37

**TNO report**

**2007-A-R0233/B**

# A high resolution gridded European emission database for the EU integrated project GEMS

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| Date | March 2007 |
| Author(s) | Antoon Visschedijk<br>Peter Zandveld<br>Hugo Denier van der Gon |
| Order no. | 034.64435 |
| Keywords | |
| Intended for | The European Centre For Medium-Range Weather Forecasts<br>Shinfield Park, Reading, RG2 9AX<br>United Kingdom |
| Number of pages | 23 (incl. appendices) |
| Appendices | 1 |

# Contents

# 1 Introduction

GEMS (Global and regional Earth-system Monitoring using Satellite and in-situ data) is a European Union funded Integrated Project (IP) within the Sixth Framework Programme. The project will create a new European operational system for operational global monitoring of atmospheric chemistry and dynamics and an operational system to produce improved medium-range & short-range air-chemistry forecasts, through much improved exploitation of satellite data. To fulfill its objectives, GEMS is in need of a high resolution gridded emission database but no emissions dataset covering Europe with sufficient resolution is currently available. TNO has recently produced a gridded anthropogenic emission database for the year 2000 (Visschedijk and Denier van der Gon, 2005). This database with some modifications can fulfill the needs of GEMS if gridded on a sufficiently high resolution and preferably as representative as possible for the year 2003. This project does not involve further emission database development but concentrates on delivering available emission data on a sufficiently high resolution in the form of gridded maps approximating as good as possible, given the limited budget and time available, the year 2003.

## 1.1 Description of existing emission data (starting point)

TNO recently developed gridded anthropogenic emission data to provide atmospheric chemistry and transport models with state-of-the-art and consistent data for the substances $NO_x$, $SO_2$, NMVOC, $CH_4$, $NH_3$, PM and CO, on a high geographical resolution (0.25º x 0.125º longitude-latitude, which is on average about 15 x 15 $km^2$) for the reference year 2000. The final gridded emission data and its development are described in detail in Visschedijk and Denier van der Gon (2005). TNO focused on obtaining a spatial distribution that is as accurate and realistic as possible and that provides a full geographical coverage of Europe, from Ireland to Kazakhstan. The TNO methodology is consistent, transparent and documented. It is based on, among other items, recent data on a wide range of point source emissions, agricultural/vegetation spatial distribution patterns, traffic intensities/road maps and rural/urban population distribution. Additionally, the emission data provide full and up-to-date coverage of off-shore emission sources, including sea shipping and oil and gas production. The final gridded data produced by Visschedijk and Denier van der Gon (2005) were scaled to the national emission totals of the CAFE baseline scenario for 2000.

The GEMS project has indicated that no scaling to official emission data is mandatory and consistency with the emission data as produced by TNO in the RETRO project (http://retro.enes.org/index.html) would be desirable.

### *1.1.1 Air Pollutants and classification of sectors*

The substances taken into consideration in the inventory are acidifying substances, ozone precursors ($SO_2$, $NO_x$, $NH_3$, CO, NMVOC, $CH_4$) and PM. The emission by substance will be given at the SNAP 97 $1^{st}$ level that consists of 11 source categories which is the grouping of sources as commonly adopted in modeling of Air Quality (Table 1).

Table 1 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 |
| 8 | Other (non-road) transport and mobile machinery |
| 9 | Waste disposal |
| 10 | Agriculture |
| 11* | Nature |

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

TNO developed a gridded emission database for the year 2000 using a bottom-up method based on emission factors and activity levels and the TNO spatial proxy information (Visschedijk and Denier van der Gon, 2005). This database is referred to as the so-called TNO reference database. The function of the reference database is to fill data gaps when no country data are available and to provide a further sub-division of source contribution ratios. Since GEMS does not require scaling to official EMEP emission data, the reference database will be used as a default starting point. For species ($SO_x$, $NO_x$, $NH_3$, $CH_4$) where country data are expected to be superior to default values the official emission data will replace the default values. For species where country data are incomplete and or thought to be less reliable (e.g. NMVOC, PM) TNO defaults will be used. Recently, TNO also delivered global gridded data sets for the RETRO project (Pulles et al., 2005). A comparison between the RETRO data and the data gridded in this project is presented in chapter 3.

# 2 Methodology and description of modifications

## 2.1 Gridding of emission data

The gridded emission data for 2003 have been produced with the aid of spatial proxy data. Proxy data in this context means geographical distribution patterns of for instance population density or land use that can be used as a key to distribute emission data to a grid. The type of source determines which of the available proxy data best approximates the real-world geographical distribution. The emission data to be gridded are usually available at the level of a limited number of source categories. These source categories comprise an aggregation of individual emission sources. For instance the source category “Agriculture” is an aggregation of combustion of fossil fuels by tractors or in greenhouses, the use of pesticides, emission by different animals, the use of fertilizer, etcetera. Each of these sources can have a unique distribution pattern where different proxy data should ideally be used for the allocation to grid. This is the reason that in order to grid emission data specified by emission sources sectors, a further sub-division into sub-sectors that harmonize with the available proxy data is necessary. In order to be able to sub-divide the sectoral emission data, TNO has developed a so-called “Shadow” or “Reference” database. This is a detailed bottom-up emission inventory for the substances under consideration based on statistical activity data and generic emission factors. Sectoral emission data from official country submissions can thus be split into individual contributions by sub-sectors at a level compatible with the available proxy data, based on source contribution ratio’s derived from the Reference database. The reference year of the TNO reference database for is 2000 for CO, $CH_4$, $NH_3$, $NO_x$ and $SO_2$, and 1995 for $PM_{10}$ and $PM_{2.5}$ (Visschedijk and Denier van der Gon, 2005).

### *2.1.1 Proxy data*

The following proxy data are available and used for the gridding of the sectoral emission data. The emission data by emission source category will be disaggregated to the level of these proxy data.

**Point sources (including location and characteristics of all European):**
- Utilities and industrial combustion plants > 50 MWth; coal-, oil- and gas-fired
- Oil refineries
- Oil and gas production facilities (including off-shore)
- Coke ovens
- Primary and secondary iron and steel plants (by sub-process)
- Primary and secondary non-ferrous metals smelters (by metal)
- Cement factories
- (Petro-, other organic and anorganic)-Chemical Plants (by product)
- Waste incinerators
- Major airports

**Area sources (distribution patterns in Europe on grid cell basis):**
- Location and (partly) traffic intensities of highways and major secondary roads
- Urban, rural and total population density
- Distribution patterns of various agricultural activities
- A detailed land use and land cover dataset, including the locations and densities of forested areas

– The location and densities of sea shipping routes on European seas (North Sea, Baltic Sea, Atlantic Ocean, Mediterranean Sea, Black Sea and the Caspian Sea)

## 2.2 Emission data to be gridded

The basic input data needed in order to create gridded emission data is emission by country and by sector. In this project our approach has been to use the best possible available emission data regardless of the data's status (e.g. official or expert estimated).

