STOCKHOLMS OCH UPPSALA
LÄNS LUFTVÅRDSFÖRBUND

2007:2

# *TESS*

## *Traffic Emissions, Socioeconomic valuation and Socioeconomic measures*

**PART 1:**

### EMISSIONS AND EXPOSURE OF PARTICLES AND $NO_x$ IN GREATER STOCKHOLM

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# Contents

# Preface

This is a report resulting from the research project TESS – Traffic Emissions, Socioeconomic valuation and Socioeconomic measures that is financed by EMFO. In 2002 an agreement about the EMFO programme was reached between the partners from the Swedish Vehicle Research Council, PFF. EMFO is a sector-wide research competence to develop vehicles and vehicle components with emission levels that are sustainable in the long term. The aim of EMFO is to offer academia, industry and authorities access to necessary knowledge and pioneering solutions that are necessary if vehicle technology is to develop in the desired direction. One important task is to coordinate activities within the programme with both national and international research in the field.

EMFO comprises subsidiary programmes and two of these were: "Socio-economic evaluation of the health and environmental impact of different emissions" and "Optimal range of socio-economic measures". TESS undertakes research in these two areas but it is also related to the subsidiary programme: "Health and Environmental Impact". The application was approved in 2005 and the project runs during 2005-2008.

The basis for the research in TESS is the valuation methods developed in the EU funded ExternE projects where the external cost of emissions is calculated by tracing the effects that the emissions have on human health and then valuing these effects. The aim is to calculate the external costs related to particles that local emissions (from traffic and other sources) generate on a local and regional scale using Stockholm as a case study. Based on this information an analysis will be made on what reductions measures are likely to be efficient from an economic point of view.

The analysis undertaken in TESS requires collaboration between researchers from different research disciplines and therefore there are four parties involved in this project. Coordinator for the project is VTI, where Lena Nerhagen is project leader as well as responsible for the economic analysis. Christer Johansson and Kristina Eneroth at SLB analys (Environment and Health Administration, Stockholm) contribute with information about local emissions and perform dispersion model calculations for the Stockholm area. Bertil Forsberg at Umeå Universitet is responsible for the health impact assessment. Finally, Robert Bergström and Joakim Langner at SMHI undertake the regional scale dispersion modelling.

This report is the result of the first part of the TESS project, the emissions inventory and the dispersion modelling for Stockholm. This analysis has been undertaken by SLB analys using the Air Quality Management system of the Stockholm and Uppsala county air quality administration.

# Introduction

## General background

It has long been recognized that emissions from traffic have a negative impact on human health. In latter years there has been emerging consensus that the main influence is due to particulate matter (WHO, 2005). From an economic point of view these negative effects are external costs caused by traffic that, if not accounted for in decision making regarding transport, will result in a non-optimal allocation of resources leading to welfare losses. There are however various measures in place aimed at reducing the negative health impact (i.e. the external costs) of the emissions from traffic. The measures include emission control legislation but also air quality objectives for local concentration levels in urban areas that if exceeded compels the local authorities to take action. Also road pricing measures are increasingly considered as an option since the new information technology has opened up for new technical solutions. One such example is the Stockholm trial where rush hour road pricing was implemented, resulting in reduced traffic to and within the city area and thereby reductions in emissions and concentration levels.

To be able to implement road pricing measures, but also for the evaluation of other control measures through benefit-cost analysis, information on the external cost of traffic emissions is needed. In the Impact pathway approach (IPA), that has been developed in the ExternE projects, the external cost is calculated as the product of exposure, effect and value. All these inputs are the result of ongoing empirical research and they are all related to uncertainties, hence the external cost that is calculated is not “the” cost. Regarding particles there is for example recognition among the research community that there are different types of particles and that it is likely that their impact on human health differ. Still the current practice is to treat fine particles (which are considered to be most detrimental to health) as equally harmful irrespective of origin. Hence, there is only one function used for the health impact of fine particles (so called PM2.5). However, what is mostly measured in urban areas is the concentration of PM10 that contain both fine and coarse particles since the current air quality guidelines are based on these[1]. The most important local source of PM10 in many urban areas in Sweden is coarse particles from road wear (Omstedt et al., 2005). In spring, when the roadways are dry, the contribution from road wear particles may be 30 times the direct emissions from the exhaust pipe. These mechanically generated road dust particles are however not considered in calculations of the external cost that is based on the original ExternE-methodology (Friedrich and Bickel, 2001; Bickel and Friedrich, 2007).

In reality the measured concentrations of fine particles and PM10 in an urban area is composed of several types of particles such as combustion particles from different sources, non-exhaust particles from road wear and secondary particles from sources outside the city. Therefore it is not possible to assess the actual impact on health from local traffic emissions using measurement data of the total concentrations. The impact of different contributions to the total PM10 concentrations at street canyon and urban background in central Stockholm is illustrated in Figure 1.

Hence, in order to undertake analysis of the influence of traffic emissions on human health dispersion models are needed. There is however an additional problem with the current measurement on which Figure 1 is based. If we are only interested in exhaust particles from local traffic, measurements or modelling of PM2.5 are not relevant. This is because exhaust particles consist mainly of ultrafine particles (with diameters <0.1 µm) and hence their

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[1] There is a new EU-directive being prepared that will include limit values for both PM10 and PM2.5

(http://ec.europa.eu/environment/air/cafe/pdf/com_2005_447_en.pdf).

contribution to the concentration of PM2.5 is small. Therefore, in TESS we will not base the analysis on PM2.5 or PM10 but we will model the contribution of *exhaust* and *non-exhaust* and *secondary* particles.

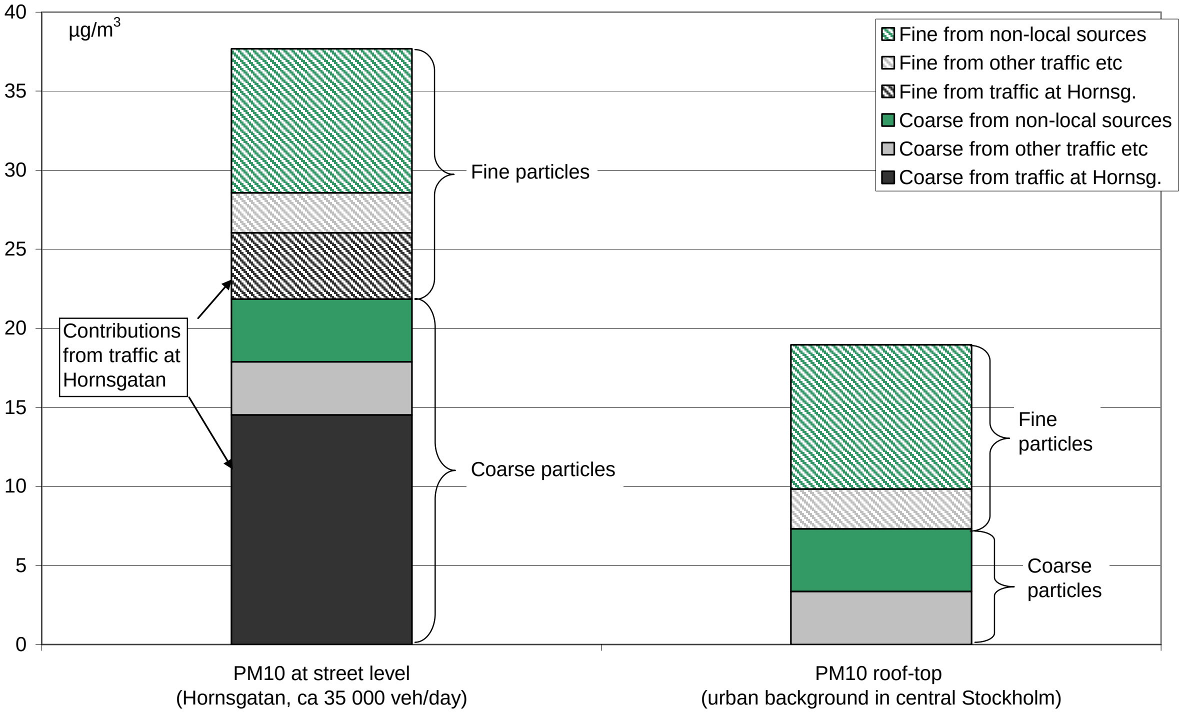

Figure 1. The relationship between the contribution from traffic and other sources to the PM10 concentration at a densely trafficked site (Hornsgatan) and at Urban background (a roof-top site) in central Stockholm (annual mean contributions). “Fine” particles refers to PM2.5 and “Coarse” particles to PM10-PM2.5.

In TESS the purpose is to investigate how important the external cost of traffic generated particle emissions are in relation to the cost of other particle emission sources. To do this we will both investigate how the exposure varies between sources but also assess if it is reasonable to assume that the impact differs between particle emissions from different sources. Recent research studies which in various ways have tried to estimate the separate impact of traffic exhaust emissions on health have found larger effects than studies using PM2.5 (Forsberg et al., 2005). One reason for this could be that although the mass concentration of exhaust particles is small the exhaust emissions largely contribute to the number of particles in urban air or that they are much more toxic than the particle fraction that dominate the PM2.5 levels. Nitrogen oxide concentrations are highly correlated with the number of exhaust particles (Gidhagen et al., 2004; Olivares et al., 2007), therefore $NO_x$ or $NO_2$ can be a good indicator for the exposure to particle exhaust emissions. In the present study we will also investigate the influence of local traffic and other sources on a regional scale, for example by studying secondary particle formation due to local emissions of $NO_x$ and $SO_2$. In the project we use Stockholm as a case study. The information on external costs will then be used to analyse the economic efficiency of different reduction measures.