For the substances CO, $CH_4$, $NH_3$, $NO_x$ and $SO_2$, countries have been obliged to submit official emission data for many years. Over time 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. While this is true for the majority of the countries, reporting errors and other inconsistencies do still occur. For example; country emission estimates can 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 are rejected in favor of a default TNO emission estimate. When official data are unavailable for 2003 or a near-by year, default TNO estimates are used.

While coverage of the country submissions for the "traditional" air pollutants and GHGs (CO, $CH_4$, $NH_3$, $NO_x$ and $SO_2$) is above 90%, official emission data for particulate matter (PM) are far from complete. The obligation for submitting PM emission data is of relatively recent date and the majority of the European countries have apparently not yet developed a reliable estimation methodology. It is our perception that the quality of the submitted PM data is at this stage significantly below that of the other substances. We therefore use the 2000 RAINS PM model results (Klimont et al., 2002) for PM emissions.

### *2.2.1 Official country-reported emission data for 2003*

Emission data for the substances CO, $CH_4$, $NH_3$, $NO_x$, $SO_2$, $PM_{10}$ and $PM_{2.5}$ as officially submitted by Parties to EMEP/CLRTAP are available from the European Environmental Agency (EEA; Wagner et al., 2005a). The EEA dataset is principally compiled based on the following sources:

- $CH_4$: Data from the country reports submitted in 2005 under the EU Monitoring Mechanism and to UNFCCC (excl. LULUCF)
- CO, $NH_3$, $NO_x$, $SO_2$, $PM_{10}$ and $PM_{2.5}$: Data from officially reported data to EMEP/LRTAP by 10 March 2005. The reported data is available from http://webdab.emep.int/

For the year 2003 official emission data was 70-80% complete. As an approximation for missing 2003 data, EEA used data obtained through a "Gap-filling" routine (Wagner et al., 2005b). Where countries have not reported data for 2003, emission values have been considered to equal the last reported emission (e.g. 2002 or earlier). In a number of cases UNFCCC data for $CH_4$ was unavailable for any year. In those cases $CH_4$ data are obtained from the IIASA GAINS model for greenhouse gases (Höglund-Isaksson and Mechler, 2005). For the other air pollutants (CO, $NH_3$, $NO_x$ and $SO_2$) no further gap-filling was attempted if no data had been reported by Parties in any (recent) year. The coverage for these substances obtained in the EEA dataset increased to 94%, leaving 6% to be filled in by other data sources (eg. TNO reference database).

The EEA distinguishes eight emission source categories in its dataset, which are listed in Table 2. 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 by relatively straightforward assumptions. The assumed link is indicated in Table 2. Besides emission data by sector, EEA (Wagner et al., 2005a) also reports the national total per substance, as submitted by the country. In spite of the gap-filling efforts that EEA has undertaken, the EEA dataset is not complete since there is still a number of countries for which no emission data for any year was available ((Wagner et al., 2005a; b). For these country-substance combinations, default data from the TNO Reference database are substituted (see Table 3). The result of official reporting and the EEA gap filling procedures cover > 90% of the countries-substance combinations, hence the additional insertion of default estimates is necessary but of limited importance on emission totals.

Table 2 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 (Difference between NatTotal and sum of reported sectors) | - |

Table 3 Country – substance combinations for which no emission data are available in the EEA dataset (Wagner et al., 2005a) for any year.

| ISO3 | Substance | ISO3 | Substance |
|---|---|---|---|
| AZE | $SO_2$ | KAZ | $NO_x$ |
| GEO | CO | KAZ | $SO_2$ |
| GEO | NMVOC | MKD | $NH_3$ |
| GEO | $NO_x$ | MKD | NMVOC |
| GEO | $SO_2$ | MLT | CO |
| ISL | $NH_3$ | TUR | $NH_3$ |
| KAZ | CO | YUG | CO |
| KAZ | $NH_3$ | YUG | $NH_3$ |
| KAZ | NMVOC | YUG | NMVOC |

### 2.2.2 *Consistency and quality assessment checks and correction of EEA emission data*

The EEA emission data for all substances except PM (based on country submissions and gap-filling techniques) have been undergoing a number of consistency and quality checks before being used for gridding. In case emission data fail to meet certain criteria it is either corrected or rejected for gridding usage, in favor of a TNO default value. For $CH_4$, CO, $NH_3$, $NO_x$ and $SO_2$, these default values are based on the results of the TNO Reference database described earlier. In some cases emission data are corrected when the error could be clearly identified (e.g. double counting). The PM data taken from the 2000 RAINS PM model results (Klimont et al., 2002) have not been further validated or checked but are used as such.

### 2.2.3 *Trend in emission data*

The reference year of the TNO database differs three years from the reference year of the latest EEA emission data (2000 vs. 2003). In order to get an impression of the general trends in the emission data for the period 2000 to 2003, we have compared the totals for 2000 and 2003 of the official emission data for a comparable group of countries. Table 4 lists the relative difference of the 2000 and 2003 data per substance. This table shows that the trend for any substance is < 10%, which is considered acceptable given the high uncertainty of this type of data. It should be noted that for individual countries the trend between 2000 and 2003 can be considerably higher than the relative trends shown by Table 4 (up to a factor of 2 in the officially reported data).

Table 4 The relative trend in the official emission data between 2000 and 2003, per substance.

| Pollutant | Trend/3yr |
|---|---|
| $CH_4$ | 1.01 |
| CO | 0.93 |
| $NH_3$ | 0.95 |
| NMVOC | 0.94 |
| $NO_x$ | 0.97 |
| $SO_x$ | 0.95 |

A confusing issue in making choices is that the separately reported national emission total is 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. 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 the exactly the opposite of a certain sector's contribution (which has somehow survived updates). The solution is to delete the value for that specific sector. Table 5 documents where such a deletion has been carried out in order to obtain consistent emission data.

In case a discrepancy between the sector sum and the national total cannot be easily explained 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 favor of TNO default values (Table 6).