## Particle sources in Stockholm

Exhaust particles from road traffic are concentrated in the 10-30 nm size intervals and normally dominate the total number of particles (PNC) in urban air. However, even in high number concentrations the ultrafine particles (UFP, diameter < 100 nm) are too small to build up aerosol mass and their contribution to the total PM10 levels at kerbside locations is consequently relatively small. Due to differences in source contributions and influence of meteorological conditions there are substantial differences in terms of the temporal and spatial distribution of total particle number and mass (as PM10) concentrations in Stockholm (Johansson et al., 2006; Johansson et al., 2004). The annual mean urban background PM10 levels are relatively uniformly distributed over the city. This is due to the importance of long range transport, which contributes with 60% to 70% to the annual mean value. Even close to roads, local vehicle exhaust emissions contribute to less than 10% of PM10 which is manifested in a poor correlation between PM10 and $NO_x$ (Johansson et al., 2006).

For particle number, the concentration is more than 5 times higher in the city centre compared to outside the city. Only 20% to 30% of the number concentration is caused by non-local sources. There is a very high correlation between particle number concentrations and $NO_x$ concentrations indicating the importance of vehicle exhaust emissions for particle number concentrations (Olivares et al., 2007; Gidhagen et al., 2004). Fig 2 shows the relation between PNC and $NO_x$ concentrations at Hornsgatan, Stockholm as a function of temperature. Both PNC and PM10 emissions depend on the speed of the vehicles and on vehicle fleet composition.

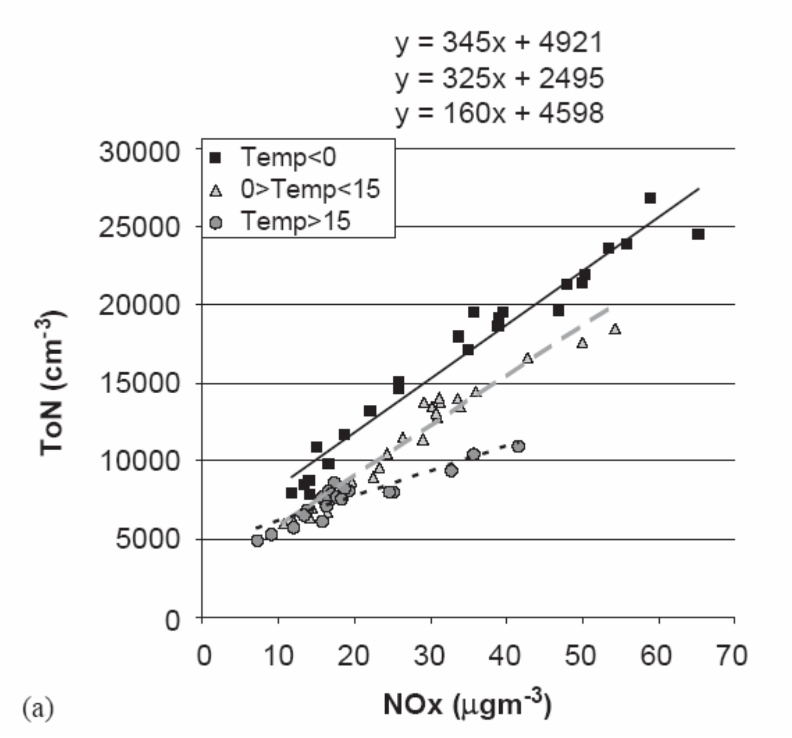

Figure 2. Relation between total particle number (ToN) and $NO_x$ concentrations at Hornsgatan, Stockholm (from Gidhagen et al., 2004).

The different source characteristics of PNC and PM10 may be important from an epidemiological point of view. In health impact studies of short term health effects based on time series analysis particle mass and number concentrations may not be well correlated and different health effects of number versus mass of particles may be observed. In long term studies analysing spatial variations in annual mean levels, PM10 and particle number concentration are well correlated since they have a common source in traffic and possible differences in health effects of the different particle metrics may not be readily seen. Short term studies of temporal variations will yield better possibilities to identify potential differences in the health response to PM10 and ultrafine particles (Johansson et al., 2006).

In this part of the TESS project we perform local exposure calculations of both traffic exhaust air pollutants ($NO_x$ and exhaust particles) and non-exhaust particles (road, brake and tyre wear) in the Stockholm area. In addition to road traffic, concentrations and emissions from sea traffic, energy production and residential heating are calculated.

# Methods

## Model calculations

The annual mean concentrations were calculated using a wind model and a Gaussian air quality dispersion model, both part of the Airviro Air Quality Management System (SMHI, Norrköping, Sweden; http://airviro.smhi.se). Meteorological conditions were based on a climatology that was created from 10 years of meteorological measurements (15 minute averages) in a 50 meters high mast located in the southern part of Stockholm. The climatology consists of a list of hourly events, each of them with a certain frequency of occurrence, which together will yield a distribution of different weather conditions that is similar to the distribution of the full scenario period. We have used a scenario that consist of 60 wind direction classes with 6 stability classes within each wind sector, making a total of 360 hourly events. The wind field for the whole model domain was calculated based on the concept first described by Danard (1977). This concept assumes that small scale winds can be seen as a local adaptation of large scale winds (free winds) due to local fluxes of heat and momentum from the sea or earth surface. Any non-linear interaction between the scales is neglected. It is also assumed that the adaptation process is very fast and that horizontal processes can be described by non-linear equations while the vertical processes can be parameterised as linear functions. The large scale winds as well as vertical fluxes of momentum and temperature are estimated from profile measurements in one or several meteorological masts (called principal masts). For the model domain analysed in this study (35x35 $km^2$) only one principal mast - located in the southern part of the city - is used. Topography and land use data for the Danard model are given by 500 meter resolution. Since the topography of Stockholm is relatively smooth, without dominating ridges or valleys, the free wind can be assumed to be horizontally uniform in the whole domain.

The dispersion calculations were performed on a 100 meter resolution (122 500 receptor points). The higher resolution in the dispersion calculations compared to the wind model (500 m) is justified by the fact that the emission data has much higher spatial resolution (around 10 m) than the wind model. Individual buildings and street canyons are not resolved but treated using a roughness parameter (similar to the treatment used by Gidhagen et al., 2005). In an open area the calculation height is 2 m above ground level. Over a city the simulation will reflect the concentrations at 2 meters above roof height. A special treatment of the Gauss model plume length is introduced to avoid unrealistically long plumes. This length depends on the stability and persistency of weather conditions. A detailed description of the model is given in the Airviro User Documentation (SMHI, 1993).

The model is continually validated against measurements at air quality monitoring stations in Stockholm and Uppsala operated by SLB analys.

## Emission data

Temporally and spatially resolved emissions are calculated for each hour based on the emission inventory of the Stockholm and Uppsala Air Quality Management Association (http://www.slb.nu/lvf). Information in this data base has been updated once per year since 1993. It is a geographic information system and contains detailed information about emissions from e.g. road and ferry traffic, petrol stations, industrial areas and households (Johansson et al., 1999).

### Road traffic

The Stockholm and Uppsala Air Quality Management Association emission inventory includes some 20 000 road links and an annual traffic volume of 12 500 million vehicle kilometres (data from 2001). Five vehicle types and six purification steps (EURO 0-5, 1987-2008) as well as 45 different road types are characterized. The classification of roads is based on the signed speed limit, the percentage heavy-duty traffic and the temporal (diurnal, weakly and annual) variation of the traffic. Furthermore, for every road link the emission factor varies depending on the vehicle speed (7 different speed intervals are defined).

Emission factors for $NO_x$ and exhaust particles from road traffic are obtained from the EVA model of the Swedish Road Administration. Emission factors for non-exhaust PM (mainly road wear but including some contributions from brake wear and tyre wear) were obtained from measurements in a street canyon using $NO_x$ as tracer (Omstedt et al., 2005).

### Sea traffic

Sea traffic includes ferries to and from Finland and the Baltic countries. The emissions occur in the harbour and during cruise. Diurnal and seasonal variations are described according to timetables and times in harbour. For the dispersion calculations it is important to describe how the plume is being emitted to the atmosphere:

| | |
|---|---|
| Chimney height | 50 m |
| Outer diameter of chimney | 1,0 m |
| Inner diameter of chimney | 0,7 m |
| Exhaust gas temperature | 120 °C |
| Exhaust gas velocity | 8 m/s |

### Energy production

Emissions from energy production have been divided into four categories depending on the size and purpose for production; energy production > 10MW, district heating < 10 MW and industrial energy power plants. The emissions are describe as individual point sources with their actual chimney heights, chimney diameters, plume temperature and plume exhaust velocity, i e data necessary for considering the dispersion of the plumes in the meteorological dispersion calculations. The emission data from the different energy production plants is obtained from the supervisory authority, i.e. the Stockholm Environment and Health Administration.