Table 5 Country-sector combinations to be deleted as a result of correction of contributions > 10%, that should be zero.

| ISO3 | Substance | EEA_sector |
|---|---|---|
| BEL | CO | Other (Non Energy) |
| CHE | $SO_2$ | Agriculture |
| CYP | $NH_3$ | Other Transport |
| CYP | $NO_x$ | Agriculture |
| CYP | $SO_2$ | Agriculture |
| CZE | NMVOC | Agriculture |
| EST | CO | Other (Non Energy) |
| GRC | $NH_3$ | Industry (Processes) |
| HUN | NMVOC | Agriculture |
| ISL | NMVOC | Other Transport |
| LUX | $NH_3$ | Industry (Processes) |
| LVA | CO | Agriculture |
| LVA | $NO_x$ | Agriculture |
| MDA | $SO_2$ | Agriculture |
| NLD | CO | Agriculture |
| NLD | $NO_x$ | Agriculture |
| POL | $NH_3$ | Energy Industries |
| POL | $NH_3$ | Industry (Energy) |
| POL | $NO_x$ | Waste |
| ROM | $NO_x$ | Agriculture |
| RUS | $SO_2$ | Fugitive Emissions |

Table 6 Country-substance combinations for which official emission data has been rejected based on a large (> 10%) difference between the sum of the sector contributions and the national total.

| ISO3 | Substance |
|---|---|
| ISL | $SO_2$ |
| KGZ | $SO_2$ |
| LUX | NMVOC |
| POL | NMVOC |
| ROM | NMVOC |
| TUR | CO |
| TUR | $NH_3$ |
| TUR | NMVOC |
| TUR | $NO_x$ |
| TUR | $SO_2$ |

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, we have simply corrected this by either adding the difference (or subtracting, depending on the sign) from the reported sector contributions to make the sum of the sector totals equal the national total (Table 7).
An isolated inconsistency that has been corrected concerns $NH_3$ emission from Agriculture in Kyrgyzstan (KGZ), which is missing and most likely equals the national total minus the other sector contributions (59056 tonnes).

Table 7 Corrected country-sector combinations as a result of a difference between the sum of the sector contributions and the national total.

| ISO3 | Substance | Corrected emission (tonnes) | EEA sector |
|---|---|---|---|
| DNK | $SO_2$ | 18805 | Energy Industries |
| DNK | $NO_x$ | 73395 | Energy Industries |
| DNK | CO | 282270 | Road Transport |
| GRC | NMVOC | 129570 | Road Transport |
| GRC | $SO_2$ | 374610 | Energy Industries |
| GRC | CO | 763190 | Road Transport |
| HRV | $SO_2$ | 22894 | Energy Industries |
| HRV | NMVOC | 33893 | Other (Non Energy) |
| HRV | CO | 149143 | Road Transport |
| IRL | $NO_x$ | 47406 | Road Transport |
| IRL | CO | 180717 | Road Transport |
| ITA | NMVOC | 490178 | Road Transport |
| LTU | $SO_2$ | 18199 | Energy Industries |
| RUS | $NO_x$ | 1070000 | Road Transport |

The next general quality check that has been performed on the country data involves a review of 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, so-called "key sectors". Per substance these key sectors are (Olivier et al., 2001):

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

If for a country the contribution 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 favor of a TNO default estimate. A valid reason for a key sector to be missing might be e.g., $SO_2$ from Energy Industries in small countries that import all electricity from other countries and hence have no emission. The country substance combinations that have been rejected following the above criterion are presented in Table 8.

Table 8 Rejected country substance combinations because one or more key sectors are lacking.

| ISO3 | Substance |
|---|---|
| ARM | CO |
| ARM | NMVOC |
| ARM | $NO_x$ |
| AZE | $CH_4$ |
| AZE | NMVOC |
| ISL | CO |
| KGZ | CO |
| KGZ | NMVOC |
| KGZ | $NO_x$ |
| RUS | CO |
| RUS | NMVOC |
| YUG | $NO_x$ |

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 reported national total should not differ more than a factor of 5 from the TNO default value in the Reference database. The national totals as found in the EEA dataset have been plotted against the corresponding TNO reference value in Figure 1.

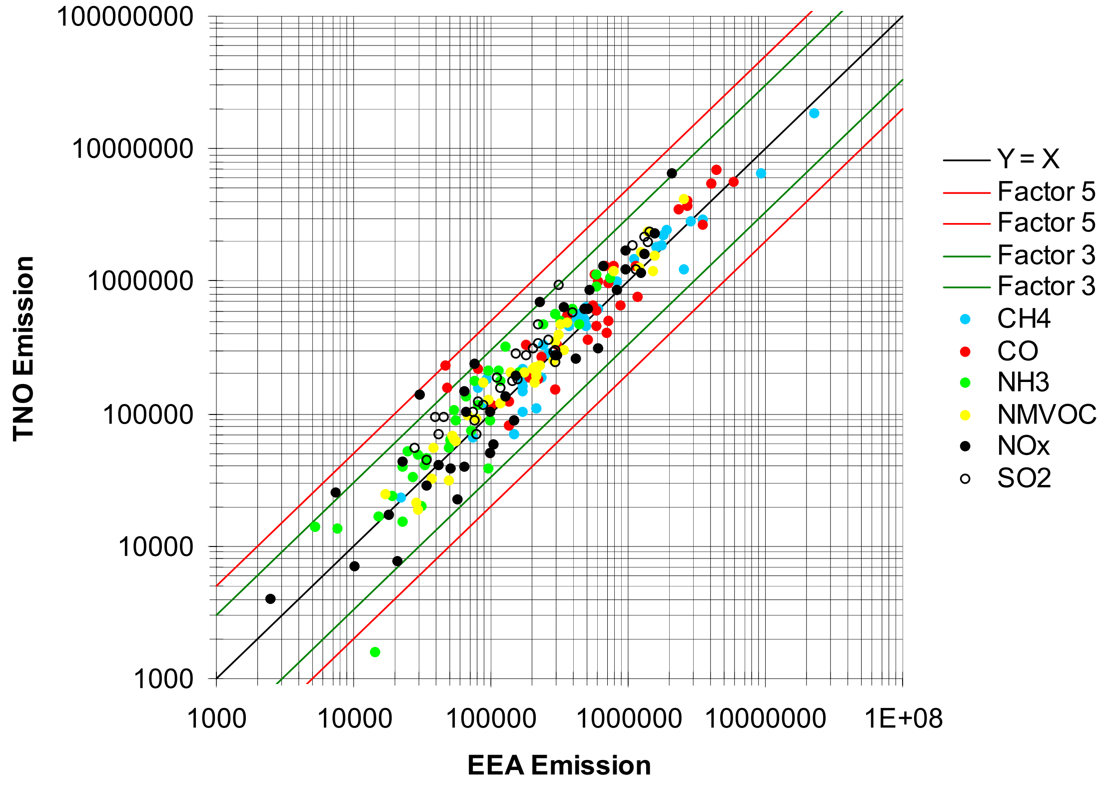


Figure 1 Comparison of the official EEA country totals with the TNO reference values for 2000.

Because the order of magnitude of the national totals varies greatly a Log/Log scale is used in Figure 1. The boundaries of what is considered acceptable (difference < factor 5) are indicated in Figure 1 as well as difference of a factor of 3. Only one value for $NH_3$, corresponding to $NH_3$ emission in Armenia (ARM), is rejected. It should be noted though that a number of $NO_x$ and CO totals are off considerably (between a factor of 3 and 5) as well. The vast majority of the national totals in the EEA dataset is however within a factor of 3 from the TNO Reference database totals. Deviations of a factor of 3 is not uncommon in this type of data. Furthermore it should be noticed that the spread is around the 1:1 line, hence there seems to be no systematic biass. Reasons why the TNO default emission data are slightly higher can be e.g., less well-coverage of local /national emission reduction policies in the TNO generic reference data base or incomplete reporting by the country. These two examples illustrate that it is not easy to say which data source is “better”.

A final correction made to the EEA dataset concerns the Russian Federation. The EEA dataset includes Russian emission data (for $NH_3$, $NO_x$ and $SO_2$) that principally passed our quality/consistency checks, albeit being systematically lower that the TNO default value by at least a factor 2. It is however not verifiable for us whether the emission data submitted by Russia include Central and Eastern Siberia or not. Since Russia makes an important contribution to the European totals it was decided to remain on “the safe side” and all emission data for $NH_3$, $NO_x$ and $SO_2$ were replaced to by TNO default values which apply to the entire Russia territory and can be redistributed on the Russion part of the emission map domain.

#### 2.2.4 *NMVOC split*

For modeling of atmospheric chemistry it is important to breakdown total NMVOC emissions into VOC compound groups. TNO has provided the GEMS project with a NMVOC split by source sector by country. The VOC compound groups that are distinguished are given in Appendix 1, including an example of a country-specific NMVOC split.

### 2.3 Summary of the data origin

The various consistency and quality checks to the EEA country data have been presented in the previous sections of this chapter. A summary of the origin of the emission data that are selected to be gridded is given in Table 9 (including the TNO Reference value when selected). Listed are the national totals by substance except for PM. The "origin number" behind the pollutant value refers to the table notes.

The data origin of the $PM_{10}$ and $PM_{2.5}$ estimates for all countries is the IIASA RAINS PM Module (Klimont et al., 2002). Note that there is a small number of countries (ISL, KAZ, KGZ and MLT) for which (for one or more substances) no country data, as well as no TNO default data is available. These countries largely fall outside the study area but any small section that would fall within the studied area will have no gridded emission data (or zero).

Table 9 Origin of the gridded emission data.