### Residential heating

Residential heating is defined as individual houses and small boilers for apartments. Fuels can be oil or biofuels. In the Greater Stockholm area about 30% of the PM10 residential heating emissions come from oil burning and about 70% come from residential wood burning. When it comes to $NO_x$ the relation is the opposite - the emissions from oil burning constitute about 80% of the total emissions whereas wood burning only contributes with about 20% to the residential heating emissions. Geographically the emissions are implemented as grid sources at 2 meters height, i.e. the release height and plume lifts of different individual appliances are not considered. The emissions occur evenly over all land area covered with residential areas, but where district heating is not available.

The quantity of fuel used for residential heating is obtained from the Statistics Sweden (Statistiska centralbyrån). Emission factors for fuel oil have been obtained from the Swedish Environmental Protection Agency (Naturvårdsverket) and rely on international recommendations from OECD. The emission factors are presented in Table 1.

Table 1. Emission factors for fuel oil used in residential heating (g/MJ).

| | $NO_x$ | CO | $CO_2$ | VOC | $SO_2$ |
|---|---|---|---|---|---|
| EO 1 | 0.05 | 0.05 | 75.3 | 0.003 | 0.03 |
| EO 2-5 | 0.1 | 0.075 | 76.2 | 0.005 | 0.18 |

For residential wood burning part of the national tax register has been used to obtain the emissions. In addition, the yearly report from the Swedish Rescue Services Agency (Räddningsverket) has been used to get information on different types of appliances (environmental classification, use of accumulator tank). Different municipalities have different emissions depending on this composition of appliances. Emission factors for wood burning are obtained from the Swedish National Testing and Research Institute’s (SP, Sveriges Provnings- och

Forskningsinstitut) report 2003:08 "BHM – småskalig biobränsleeldning" (http://www.itm.su.se/bhm). There are large uncertainties in the emissions from residential heating due to biomass burning.

### Off-road machinery

Off-road machinery includes working machinery used in road and building construction, industry, harbours, agriculture, forestry and households according to the report by IVL (1999, B1342; "Kartläggning av emissioner från arbetsfordon och arbetsredskap i Sverige"). Emission factors for diesel engines running on standard diesel have been taken from Corinair 94. Since most machines run on MK1 diesel the emission factors have been reduced by 10% for $NO_x$ and 15% for particles. Gasoline driven 4- and 2-stroke engines are based on laboratory measurements at MTC and factors estimated from the EMV model.

The emissions from off-road machinery are distributed geographically as area sources. They are not included when dispersion calculations are performed since the real temporal and geographic variation is unknown.

# Results and Discussion

## Emissions

Table 2 shows the total emissions of $NO_x$ and particles from road and sea traffic, power plants, residential heating and off-road (working) machinery in the greater Stockholm area. For $NO_x$, light and heavy duty vehicle emissions from road traffic are the largest sources. Table 3 shows that the mean emission factor (g per vehicle kilometre for the greater Stockholm area) for heavy duty vehicles is more than 10 times larger compared to light duty vehicles. However, on average heavy duty vehicles account for only around 6% of the total traffic transports. Around 6% of the $NO_x$ emissions from light duty vehicles are due to light duty diesel vehicles.

Energy production and off-road machinery are about equally important.

For combustion[2] particles around twice as much is emitted from light duty vehicles as compared to heavy duty vehicles. Light duty diesel cars account for about 40% of the total light duty vehicle emissions. As shown in Table 3 the emission factor for heavy duty vehicles is more than 7 times larger than light duty vehicles.

Other (than vehicle exhaust) large sources of combustion particles are power plant emissions and residential heating. The main part (70%) of the emission of combustion particles from residential heating is due to biomass combustion.

For off-road machinery only combustion particles is included. Road and building construction/maintenance work will generate large amounts of non-combustion particles, but this has not been estimated here.

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[2] Combustion particles in vehicle exhaust is also termed "exhaust particles" in this text.

Table 2. Total emissions (tons/year) of $NO_x$ and particles from road traffic and other sources in the Greater Stockholm (35x35 $km^2$) area during 2003. LDV=light-duty vehicles. HDV=heavy-duty vehicles.

| | **Road traffic** | **Sea traffic**[a] | **Energy production** | **Residential heating** | **Off-road vehicles** | **Other** | **Sum** |
|---|---|---|---|---|---|---|---|
| $NO_x$ (LDV) | 3029 | | | | | | |
| $NO_x$ (HDV) | 2645 | | | | | | |
| **$NO_x$ Total** | **5674** | **885** | **2002** | **487** | **1913** | **231** | **11180** |
| | | | | | | | |
| Exhaust particles (LDV) | 82 | | | | | | |
| Exhaust particles (HDV) | 40 | | | | | | |
| Exhaust particles (all vehicles) | 122 | | | | | | |
| Non-exhaust particles (road, brake and tyre wear[b]) | 1859 | | | | | | |
| Combustion particles (other than from road traffic) | | 33 | 249 | 490 | 110[c] | 46 | 1050 |
| **Total PM emissions** | **1981** | **33** | **249** | **490** | **110**[c] | **46** | **2909** |

[a] Emissions from pleasure boats and merchant shipping are not included.

[b] Only non-combustion particles with a diameter <10 µm. The size is mainly larger than 1 µm.

[c] Only combustion particles due to the use of diesel fuel. Emissions of brake,

Table 3. Mean emission factors of $NO_x$ and particulate matter in the Greater Stockholm area (grams per vehicle kilometre) from road traffic. LDV=light-duty vehicles. HDV=heavy-duty vehicles.

| | Emission factor (g/vkm) |
|---|---|
| $NO_x$ (LDV) | 0,50 |
| $NO_x$ (HDV) | 6,61 |
| $NO_x$ (all vehicles ) | 0,88 |
| Exhaust particles (LDV) | 0,014 |
| Exhaust particles (HDV) | 0,10 |
| Exhaust particles (all vehicles) | 0,019 |
| Non-exhaust particles (sum of road, brake and tyre wear) | 0,29 |

Figure 2 shows the relative contribution of emissions of $NO_x$ and PM10 from different source sectors in the Greater Stockholm area. The road traffic dominates the emissions of particles measured as PM10 and $NO_x$, whereas residential heating is the dominating source for combustion particles. There are, however, large uncertainties in the emissions from residential heating due to biomass burning.

Combustion particles (including vehicle exhaust particles) are part of PM10, but PM10 also include non-combustion particles. In this case non-combustion particles come from road traffic due to mechanical wear of road, brakes and tyres. Road wear is the dominating contributor, but the contributions from brakes and tyres are somewhat uncertain (Johansson et al., 2004).

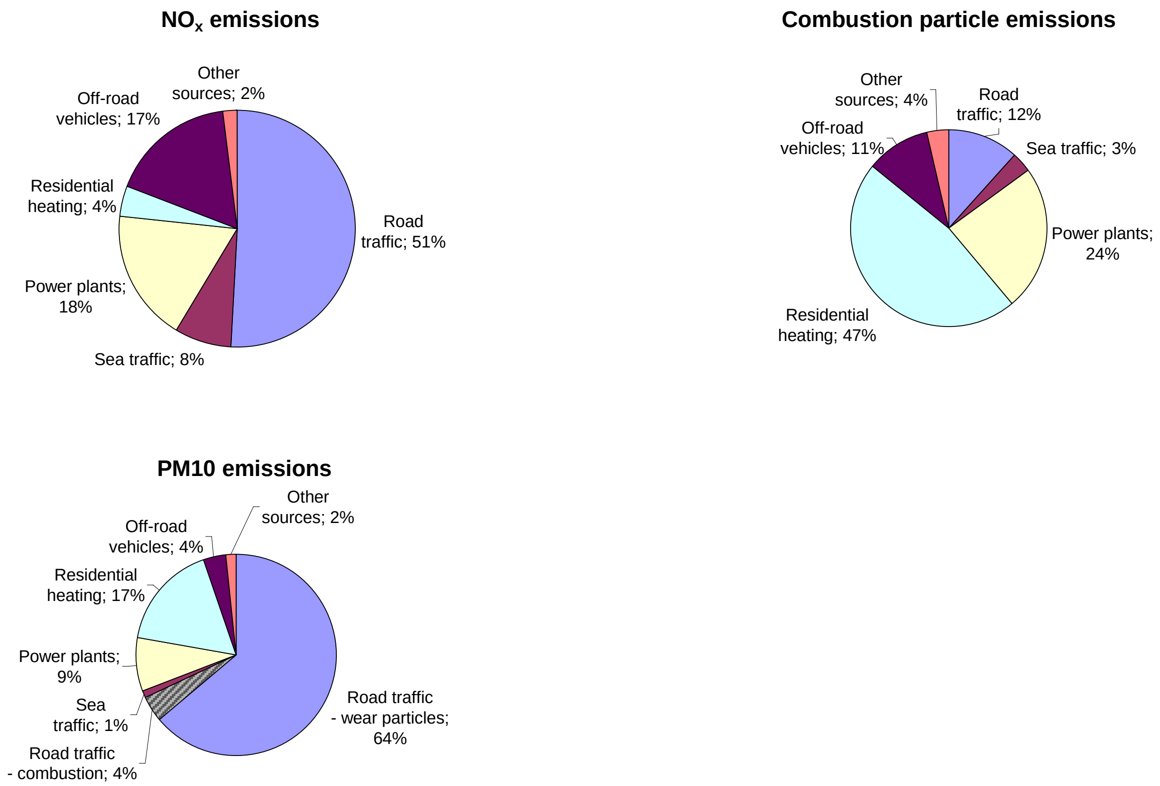


Figure 1. Percentage contribution of emissions of $NO_x$, combustion particles and PM10 from different source sectors in the Greater Stockholm area 2003.

### Size and chemistry of particle emissions

Size, shape and chemistry differ substantially between particles from different sources. The main mass of road wear particles consists of stone material particles that are larger than about 1 µm (Gustafsson et al., 2005). Particles from wear of brakes consist of metals and may be both fine and coarse but there is not so much data on the size distribution (Gustafsson, 2001). Likewise tyre particles may be fine and coarse depending on the type of tyre and road surface conditions and they consist of rubber material with traces of metals and PAH (Gustafsson, 2001). The sizes of vehicle exhaust particles are less than 0,2 µm and they consist mainly of soot and organic compounds (Kristensson et al., 2004). The particle size distribution of particles from wood burning can vary drastically but in general they are smaller than 0,2 µm and they consist of soot and organic compounds.

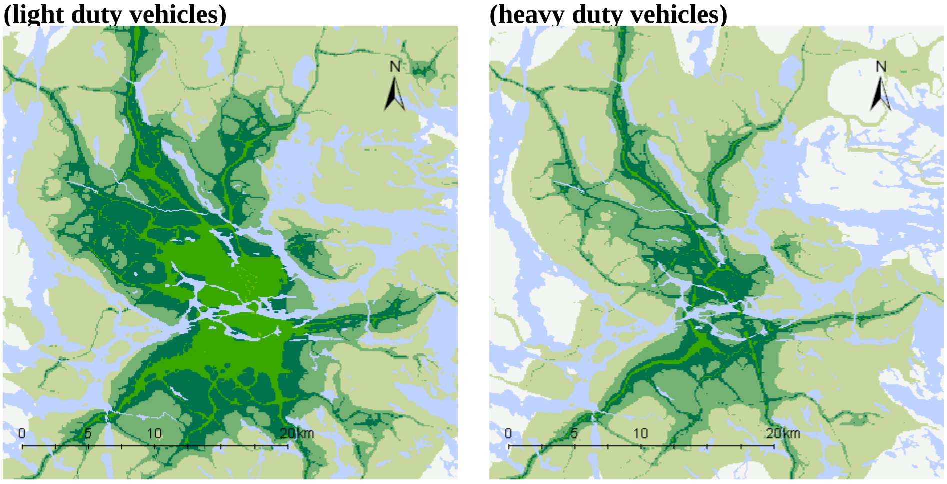
In the real world particles from different sources may be mixed depending on the distance from the sources and the meteorological conditions.

## Concentrations – geographic distribution and contribution from different sectors

Figures 3 and 5 show model calculated concentrations of PM10 and $NO_x$ due to different sources in the Greater Stockholm area. The single largest contribution to the total concentrations of particles (PM10) is due to non-combustion particle emissions from road traffic, whereas light duty and heavy duty vehicle exhaust emissions are the dominating sources of $NO_x$.

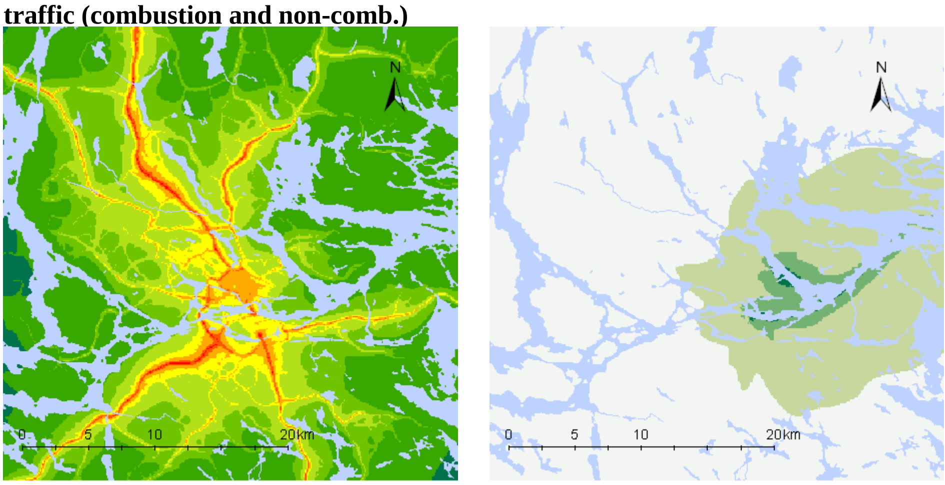
**Combustion particles from road traffic (light duty vehicles)**

**Combustion particles from road traffic (heavy duty vehicles)**



**Total particle concentrations from road traffic (combustion and non-comb.)**

**Combustion particles from sea traffic**



**Combustion particles from energy production**

**Combustion particles from residential heating**

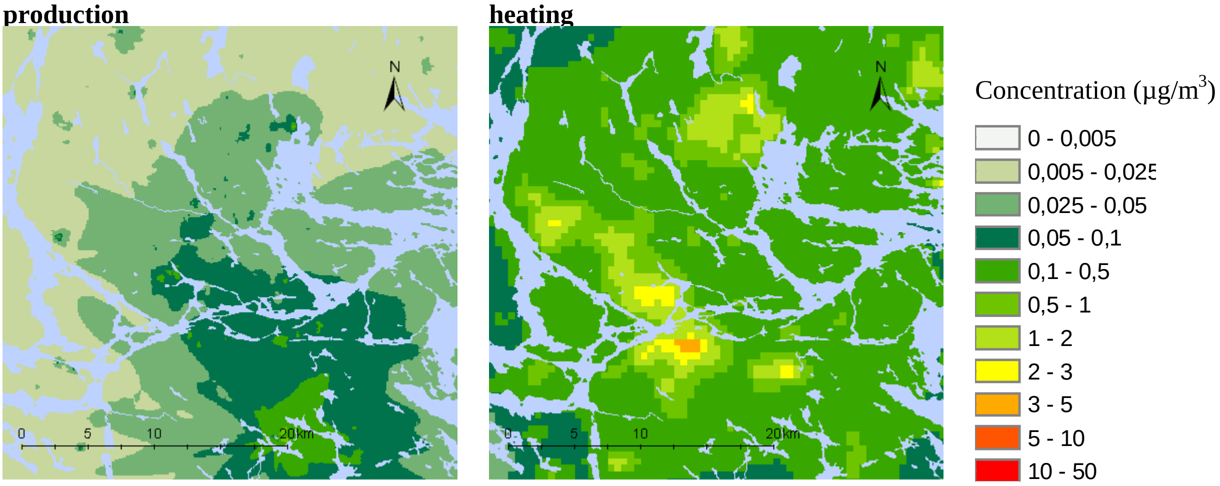


Figure 2. Simulated yearly mean PM10 concentrations due to different sources in the Greater Stockholm area.

Long-range transport is much more important for the urban and kerb-side PM10 annual mean levels as compared to particles number concentration (PNC). Figure 3 shows the calculated relative variation of the total annual mean urban background concentrations of PNC and PM10 in the Greater Stockholm area (35x35 $km^2$, 100 meter spatial resolution) (from Johansson et al., 2006). The values have been normalized to the rural background level, which is 3200 $cm^{-3}$ for PNC (Gidhagen et al., 2005) and 10 $\mu g/m^3$ for PM10 (Forsberg et al., 2005). Only road traffic emissions are included in the local emissions. Maximum PNC levels in central Stockholm are more than 5 times higher than background levels. For PM10 much smaller gradients are observed, maximum levels in central Stockholm are only 2 times higher than rural background levels.