| Country | CH4 | | CO | | NH3 | | NMVOC | | NOx | | SOx | | PM10 | | PM2.5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ISO3 | Value | Origin | Value | Origin | Value | Origin | Value | Origin | Value | Origin | Value | Origin | Value | Origin | Value | Origin |
| ALB | 172 | 0 | 101 | 0 | 32 | 0 | 34 | 0 | 29 | 0 | 58 | 0 | 9 | 3 | 7 | 3 |
| ARM | 81 | 0 | 75 | 7 | 2 | 8 | 26 | 7 | 9 | 7 | 10 | 0 | N/A | | N/A | |
| AUT | 372 | 0 | 802 | 0 | 54 | 0 | 182 | 0 | 229 | 0 | 34 | 0 | 49 | 3 | 37 | 3 |
| AZE | 443 | 7 | 47 | 1 | 25 | 0 | 104 | 7 | 80 | 1 | 185 | 4 | N/A | | N/A | |
| BEL | 406 | 0 | 888 | 5 | 77 | 0 | 226 | 0 | 297 | 0 | 153 | 0 | 70 | 3 | 43 | 3 |
| BGR | 446 | 0 | 716 | 0 | 52 | 0 | 119 | 0 | 209 | 0 | 968 | 0 | 94 | 3 | 59 | 3 |
| BIH | 148 | 0 | 193 | 0 | 23 | 0 | 42 | 0 | 55 | 0 | 419 | 1 | 48 | 3 | 20 | 3 |
| BLR | 599 | 0 | 733 | 0 | 120 | 0 | 308 | 0 | 140 | 0 | 131 | 0 | 64 | 3 | 43 | 3 |
| CHE | 175 | 0 | 368 | 0 | 52 | 0 | 111 | 0 | 89 | 0 | 18 | 2, 5 | 15 | 3 | 10 | 3 |
| CYP | 47 | 0 | 85 | 0 | 6 | 2, 5 | 16 | 2 | 22 | 2, 5 | 46 | 2, 5 | 3 | 3 | 2 | 3 |
| CZE | 483 | 0 | 579 | 0 | 82 | 0 | 203 | 2, 5 | 324 | 0 | 232 | 0 | 104 | 3 | 66 | 3 |
| DEU | 3582 | 0 | 4155 | 0 | 601 | 2 | 1460 | 0 | 1428 | 0 | 616 | 0 | 260 | 3 | 171 | 3 |
| DNK | 280 | 0 | 591 | 6 | 98 | 0 | 158 | 0 | 209 | 6 | 31 | 2, 6 | 33 | 3 | 22 | 3 |
| ESP | 1765 | 0 | 2377 | 2 | 399 | 0 | 1146 | 2 | 1519 | 2 | 1353 | 2 | 235 | 3 | 169 | 3 |
| EST | 94 | 0 | 183 | 2, 5 | 8 | 2 | 40 | 0 | 39 | 0 | 101 | 2 | 42 | 3 | 22 | 3 |
| FIN | 236 | 0 | 564 | 0 | 33 | 2 | 145 | 0 | 219 | 0 | 99 | 0 | 44 | 3 | 36 | 3 |
| FRA | 2862 | 0 | 5897 | 0 | 753 | 0 | 1400 | 0 | 1220 | 0 | 492 | 0 | 375 | 3 | 290 | 3 |
| GBR | 1932 | 0 | 2768 | 0 | 300 | 0 | 1089 | 2 | 1570 | 0 | 979 | 0 | 202 | 3 | 129 | 3 |
| GEO | 175 | 0 | 181 | 4 | 97 | 0 | 52 | 4 | 44 | 4 | 14 | 4 | N/A | | N/A | |
| GRC | 484 | 0 | 1169 | 6 | 73 | 1, 5 | 268 | 6 | 318 | 0 | 509 | 6 | 66 | 3 | 49 | 3 |
| HRV | 172 | 0 | 309 | 1, 6 | 51 | 1 | 88 | 1, 6 | 69 | 1 | 67 | 1, 6 | 30 | 3 | 20 | 3 |
| HUN | 452 | 0 | 600 | 0 | 67 | 0 | 155 | 2, 5 | 180 | 0 | 347 | 2 | 87 | 3 | 60 | 3 |
| IRL | 607 | 0 | 239 | 2, 6 | 116 | 2 | 79 | 2, 5 | 120 | 2, 6 | 76 | 0 | 22 | 3 | 14 | 3 |
| ISL | 22 | 0 | N/A | | N/A | | 10 | 2 | 28 | 2 | N/A | | N/A | | N/A | |
| ITA | 1646 | 0 | 4476 | 2 | 447 | 2 | 1343 | 2, 6 | 1267 | 2 | 665 | 2 | 273 | 3 | 209 | 3 |
| KAZ | 1340 | 0 | N/A | | N/A | | N/A | | N/A | | N/A | | N/A | | N/A | |
| KGZ | 151 | 0 | N/A | | 59 | 1 | N/A | | N/A | | N/A | | N/A | | N/A | |
| LTU | 171 | 2 | 225 | 0 | 34 | 0 | 74 | 0 | 53 | 0 | 43 | 6 | 21 | 3 | 17 | 3 |
| LUX | 22 | 0 | 49 | 0 | 5 | 2, 5 | 14 | 9 | 18 | 0 | 2 | 0 | 4 | 3 | 3 | 3 |
| LVA | 91 | 0 | 295 | 5 | 15 | 0 | 79 | 0 | 37 | 5 | 8 | 0 | 10 | 3 | 7 | 3 |
| MDA | 214 | 0 | 139 | 0 | 28 | 0 | 29 | 0 | 30 | 0 | 21 | 2, 5 | 41 | 3 | 23 | 3 |
| MKD | 76 | 0 | 139 | 2 | 14 | 4 | 27 | 4 | 50 | 2 | 150 | 2 | 21 | 3 | 9 | 3 |
| MLT | 17 | 2 | N/A | | 1 | 0 | 8 | 0 | 12 | 0 | 33 | 0 | 1 | 3 | 1 | 3 |
| NLD | 831 | 0 | 609 | 2, 5 | 128 | 2 | 225 | 0 | 364 | 2, 5 | 65 | 2 | 58 | 3 | 36 | 3 |
| NOR | 241 | 0 | 509 | 0 | 23 | 0 | 300 | 0 | 220 | 0 | 23 | 0 | 35 | 3 | 29 | 3 |
| POL | 1805 | 2 | 3528 | 0 | 328 | 2, 5 | 828 | 9 | 805 | 2, 5 | 1564 | 0 | 307 | 3 | 215 | 3 |
| PRT | 499 | 0 | 729 | 0 | 99 | 0 | 293 | 0 | 288 | 0 | 295 | 0 | 59 | 3 | 46 | 3 |
| ROM | 1132 | 0 | 1194 | 1 | 164 | 1 | 327 | 9 | 349 | 1, 5 | 833 | 1 | 171 | 3 | 115 | 3 |
| RUS | 22815 | 0 | 16382 | 7 | 1097 | 10 | 5625 | 7 | 4109 | 10 | 6470 | 10 | 1414 | 3 | 899 | 3 |
| SVK | 217 | 2 | 308 | 0 | 30 | 0 | 82 | 0 | 98 | 0 | 106 | 0 | 29 | 3 | 18 | 3 |
| SVN | 94 | 0 | 81 | 0 | 19 | 0 | 46 | 0 | 56 | 0 | 64 | 0 | 21 | 3 | 15 | 3 |
| SWE | 263 | 0 | 697 | 0 | 56 | 0 | 303 | 0 | 206 | 0 | 52 | 0 | 79 | 3 | 67 | 3 |
| TUR | 2599 | 0 | 2861 | 9 | 504 | 9 | 969 | 9 | 804 | 9 | 2894 | 9 | 424 | 3 | 305 | 3 |
| UKR | 9349 | 0 | 2766 | 0 | 242 | 0 | 318 | 0 | 523 | 0 | 1252 | 0 | 527 | 3 | 319 | 3 |
| YUG | 498 | 0 | 315 | 4 | 118 | 4 | 154 | 4 | 148 | 7 | 396 | 0 | 93 | 3 | 45 | 3 |

**Legend to Origin column**

0 National total & sector totals as reported by the country for 2003
1 National total & sector totals both gap-filled by EEA
2 1 Or more sector contributions gap-filled by EEA; National total as reported by country for 2003
3 Emission value taken from IIASA RAINS PM Module
4 No emission data available from EEA for any year, TNO defaults
5 Certain sector contribution deleted as a result of correction
6 Certain sector contributions changed as a result of correction
7 Contribution by one or more key sectors lack in country data; TNO defaults
8 EEA data rejected as a result of a too large difference with the TNO default
9 EEA data rejected because sector contributions do not add up to national total; TNO defaults
10 Additional correction of data for Russia; TNO defaults
11 No emission data available anywhere

# 3 Comparison with RETRO emission data

Gridded emission data are also available for the substances CO, NMVOC and $NO_x$ from the RETRO project (http://retro.enes.org/index.html). The RETRO emission data set (Pulles et al., 2007) is a global bottom-up emission inventory of which the methodology is quite similar to the TNO Reference database (as it was also developed by TNO). The RETRO emission data aims to capture the emission trend of the last decades of the 20$^{th}$ century upto the year 2000. It only includes combustion-related emissions. A comparison between the emission data compiled and gridded in the present study and the RETRO results for 2000 is presented in Figure 2.