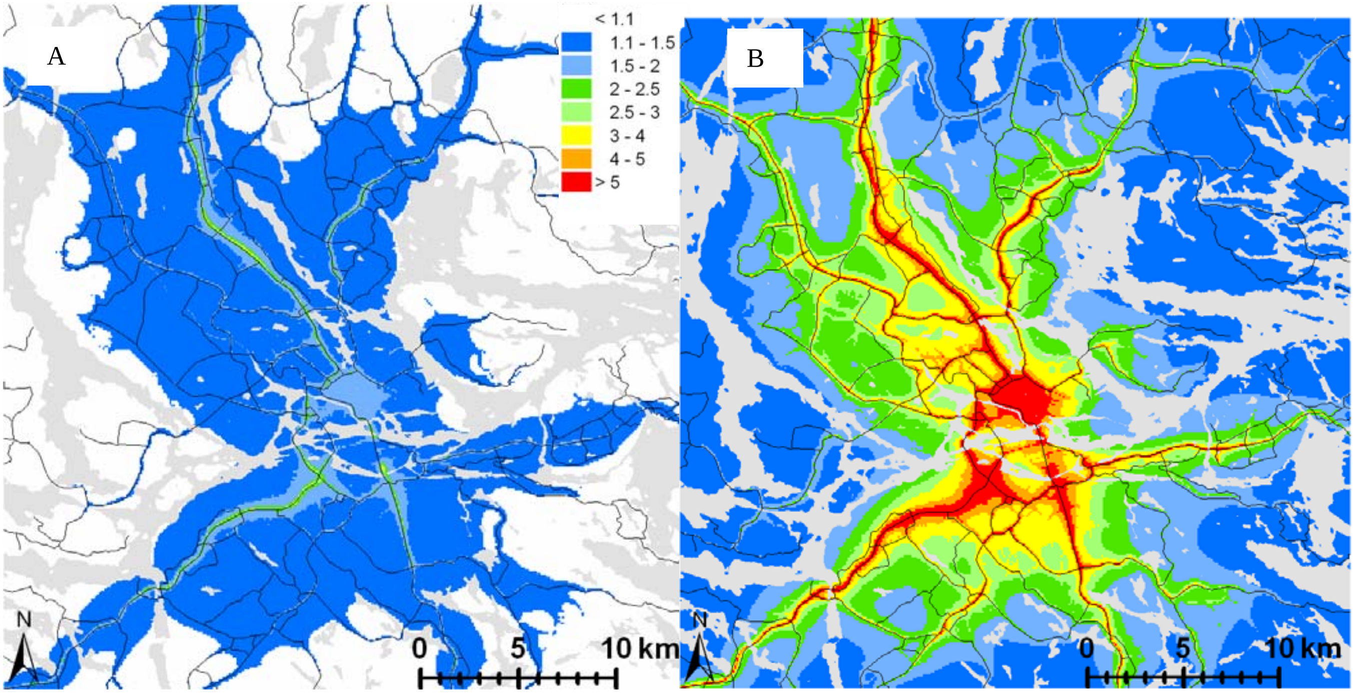
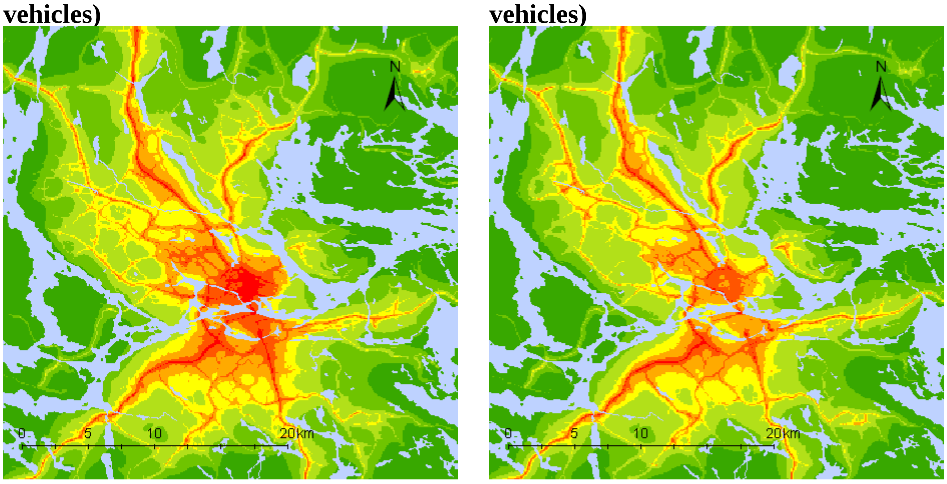
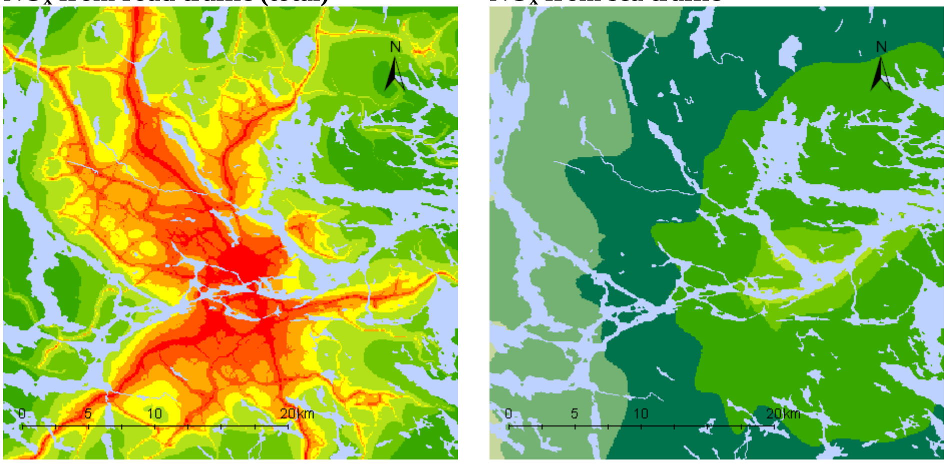


Figure 3. Model calculated relative spatial variation of annual mean concentrations of A) PM10 and B) PNC (total particle number concentration) in the Greater Stockholm area (35x35 $km^2$). The colours indicate the increase above rural background (10 $\mu g\ m^{-3}$ for PM10 and 3500 $cm^{-3}$ for PNC) due to local traffic emissions in the area.

**NO$_x$ from road traffic (light duty vehicles)** **NO$_x$ from road traffic (heavy duty vehicles)**



**NO$_x$ from road traffic (total)** **NO$_x$ from sea traffic**



**NO$_x$ from energy production** **NO$_x$ from residential heating**

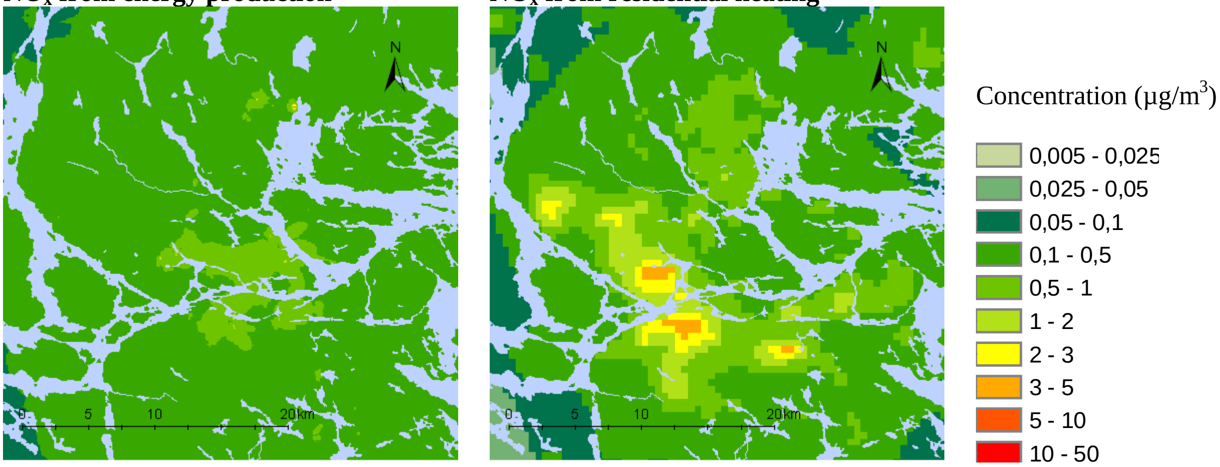


Figure 4. Simulated yearly mean NO$_x$ concentrations due to different sources in the Greater Stockholm area.

## Population weighted concentrations

The population weighted and arithmetic mean concentrations of PM and $NO_x$ due to different sources are presented in Tables 4  and 5, respectively. For both $NO_x$ and combustion particles the population weighted values are higher than the arithmetic mean values. For light duty vehicle contributions population weighted concentrations are 2,6 and 2,8 times higher than the arithmetic mean values for $NO_x$ and combustion particles, respectively. This is due to the fact that most emissions occur in the most densely populated areas. Emissions from sea traffic occur east of the city centre, in less populated areas, as compared to light duty vehicle emissions. Thus, for sea traffic much smaller differences between population weighted values and arithmetic mean values is seen; 11 % and 20 %, higher population weighted values for $NO_x$ and combustion particles, respectively.

Table 4. Arithmetic mean concentrations of $NO_x$ and particles ($\mu g/m^3$).

| Substance | Road traffic | Road traffic, ldv[1] | Road traffic, hdv[2] | Sea traffic | Power plants | Residential heating |
|---|---|---|---|---|---|---|
| $NO_x$ | 2.46 | 1.32 | 1.14 | 0.16 | 0.26 | 0.37 |
| Particles (excluding non-exhaust road traffic) | 0.053 | 0.036 | 0.017 | 0.0052 | 0.037 | 0.36 |
| Non-exhaust road traffic particles | 0.79 | | | | | |

[1] ldv = light duty vehicles

[2] hdv = heavy duty vehicles

Table 5. Populated weighted mean concentrations of $NO_x$ and particles ($\mu g/m^3$).

| Substance | Road traffic | Road traffic, ldv[1] | Road traffic, hdv[2] | Sea traffic | Power plants | Residential heating |
|---|---|---|---|---|---|---|
| $NO_x$ | 5.86 | 3.14 | 2.44 | 0.18 | 0.36 | 0.68 |
| Particles (excluding non-exhaust road traffic) | 0.14 | 0.10 | 0.036 | 0.0063 | 0.051 | 0.59 |
| Non-exhaust road traffic particles | 1.56 | | | | | |

[1] ldv = light duty vehicles

[2] hdv = heavy duty vehicles

For $NO_x$, road traffic emissions dominate the exposure. For combustion particles and PM10, residential heating might be of some importance, but the emissions are uncertain. Figure 6 shows the contributions of different local sources in the Greater Stockholm area to the population weighted concentrations of $NO_x$ and combustion particles. For $NO_x$, light and heavy duty vehicle emissions account for around 50% and 35%, respectively to the total local exposure concentrations. For $NO_x$, residential heating contribute with only 10%, whereas for combustion particles 75% is due to emissions from residential heating. As discussed above particle emissions from residential heating are mainly (74%) due to wood combustion; only 26% is due to combustion of fossil fuels. There are large uncertainties in wood combustion emissions.

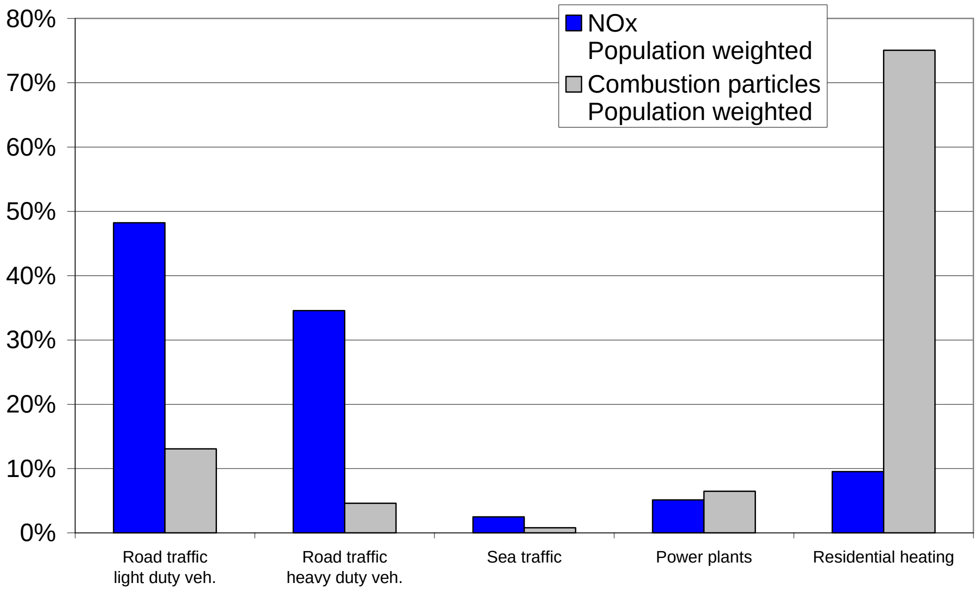


Figure 5. Contributions of different local sources in the Greater Stockholm area to the population weighted concentrations of $NO_x$ and combustion particles in the area.

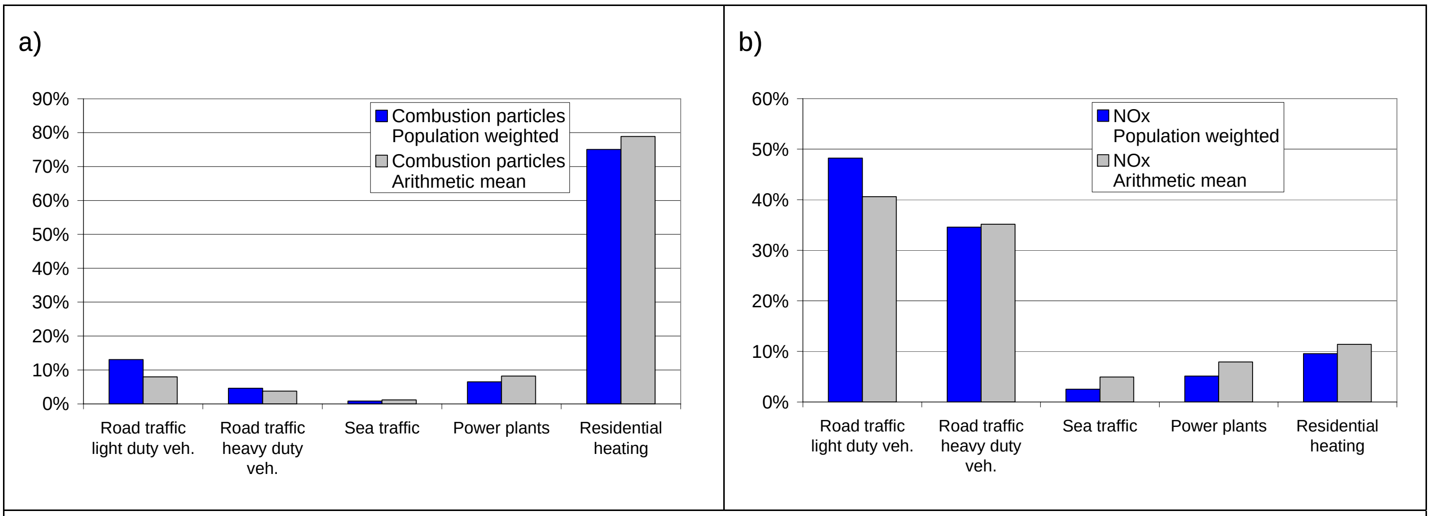


Figure 6. Comparison between the arithmetic mean and population weighted mean concentration contributions from different sources for a) combustion particles and b) NOx.

## Traffic air pollutants on the regional scale

To study the regional impact of air pollutants emitted in the Stockholm area, exposure calculations for a larger region (covering Copenhagen, Oslo, Helsinki, St Petersburg and the coastline of the Baltic States) will be performed by SMHI. Input emission data for these regional simulations were extracted from the 2003 emission data base administrated by the Stockholm – Uppsala Air Quality Management Association, i.e. the same data base that was used for the local exposure calculations.

Total annual emissions of $NO_x$, particulate matter, VOC and $SO_2$ was calculated for the sectors; road traffic, sea traffic, energy production and residual heating. The emissions from road traffic were divided into emissions from heavy-duty vehicles and light-duty vehicles, respectively. The emissions of particulate matter from road traffic were calculated both for exhaust and non-exhaust emissions. The energy production sector included emissions from power plants > 10 WW (energy production), power plants < 10 WW (district heating) and industrial energy power plants. The residual heating sector included emissions from both wood burning and combustion of oil fuel (not $SO_2$, which only included emissions from oil combustion). The emissions from sea traffic did not include emissions from pleasure boats and working ships.

The emission data was extracted for the Greater Stockholm area (35x35 $km^2$) on a 5 km resolution, resulting in 49 grid squares per pollutant and sector (see Figure 8).

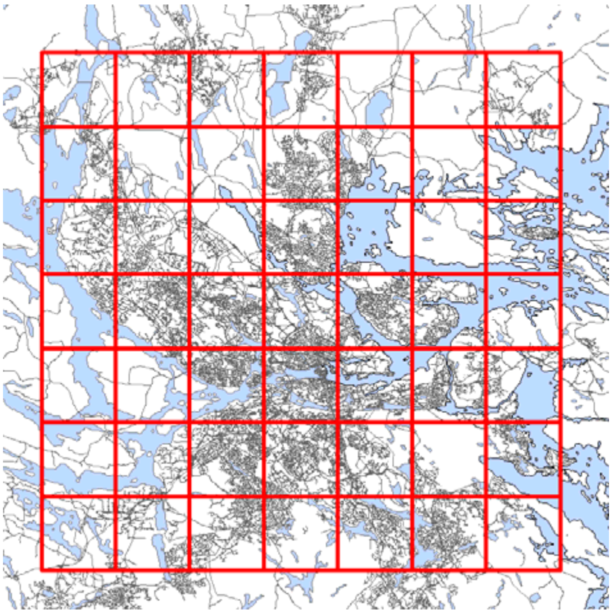
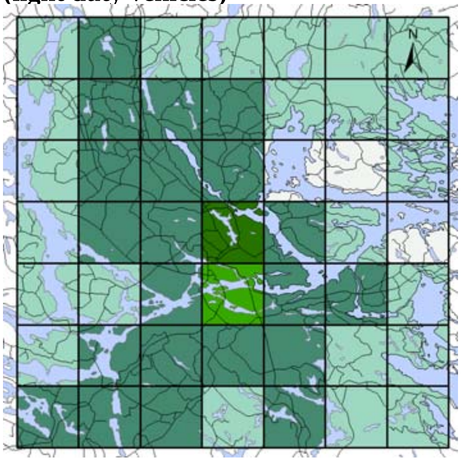


Figure 8. Grid net over the Greater Stockholm area (35x35 $km^2$).

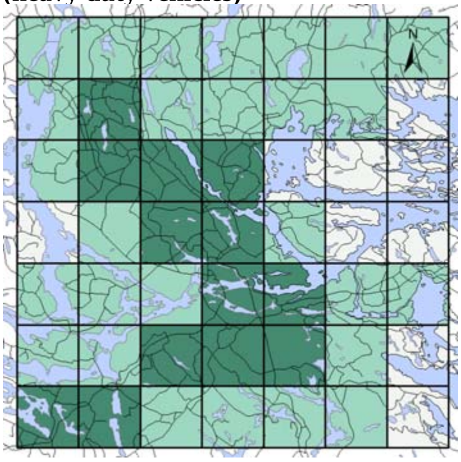
Figures 9-12 present emissions of PM, $NO_x$, VOC and $SO_2$ due to different sources for the 49 grid squares in the Greater Stockholm area.

## PM10 emissions 2003

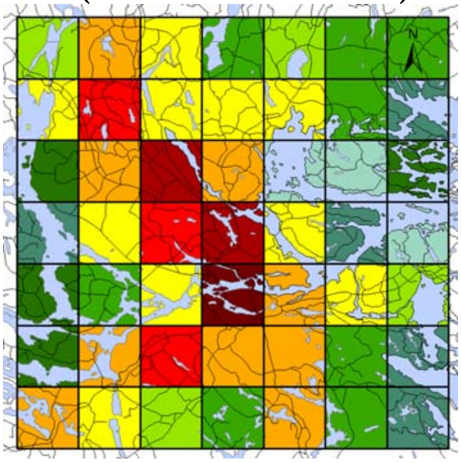
**Combustion particles from road traffic (light duty vehicles)**



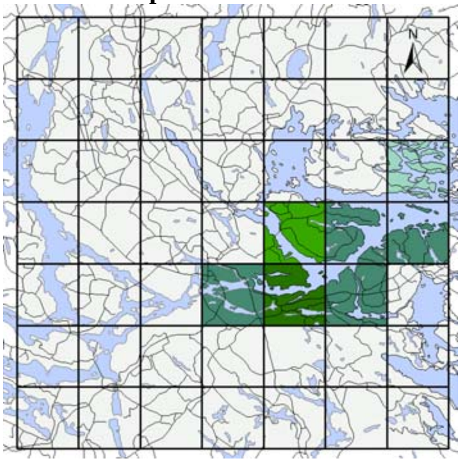
**Combustion particles from road traffic (heavy duty vehicles)**



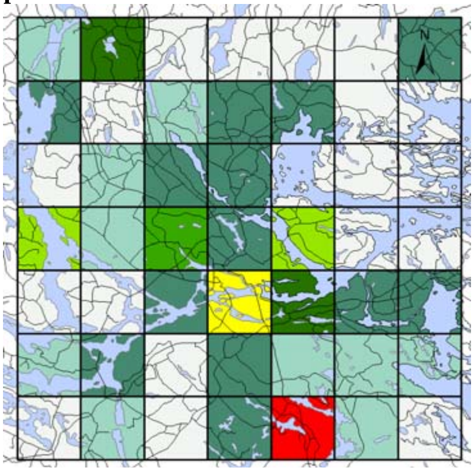
**Total particle emissions from road traffic (combustion and non-comb.)**



**Combustion particles from sea traffic**



**Combustion particles from energy production**



**Combustion particles from residential heating**

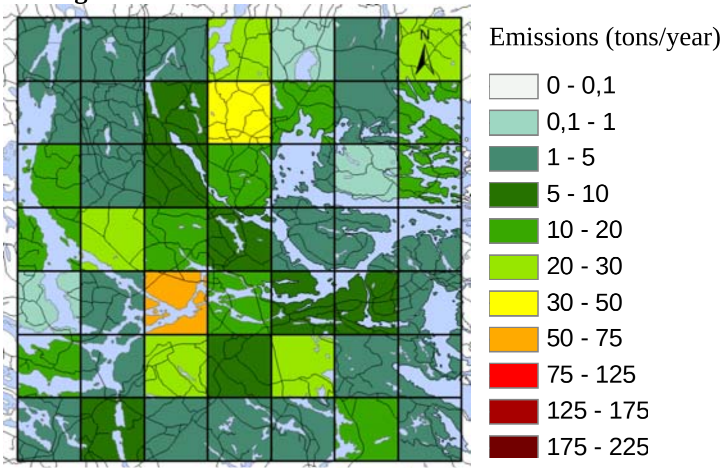
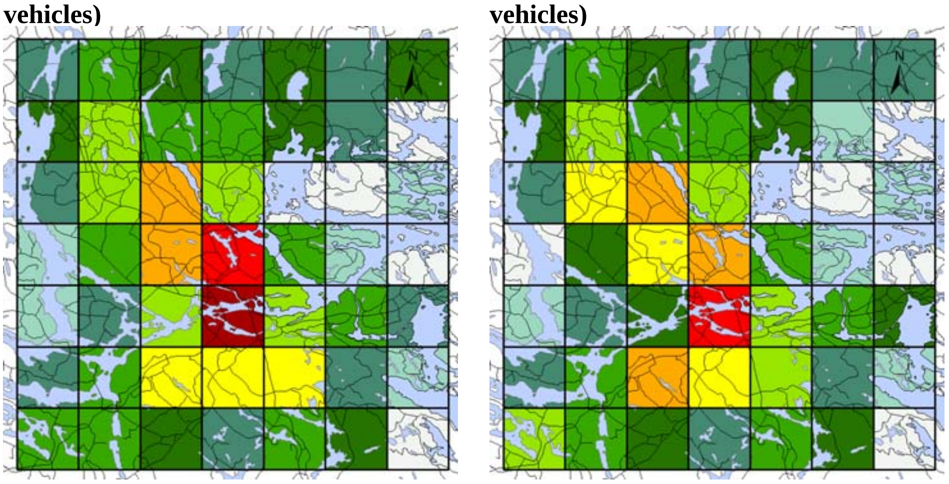


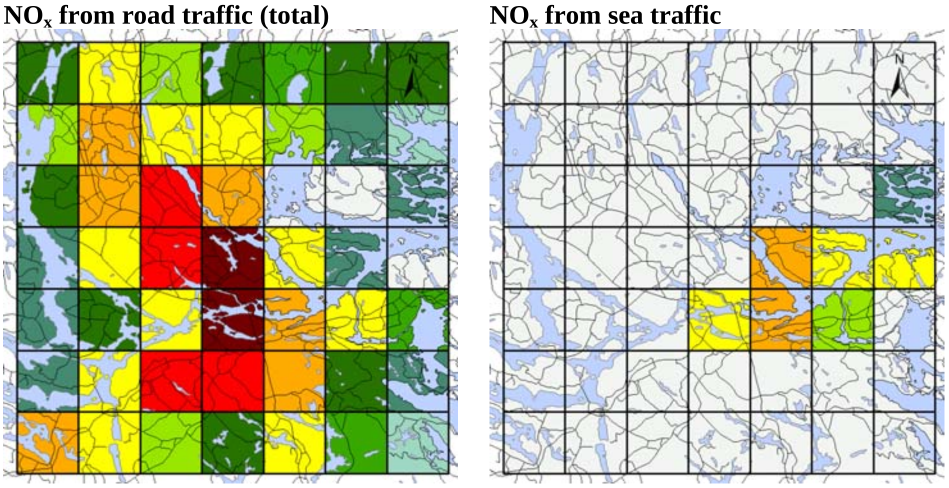
Figure 9. Emissions of particulate matter in the Greater Stockholm area, 2003.

## NO$_x$ emissions 2003



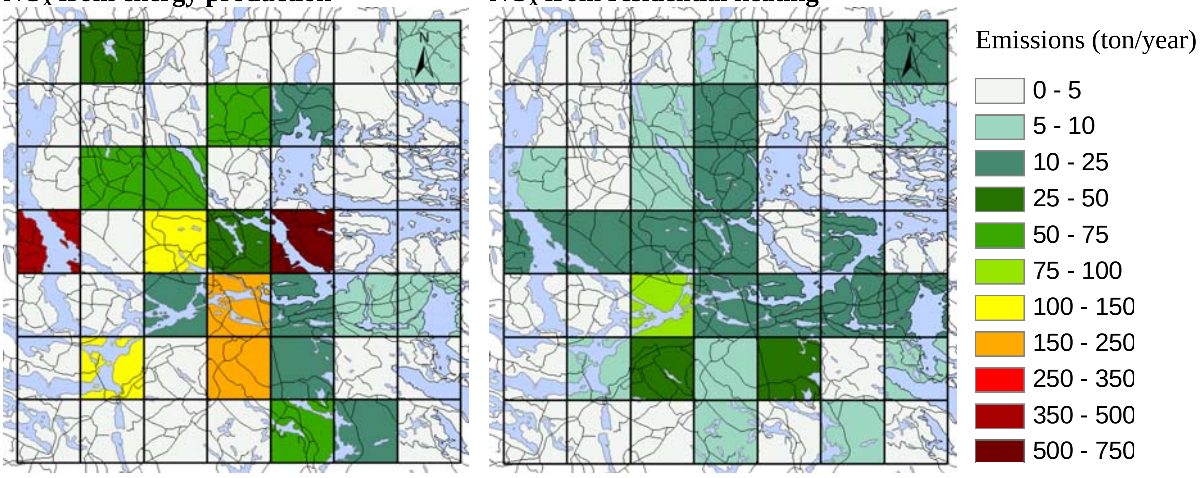
**NO$_x$ from road traffic (light duty vehicles)**

**NO$_x$ from road traffic (heavy duty vehicles)**



**NO$_x$ from road traffic (total)**

**NO$_x$ from sea traffic**

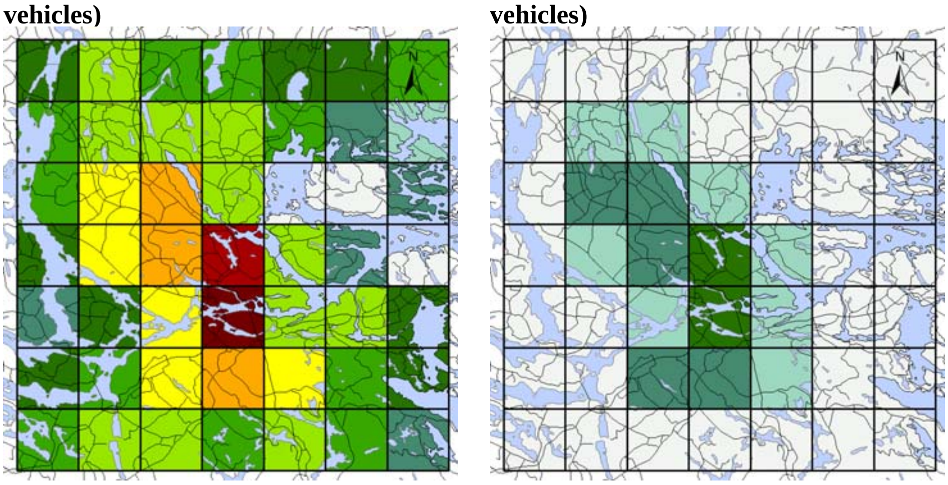


**NO$_x$ from energy production**

**NO$_x$ from residential heating**

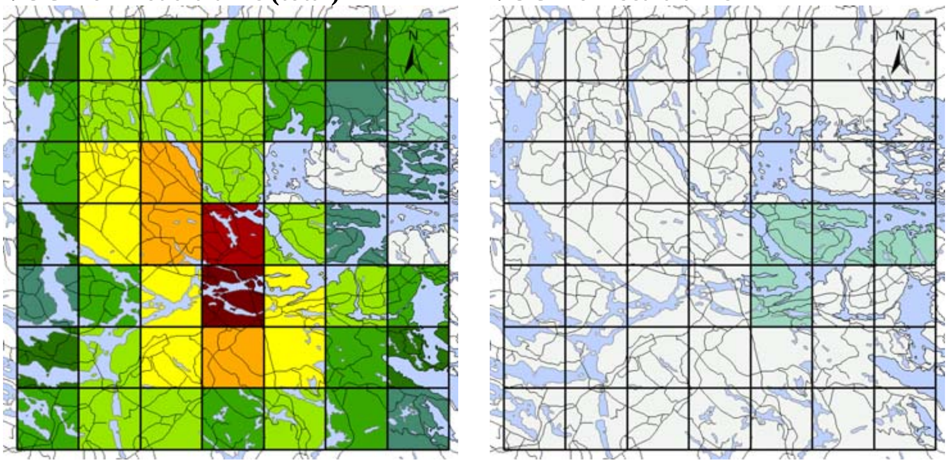
Figure 10. Emissions of NO$_x$ in the Greater Stockholm area, 2003.

## VOC emissions 2003



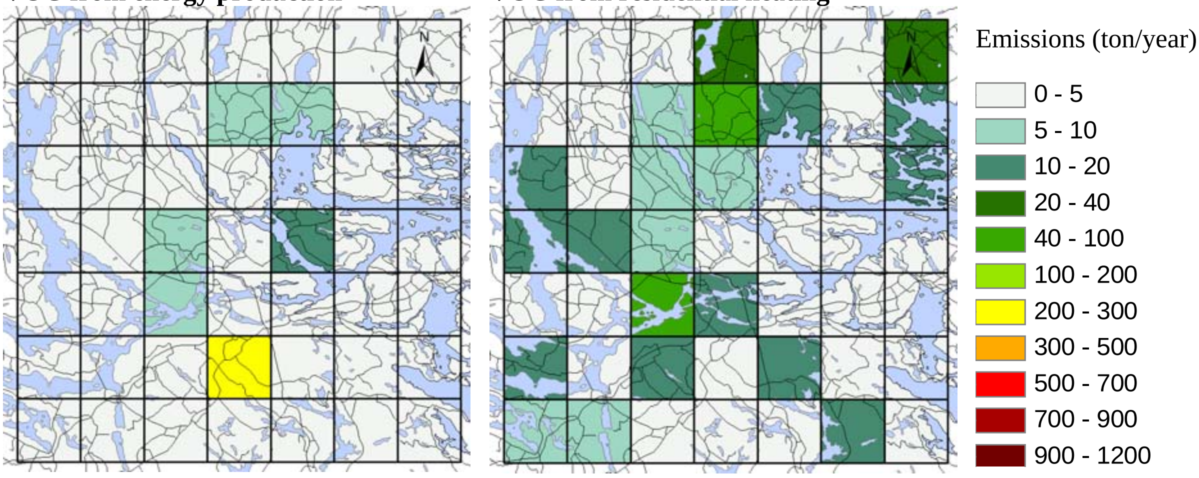
VOC from road traffic (light duty vehicles)

VOC from road traffic (heavy duty vehicles)



VOC from road traffic (total)

VOC from sea traffic

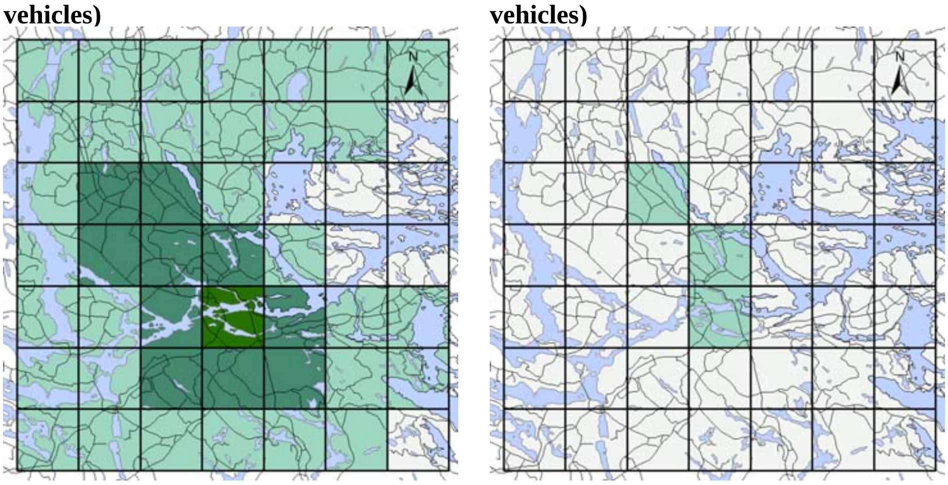


VOC from energy production

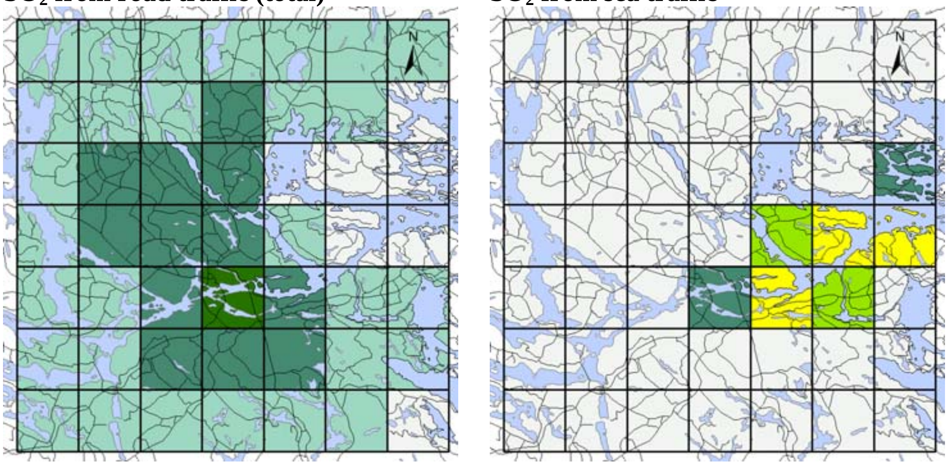
VOC from residential heating

Figure 11. Emissions of VOC in the Greater Stockholm area, 2003.

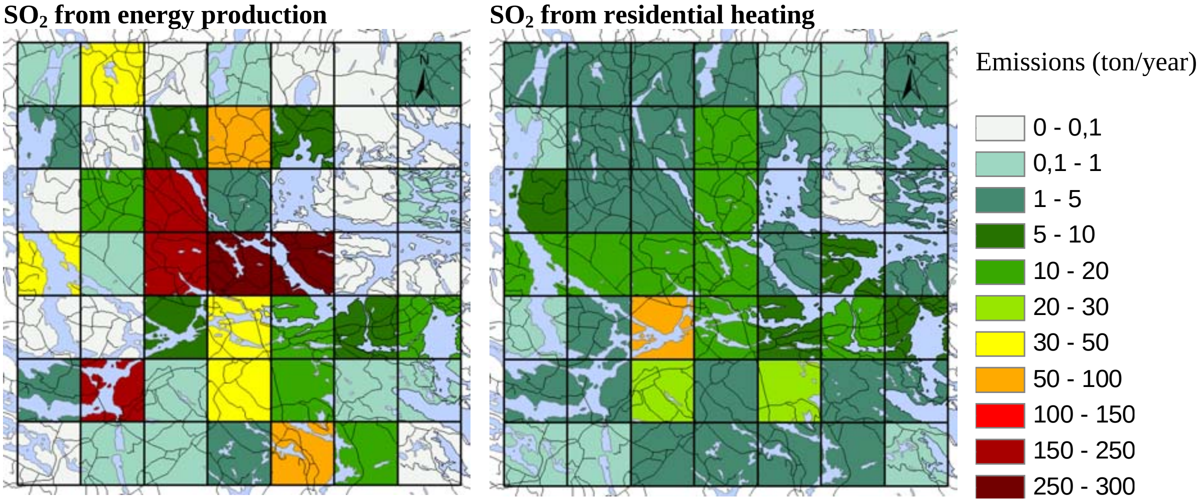
## SO$_2$ emissions 2003


SO$_2$ from road traffic (light duty vehicles)

SO$_2$ from road traffic (heavy duty vehicles)


SO$_2$ from road traffic (total)

SO$_2$ from sea traffic


SO$_2$ from energy production

SO$_2$ from residential heating

Figure 12. Emissions of SO$_2$ in the Greater Stockholm area, 2003.

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