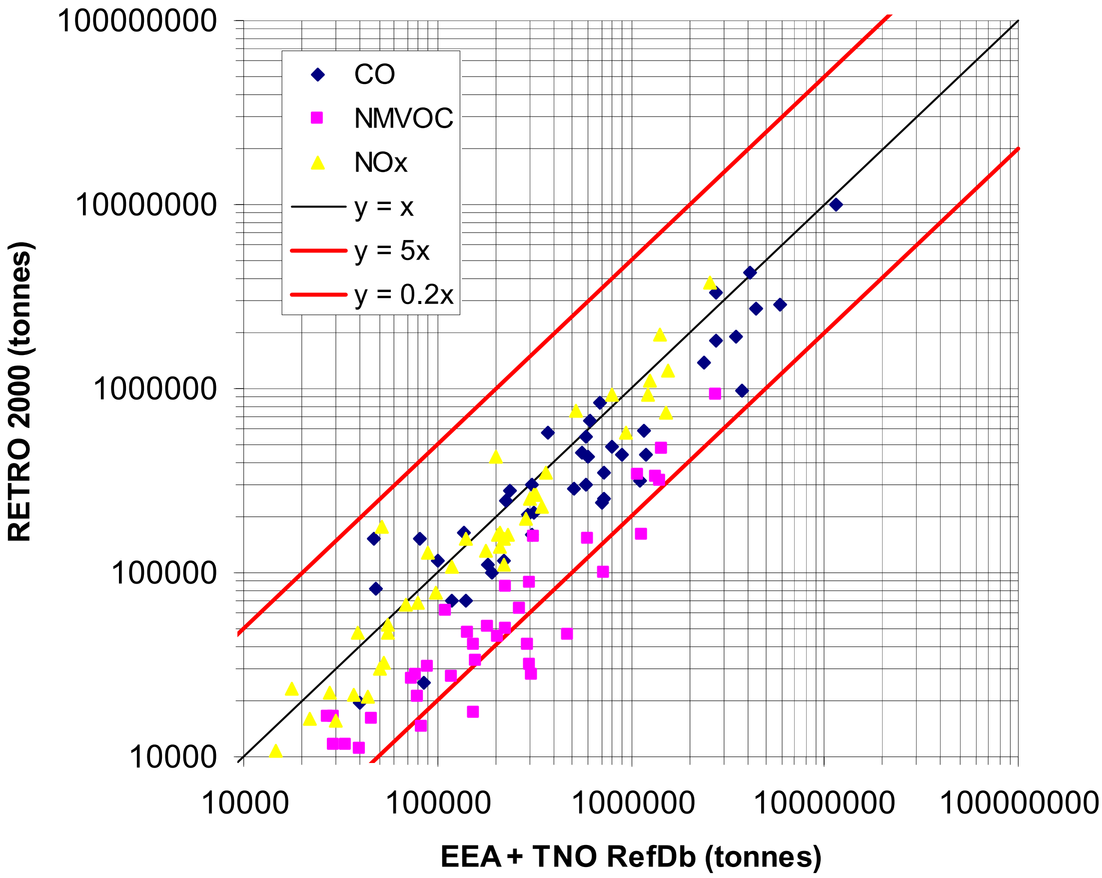


Figure 2 Comparison of the RETRO results for Europe with the emission data compiled in this project.

Since emission of individual countries differ orders of magnitude, a Log/Log scale is used in Figure 2. However, it should be realized that the Log/Log scale is suitable to look at patterns but the absolute differences between points may be substantial. Therefore, indicative lines showing a factor 5 deviation are presented in Figure 2. It is concluded that the correlation between RETRO and the results of the current emission data set is reasonable for $NO_x$, somewhat worse but still fair for CO. However a systematic difference for NMVOC is found. Most of the differences can be explained by the fact that RETRO only includes combustion emissions. For CO, but especially NMVOC, a considerable contribution comes from other (non-combustion sources) such as solvent use and fugitive emission. For CO, process emission from the iron and steel industry contributes significantly and is not included in the RETRO data. However, these non-combustion sources for CO and NMVOC are covered by the TNO Reference database and the selected data for gridding in this project. It may be concluded that the presently gridded emission data are more complete than the RETRO emission data due to inclusion of non-combustion sources.

# 4 Results and final remarks

The result of gridding the emission data are high resolution gridded emission data for $NO_x$, $SO_2$, CO, NMVOC, $CH_4$, $NH_3$, $PM_{10}$ and $PM_{2.5}$. An example of such a gridded emission map is given in Figure 3 for $NO_x$ emissions from all sectors. At the scale of Europe the achieved resolution cannot be seen because the grid cells are to small. Figure 4 shows a detail of Figure 3, zoomed into Western Europe. In Figure 4 individual grid cell sizes can be seen.

The GEMS project uses and aims to interpret satellite data for the year 2003. Therefore, the emission data represent as well as possible, within the limitations of the project budget and time table, the year 2003. Only limited QA/QC cross checking was performed, e.g., looking at key sectors as described in chapter 2. In the future, if and when more time is available, this could be expanded by looking at more detail at all source sectors and patterns between countries. For example, is the emission for a certain SNAP sector per inhabitant comparable for countries where we expect a similar level of technological development? Hence, it should be noted that significant improvement of the emission data is still expected if the necessary effort is made. However, at this moment it is of equal importance to get feed back from users of the emission data which may give guidance to singling out the most important issues, regions or sectors that need improvement.

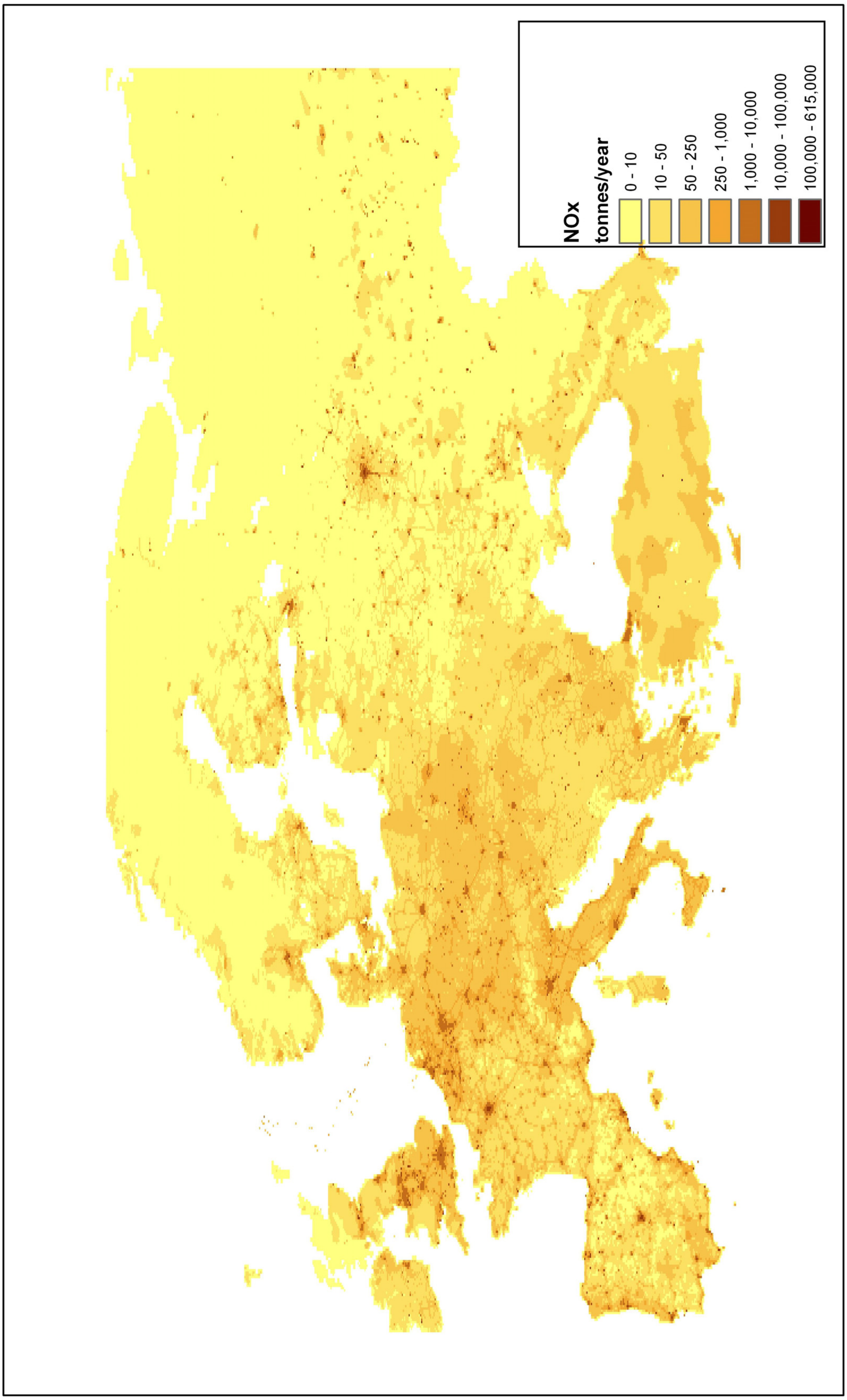


Figure 3 European $NO_x$ emissions for all sectors in the year 2003.

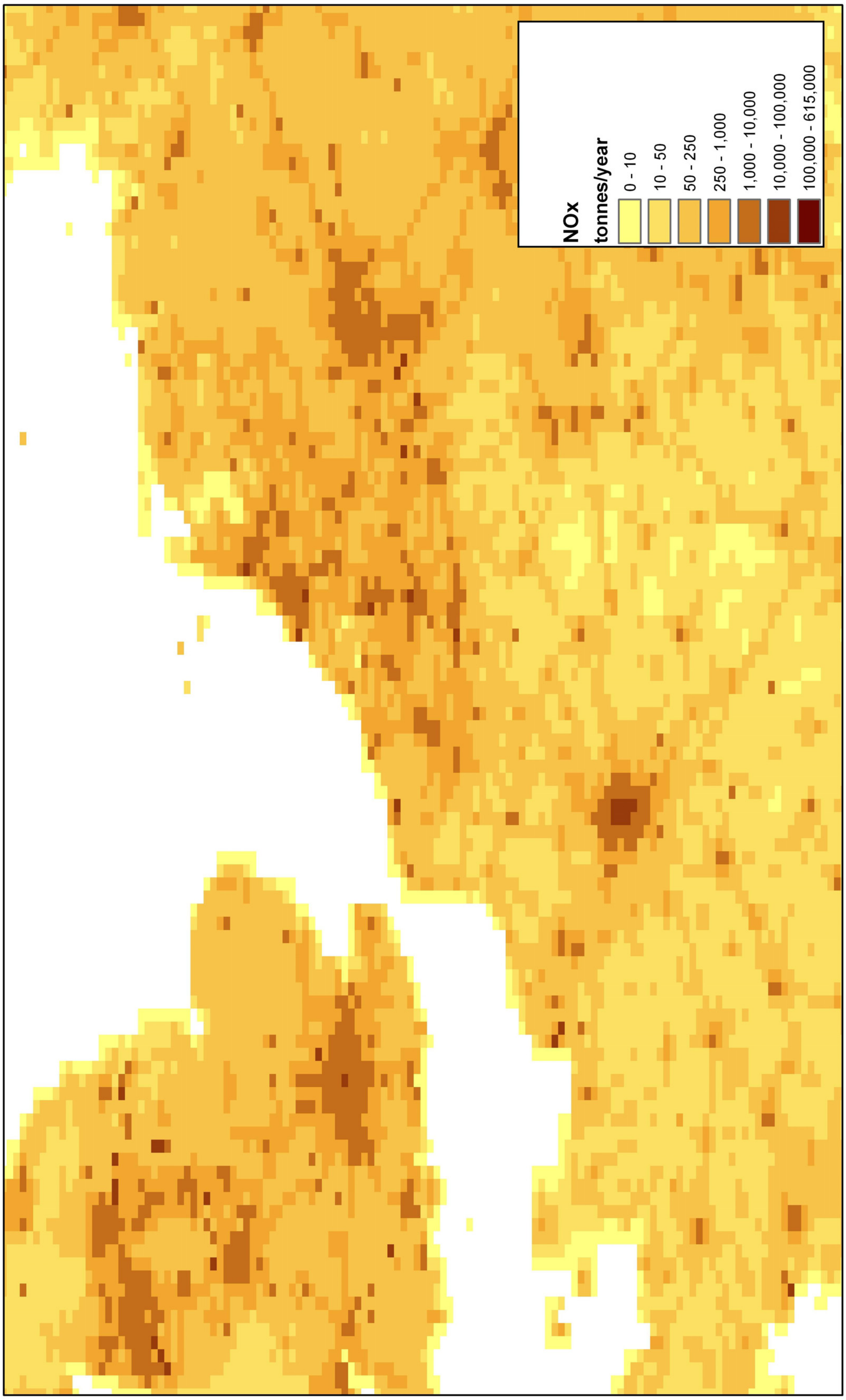


Figure 4 Detail of the European $NO_x$ emissions for all sectors in the year 2003 (zoom Western Europe).

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# 6 Authentication

Name and address of the principal

The European Centre For Medium-Range Weather Forecasts
Shinfield Park, Reading, RG2 9AX
United Kingdom

Names and functions of the cooperators

Antoon Visschedijk
Peter Zandveld
Hugo Denier van der Gon

Names and establishments to which part of the research was put out to contract

-

Date upon which, or period in which the research took place

1 October 2006 – 1 April 2007

Signature:

H.A.C. Denier van der Gon
project leader

Approved by

H.S. Buijtenhek
team manager

# 1 NMVOC split

In polluted regions the oxidation of (mostly shorter lived) volatile hydrocarbons other than $CH_4$, collectively called Non-Methane Volatile Organic Compounds (NMVOC) is of importance for modeling atmospheric chemistry. The emission database provides total NMVOC emitted per source sector. To fulfill the needs of atmospheric modelers, total NMVOC emissions have been split in 25 compound groups (Table A1.) For two compound groups (isoprenes and monoterpenes) no specific emissions are given because the emission of these compounds is completely dominated by natural emissions and the emission database contains anthropogenic sources only. Since the NMVOC emissions for a source sector depend on the fuels and technologies used, the relative contribution of compound groups to the total NMVOC source sector emissions may differ by country. Therefore, a country-specific NMVOC source sector split is made. Table A2 gives an example of such a NMVOC split for a country (The Netherlands).

The NMVOC split provided in this project is based on the work for the EDGAR database (Olivier et al., 2001) and represents the best approximation of the relative contribution of different compound groups to total NMVOC emissions for different source sectors in the year 1995. Although absolute NMVOC emissions have changed over time, the NMVOC split for 1995 remains a reasonable approximation. However, in the future an update of the NMVOC split is recommendable.

Table A1. NMVOC compound groups.

| Main group | Group code | Standard NMVOC Compound Group |
|---|---|---|
| Alkanols (alcohols) | v01 | Alkanols (alcohols) |
| Alkanes | v02 | Ethane |
| " | v03 | Propane |
| " | v04 | Butanes |
| " | v05 | Pentanes |
| " | v06 | Hexanes and higher alkanes |
| Alkenes/alkynes (olefines) | v07 | Ethene (ethylene) |
| " | v08 | Propene |
| " | v09 | Ethyne (acetylene) |
| " | v10 | Isoprenes : *no anthropogenic sources** |
| " | v11 | Monoterpenes : *no anthropogenic sources** |
| " | v12 | Other alk(adi)enes and alkynes (olefines) |
| Aromatics | v13 | Benzene (benzol) |
| " | v14 | Methylbenzene (toluene) |
| " | v15 | Dimethylbenzenes (xylenes) |
| " | v16 | Trimethylbenzene |
| " | v17 | Other Aromatics |
| Esters | v18 | Esters |
| Ethers | v19 | Alkoxy alkanes (ethers) |
| Chlorinated hydrocarbons | v20 | Chlorinated hydrocarbons |
| Alkanals (aldehydes) | v21 | Methanal (formaldehyde) |
| " | v22 | Other alkanals (aldehyedes) |
| Alkanones (ketones) | v23 | Alkanones (ketones) |
| Carboxylic acids | v24 | (Alkanoic) acids |
| Other NMVOCs | v25 | Other NMVOC (HCFCs, nitriles, etc.) |

Table A2. Relative share of NMVOC compound groups to total NMVOC emissions by source sector for the Netherlands.

| Compound group | SNAP source sector | | | | | | | | SNAP 7 Road transport | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 71 | 72 | 73 | 74 |
| | Relative contribution of compound group to total NMVOC (%) | | | | | | | | | | | |
| acids | 0.1 | 12.6 | 6.1 | | | | | 11.1 | | | | |
| alcohols | 0.0 | 6.0 | 4.3 | 0.1 | | 9.4 | 0.0 | 5.7 | | | | |
| benzene | 2.5 | 7.8 | 5.7 | 1.7 | 0.8 | | 2.0 | 3.3 | 4.5 | 2.0 | | 1.0 |
| butanes | 19.7 | 10.0 | 13.9 | 5.8 | 28.9 | | 1.9 | 11.1 | 4.3 | 2.0 | | 32.0 |
| chlorinated HC's | | | | | | 10.2 | | 0.6 | | | | |
| esters | | | | 0.0 | | 11.7 | | 0.7 | | | | |
| ethane | 4.6 | 3.1 | 0.4 | 15.7 | 11.6 | | 1.0 | 18.1 | 1.4 | 1.0 | 3.0 | |
| ethene | 0.9 | 6.3 | 0.2 | 6.1 | | | 12.5 | 6.2 | 7.2 | 12.0 | 15.0 | |
| ethers | | 2.4 | | 0.1 | | 4.6 | | 2.3 | | | | |
| ethyne | 0.0 | 2.2 | 0.2 | 0.2 | | | 4.0 | 2.2 | 4.5 | 4.0 | | |
| hexanes & higher alkanes | 18.8 | 2.6 | 8.3 | | 12.6 | 30.9 | 28.5 | 6.8 | 22.8 | 30.0 | | 15.0 |
| ketones | 0.0 | 0.5 | 1.1 | | | 10.9 | 1.6 | 1.0 | 0.1 | 1.5 | | |
| methanal | 1.3 | 9.7 | 13.8 | | | | 6.7 | 1.0 | 1.7 | 6.0 | 4.0 | |
| other alk(adi)enes & alkynes | 0.6 | 3.0 | 2.4 | 20.2 | 7.5 | | 5.2 | 3.3 | 6.9 | 5.0 | 22.0 | 9.5 |
| other alkanals | 0.0 | 3.4 | 1.1 | 0.0 | | | 7.1 | 2.8 | 1.2 | 6.5 | 2.0 | |
| other aromatics | 0.6 | 0.4 | 2.4 | | | 1.7 | 19.3 | 1.3 | 11.1 | 20.5 | 0.1 | |
| others | 0.3 | 0.1 | 1.5 | 37.3 | | 4.0 | 0.8 | 3.3 | | | | |
| pentanes | 25.3 | 17.4 | 21.1 | 3.0 | 33.3 | | 1.9 | 3.9 | 6.4 | 2.0 | | 40.0 |
| propane | 18.9 | 5.3 | 5.7 | 9.1 | 4.2 | | 0.9 | 8.2 | 0.1 | 1.0 | 44.0 | 1.0 |
| propene | 0.9 | 2.7 | 0.2 | 0.4 | | | 3.2 | 2.7 | 3.8 | 3.0 | 10.0 | |
| toluene | 3.2 | 3.9 | 5.1 | 0.3 | 0.8 | 8.3 | 1.4 | 2.6 | 12.0 | 1.5 | | 1.0 |
| trimethylbenzenes | 0.0 | 0.0 | 0.3 | | | | | 0.3 | 3.9 | | | |
| xylene | 2.2 | 0.5 | 5.9 | 0.0 | 0.4 | 8.3 | 1.9 | 1.5 | 8.1 | 2.0 | | 0.5 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |