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Dispersion and Exposure Calculations of PM_{10}, NO_2 and Benzene in Oslo and Trondheim for 2007

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Executive Summary

Commissioned by the Norwegian Pollution Control Authority (SFT), NILU has performed dispersion and exposure calculations for PM_{10}, NO_2 and Benzene (C_6H_6) in Oslo and Trondheim for 2007. The calculations have been performed through use of AirQUIS, a NILU developed modelling system (AirQUIS, 2006).

NILU has calculated the outdoor concentration levels of PM_{10}, NO_2 and C_6H_6 (Benzene) for the winter season (January through April, and October through December)for 2007. Ambient air concentrations and population exposure have been calculated both in the positions of buildings located close to the main road network, and within a two-dimensional grid domain (quadratic 1 km^2 grid size). The inhabitants of the representative buildings are assigned to the building point concentrations, while the remaining population is assigned concentration values computed in the grids containing the location of their home address.

The exposure calculations have been performed with respect to the goals defined in the "National Air Quality Targets"(Statens forurensningstilsyn 1998). These targets specify that during a one year period the following limits should be met: no more than 8 hours (hourly mean) of NO_2 concentration levels above 150 $\mu g/m^3$, no more than 7 days (daily mean) of PM_{10} concentration levels above 50 $\mu g/m^3$, and the yearly averaged Benzene concentration should not exceed 2 $\mu g/m^3$. The total exposure results for Oslo and Trondheim for 2007 (and 2005) are summarized in Table A.

Table A: Number of people exposed to exceedances of the goals defined in the "National Air Quality Targets" for PM_{10}, NO_2 and Benzene in Oslo and Trondheim for 2007. Results for 2005 are given in parenthesis.

	OSLO	**TRONDHEIM**
PM_{10}	186 744 (235 849)	4994 (20 914)
NO_2	4193 (652)	85 (40)
Benzene	6224 (31585)	0 (0)

When considering the exposure estimate presented in Table A, it should be noted that relatively small changes in the calculated concentration levels can result in large changes in the numbers of inhabitants exposed to exceedances. This is especially the case when grid square concentrations in proximity to the target value are computed.

For the building points and grid squares in which exceedances of the "National Air Quality Targets" have been found, the relative contribution from the main source categories have also been estimated. When performing this source apportionment calculation, only hours (for NO_2) and days (for PM_{10}) contributing to the exceedances have been considered, and the final estimate is the average percent contribution from the various sources. No source apportionment estimate was performed for Benzene in this study.

The average source contribution (in percent) to the exceedances are summarized in Tables B, C, D, and E. Since only buildings in the vicinity of the main roads have been treated separately as building points, the exceedances in these points are naturally influenced by traffic. The main source for exceedances is clearly road traffic for both components. For PM_{10}, domestic wood combustion is the second most dominant local source.

Table B: Source contribution (percentage) to the exceedances of the "National Air Quality Targets" for NO_2 for Oslo in 2007.

Calculated in	Domestic wood comb.	Traffic	Regional background	Other sources
Building points	0.06	93.52	0.18	6.25

Table C: Source contribution (percentage) to the exceedances of the "National Air Quality Targets" for PM_{10} for Oslo in 2007.

Calculated in	Domestic wood comb.	Traffic	Regional background	Other sources
Building points	20.68	72.26	4.60	2.46
Grid squares	29.71	62.29	3.90	4.10

Table D: Source contribution (percentage) to the exceedances of the "National Air Quality Targets" for NO_2 for Trondheim in 2007.

Calculated in	Domestic wood comb.	Traffic	Regional background	Other sources
Building points	0.02	98.88	0.32	0.78

Table E: Source contribution (percentage) to the exceedances of the "National Air Quality Targets" for PM_{10} for Trondheim in 2007.

Calculated in	Domestic wood comb.	Traffic	Regional background	Other sources
Building points	10.10	83.50	5.95	0.45

Note: A Norwegian version of the Executive Summary can be found in Appendix E

Dispersion and Exposure Calculations of PM10, NO2 and Benzene in Oslo and Trondheim for 2007

1 Introduction

Commissioned by the Norwegian Pollution Control Authority (SFT), NILU has performed dispersion and exposure calculations for PM_{10}, NO_2 and Benzene (C_6H_6) in Oslo and Trondheim for 2007. The calculations have been performed through use of AirQUIS, a NILU developed modelling system (AirQUIS, 2006).

NILU has calculated the outdoor concentration levels of PM_{10}, NO_2 and C_6H_6 (Benzene) for the winter season (January through April, and October through December)for 2007. Ambient air concentrations and population exposure have been calculated both in the positions of buildings located close to the main road network, and within a two-dimensional grid domain (quadratic 1 km^2 grid size). The inhabitants of the representative buildings are assigned to the building point concentrations, while the remaining population is assigned concentration values computed in the grids containing the location of their home address.

The exposure calculations have been performed with respect to the goals defined in the ”National Air Quality Targets” (Statens forurensningstilsyn 1998). These targets specify that during a one year period the following limits should be met: no more than 8 hours (hourly mean) of NO_2 concentration levels above 150 $\mu g/m^3$, no more than 7 days (daily mean) of PM_{10} concentration levels above 50 $\mu g/m^3$, and the yearly averaged Benzene concentration should not exceed 2 $\mu g/m^3$.

For the building points and grid squares in which exceedances of the “National Air Quality Targets” have been found, we have estimated the relative contribution from the main source categories; traffic and domestic wood combustion. When performing this source apportionment calculation, only hours (for NO_2) and days (for PM_{10}) contributing to the exceedances have been considered, and the final estimate is the average percent contribution from the various sources. No source apportionment estimate was performed for Benzene in this study.

2 Input data

The input data for the dispersion and exposure calculations consist of:

1. Meteorological data.
2. Consumption data on various fuel types (or as grid distributed area sources).
3. Road traffic data.
4. Background concentration levels of NO_2, Ozone, and PM_{10} for application as boundary conditions (at the open model boundaries during the simulation period).

5. Population distribution both in building points and in the grid squares[1]..

2.1 Meteorological data

The diagnostic wind field model *Mathew* (Sherman, 1978; Foster et al., 1995) has been applied to compute the three-dimensional wind field within the model domain for both Oslo and Trondheim. This model use measured meteorological data (wind speed, wind direction, air temperature, and atmospheric stability) to construct a three-dimensional wind field which also incorporates the modifying effects of the underlying topography. The model also ensures that the resulting wind field is mass consistent (i.e., that there is no artificial gain or loss of air within the model domain).

The meteorological input data for Oslo was taken from the measurement station at Valle Hovin. This data consists of hourly measurements of temperature, wind speed, and direction (at a height of 25 meters above ground). Additional data collected includes the vertical temperature difference between the height of 25 meters and 8 meters above the ground, relative humidity at the height of 2 meters and precipitation (in mm/h).

Meteorological observations for Trondheim come from the measurement station Voll. Only hourly measurements of temperature, wind speed and wind direction have been available from this station, and the atmospheric stability has therefore been subjectively estimated based on these parameters and meteorological experience.

2.2 Emission data

Most emission data for the various components have been supplied by Statistics Norway (SSB). There are 7 emission group categories (see Table 1). Group categories 1 to 6 are containing SSB data. Road traffic emission (emission category 7) is treated separately and is described further in Section 2.3.

Table 1: Assembled emission categories used in the calculations.

EMISSION CATEGORIES	DESCRIPTION
1	Domestic wood combustion
2	Industry
3	Agriculture, Public and Private service sector
4	Domestic heating except wood burning
5	Motorized equipment
6	Ship and railroad
7	Road traffic

The consumption data for each SSB source category is multiplied by individual emission factors for NO_X, NO_2, PM_{10} and Benzene. This provides estimates of the primary emissions of NO_X, NO_2[2], PM_{10} and Benzene for each source category. When analyzing the relative source contribution to the estimated exceedances,

[1] Note that the persons that are assigned to building points are subsequently subtracted from the total number in the corresponding grid square, so that all inhabitants are considered only once.
[2] The emission factor for NO_2 is defined as 10 % of the emission factor of NOx.

domestic wood combustion and road traffic are treated separately, where the 5 other category groups in Table 1 are referred to as “other area distributed sources”.

Oslo

All consumption and emission data, except for domestic wood combustion, for Oslo is based on data from 1998, and has not been modified. This data were prepared for use in AirQUIS in connection with the project ”Dispersion and exposure calculation of PM_{10}, NO_2, and Benzene for Oslo and Trondheim for the year 2001” (Laupsa, 2002). Data on domestic wood combustion is valid for the year 2002 **(**Finstad et al., 2004**).** The emission data from domestic wood combustion has then been adjusted in accordance with the expected renewal of domestic wood-burning ovens. The applied adjustment procedure is the same as for 2005 calculations for Oslo (Slørdal et al, 2007). Compared to area source emission data used for calculations for 2005, only PM_{10} emissions from wood combustion differ with a decrease of about 9 % (from 587 tons to 533 tons).

Trondheim

Updated emission data was supplied by SSB for Trondheim, valid for 2006. The data used for similar calculations for the year 2005 for Trondhiem were valid for the year 1998, except for wood combustion which was then valid for 2003. An overview of the total emissions used in the calculations for 2007 is listed below and compared to the data used for 2005 (Slørdal et al, 2007).

Table 2: Total emissions in kilos/year for the Benzene, NO_2, and PM_{10}, including the increase in percentage from 2005 to 2007.

	2005	**2007**	**Increase in %**
Benzene	33 737	40 069	19
NO_2	47 316	60 181	27
PM_{10}	570 670	693 003	21

PM_{10} emissions are mainly due to domestic wood combustion (which increased 20% from 2005 to 2007). Unfortunately, the data delivered by SSB was missing some PM_{10} emission data from wood combustion. Also, the emissions from each of the different categories vary extremely compared to the data used for 2005. It can therefore be questioned if the categories reflect the same emission sources in the two data sets. The temporal distributions which are unique to each category were not updated and are hence applied to emissions which might have needed a different time variation.

2.3 Traffic data

New traffic data (traffic amount, road classifications, speed limits, road slope, etc.) have been applied for Oslo and were retrieved from the National Road-Data Bank (NVDB). Manual updates of the traffic information at some road segments have been made to include the environmental speed limit reductions at RV4, Ring 3 and E18. The reduction in speed limit will mainly have an effect on the PM_{10}

suspension from the roads. Jets from tunnels have also been added manually. For Trondheim, the road net is the same as was applied in the previous project for 2005.

New emission factors considered valid for 2007 have been applied in both cities. They have been estimated as an interpolation of the emission factors used in the 2005 calculations and data used for a scenario calculations for the year 2010 (Tønnesen, D. and Sundvor, I., 2008). The Tønnesen et. al. study demonstrated that the main effect of the new emission factors is that they are increasing the basic NO_2 emissions from traffic.

The percentage of vehicles with studded tyres has been set to 19.5 % in Oslo and 30.4 % in Trondheim. The studded tyre season has been defined from November 1 until May 1.

2.4 Background concentrations applied as model boundary conditions

The daily averaged values of NO_2 and the hourly values of Ozone measured at the closest regional background stations have been applied as boundary conditions for the model domain (see Table 3). Measured daily background values of PM_{10} from Birkenes were applied for Oslo, whereas the background PM_{10} levels in Trondheim were estimated from measurements of SO_4, NO_3 and NH_4 at the regional station Kårvatn. Based on an empirical relation found between the concentrations of these compounds and the measured PM_{10} levels at Birkenes in 2007, an estimate is calculated for Kårvatn from the following formula:

$$[PM_{10}] = ([SO_4] + [NO_3] + [NH_4])*3.5$$

Table 3: Measurement stations applied in estimating the boundary conditions for Oslo and Trondheim.

	NO_2	Ozone	PM_{10}
Oslo	Birkenes	Birkenes/Prestebakke/Hurdal	Birkenes
Trondheim	Kårvatn	Kårvatn	Kårvatn

A more detailed description of the boundary value estimation is given in Appendix D.

2.5 Population data

The applied population data, which is a stationary geographical distribution, is based on information on home addresses of the inhabitants, and this data is valid for the year 2005.

The outdoor concentrations are calculated for each building that is located within a certain distance from the main road network, typically within a distance of 100 – 400 meters, depending on the Annual Daily Traffic (ADT) of the road. The concentration values for the exposure computations are calculated based on the geographical position of the building, which is estimated at a height of 2 meters above ground, which is in turn assigned to all of the persons registered as inhabitants in the particular building. Persons living in buildings further away from the main road network are assigned to the concentration values which are computed in the grid squares containing the buildings. The total number of inhabitants within the two model domains as well as the total number of persons assessed in individual buildings, are shown in Table 4.

Table 4: Population data distributed between grids and building points for Oslo and Trondheim

	Total number of inhabitants within the model domain	Total number of persons assessed in building points
Oslo	526 258	93 752
Trondheim	151 678	11 850

3 Evaluation of the model predicted concentrations against local air quality measurements

To evaluate the performance of the model and to indicate the validity of the exposure results, comparison of measured and calculated values have been compared at selected sites in both Trondheim and Oslo. For NO_2 and $PM_{10,}$ comparisons have been made between the measured and the calculated mean value, standard deviation, and maximum hourly value. The correlation coefficient, interception point, and the slope of the linear regression line have also been included in the evaluation of the calculated hourly values against measurements. Plots of the hourly values for the month of March are given in Appendix A together with plots of the highest hourly values for NO_2 and daily means for PM_{10} in descending order. For Benzene, however, only the calculated mean value for 2007 has been evaluated against the measured counterpart.

3.1 Model evaluations for Oslo

The calculated values of NO_2 and PM_{10} for Oslo have been evaluated against measurements from Kirkeveien and RV4, and calculated values of Benzene have been compared with measurements made at Kirkeveien. Both of these stations are located close to main roads (i.e., within a distance of 5 meters from the road side) and are therefore termed "street stations". Since the concentration levels decrease rapidly with increasing distance from the road side, especially within the nearest 100 meters, the measurements from these stations are made in an area of very strong concentration gradients. As a consequence, street station measurements are rather difficult to model correctly and will, when compared with measurements, generally reflect the maximum absolute error levels in the model results.

3.1.1 NO_2

Statistical comparisons between measured and calculated NO_2 values at RV4 and Kirkeveien are shown in Table 5. As seen in this table, the NO_2 levels are somewhat under predicted, with both the calculated mean and maximum being smaller than the measured values. In Figure A1 and Figure A3, the 500 highest measured and calculated NO_2 values are plotted in descending order. These plots show a very good modelling result for RV4, whereas the under estimation becomes more visible for Kirkeveien. The observed and calculated 9th highest hourly values at Kirkeveien are 166.8 μg/m^3 and 128.8 μg/m^3, which is over and under the limit value of 150 μg/m^3 respectively. The same values at RV4 are

137.3 µg/m^3 and 135.0 µg/m^3, hence both below the stated limit value. Both stations demonstrate rather high values of the correlation coefficients.

Direct comparisons of the measured and calculated hourly NO_2 concentrations for one month (March 2007) are presented in Figure A2 and Figure A4 for RV4 and Kirkeveien. These plots clearly reveal the high degree of correlation between the measured and calculated values.

Based on the statistics presented in Table 5, and the various plots in Appendix A, the best fit is found at RV4. A probable reason for this conclusion is that the traffic time variation is highly representative at RV4, together with the fact that RV4 has a rather open road structure, which is well described by the road/line model applied in AirQUIS.

Table 5: Statistical comparison between calculated and observed hourly values of NO_2 in Kirkeveien and RV4 for the periods 01.01.2007 to 01.05.2007 and 01.10.2007 to 01.01.2008.

	Mean value (µg/m^3)		**Standard deviation (µg/m^3)**		**Maximum value (µg/m^3)**	
	Measured	Calculated	Measured	Calculated	Measured	Calculated
RV4	40.5	36.2	27.8	31.3	173.4	148.5
Kirkeveien	40.7	35.4	30.7	28.2	212.3	141.2
Comparison observed – calculated						
	Correlation coefficient		**Slope of linear regression line**		**Linear regression intercept point**	
RV4	0.60		0.68		8.83	
Kirkeveien	0.50		0.50		11.26	

3.1.2 PM_{10}

The statistical comparisons between the measured and calculated PM_{10} values at RV4 and Kirkeveien are shown in Table 6. When compared with the statistical values for NO_2 (Table 5) it is seen that the deviations between predicted and observed values are somewhat larger for PM_{10} than for NO_2. The mean value is over estimated at RV4 whereas it is under estimated at Kirkeveien, and the same pattern is seen for the maximum value.

Direct comparisons of the hourly measured and calculated PM_{10} concentrations are shown in Figure A6 (RV4) and Figure A8 (Kirkeveien) for the month of March 2007. The predicted PM_{10} concentrations are both overestimated and underestimated at the two stations. At Kirkeveien we see that underestimations are the most common, whereas overestimations are dominant at RV4. The difference between the stations is again made evident when looking at Figure A5 (RV4) and Figure A7 (Kirkeveien), where the measured and calculated daily values are plotted in descending order. At Kirkeveien, all modelled values are under the observed values. At RV4, the two curves are crossing, with the model over predicting the highest daily means. The 8th highest daily means are 55.5 µg/m^3 (observed) and 56.4 µg/m^3 (calculated) at Kirkeveien, and 55.6 µg/m^3 (observed) and 64.5 µg/m^3 (calculated) at RV4. All these values are above the limit value of 50 µg/m^3 .

Table 6: Statistical comparison between calculated and observed hourly values of PM_{10} in Kirkeveien and RV4 for the periods 01.01.2007 to 01.05.2007 and 01.10.2007 to 01.01.2008.

	Mean value (µg/m^3)		**Standard deviation (µg/m^3)**		**Maximum value (µg/m^3)**	
	Measured	Calculated	Measured	Calculated	Measured	Calculated
RV4	22.3	25.7	19.4	33.4	215.9	282.1
Kirkeveien	24.7	18.4	20.4	22.9	372.4	246.5
Comparison observed – calculated						
	Correlation coefficient		**Slope of linear regression line**		**Linear regression intercept point**	
RV4	0.27		1.00		3.05	
Kirkeveien	0.41		0.37		8.38	

3.1.3 Benzene

Since calculations have not been performed for the summer period (no calculations from 01.05.2007 to 01.10.2007) the yearly concentration level of Benzene has been estimated by multiplying the computed average Benzene concentration with a scaling factor. This factor is the ratio of the observed yearly concentration of Benzene for 2007 and the observed average for the calculation period. The factor used in Oslo was 0.75, which was based on the available observations of Benzene at Manglerud and Kirkeveien. Table 7 shows a good agreement between the calculated and the observed yearly value of Benzene at Kirkeveien with only 0.3 µg/m^3 in difference. However the two values are over and under the limit value of 2 µg/m^3 set in the "National Air Quality Target" for Benzene. This point should be kept in mind when evaluating the exposure results.

Table 7: Measured and calculated Benzene concentration at Kirkeveien for 2007.

	Average value (µg/m^3)	
	Measured	Calculated
Kirkeveien	2.2	1.9

3.2 Model evaluations for Trondheim

Computed values of PM_{10} are evaluated against measurements from Elgeseter and Bakke Kirke; calculated values of Benzene are evaluated against measurements from Elgeseter. Both stations are close to main roads and are thus referred to as "street stations". No evaluation has been done with NO_2 as the observation data has been considered not good enough for a useful comparison (Oral communication with Mona Jonsrud and Dag Tønnesen. Information about problems with the zero level for NOx measurements has been given to SFT in a note from Jonsrud for 2008 data "Kommentarer til EU-data for 2. Kvaratal 2008" and similar problems were found for the stations in Trondheim.)

3.2.1 PM_{10}

The statistical evaluation of the PM_{10} results at Elgeseter and Bakke Kirke (see Table 8) indicate a general under estimation by the model as both the calculated mean value and the maximum value is below what is measured. The correlation coefficients and the regression parameters also show that there are deviations between model predictions and observations from hour to hour.

Hourly measured and calculated concentrations in March are shown in Figure A10 and A12. For this particular month the concentration levels are very high and it is clear that there are both over estimating and under estimating by the model at both stations.

Despite the fact that the statistical evaluation for PM_{10} in Trondheim is weaker when compared to Oslo, the agreement between the highest measured and computed daily values is favourable. These values are shown in descending order in Figure A9 (Elgeseter) and A11 (Bakke Kirke). The modelled values are again seen to be on average slightly underestimating the observed values. The modelled and observed 8^{th} highest daily mean are well over the limit value at both stations. For Bakke Kirke, the observed 8^{th} highest daily mean is 69.6 µg/m^3 and the calculated value 66.6 µg/m^3. For Elgeseter the two values are 111.4 µg/m^3 and 72.7 µg/m^3, respectively.

Table 8: Statistical comparison between calculated and observed hourly values of PM_{10} at Elgeseter and Bakke Kirke for the periods 01.01.2007 to 01.05.2007 and 01.10.2007 to 01.01.2008.

	Mean value (µg/m^3)		**Standard deviation (µg/m^3)**		**Maximum value (µg/m^3)**	
	Measured	Calculated	Measured	Calculated	Measured	Calculated
Elgeseter	34.6	27.3	44.2	35.1	528.1	410.6
Bakke Kirke	26.6	20.3	34.4	29.4	576.8	374.2

	Correlation coefficient	**Slope of linear regression line**	**Linear regression intercept point**
Elgeseter	0.36	0.29	16.13
Bakke Kirke	0.33	0.28	12.56

3.2.2 Benzene

Yearly concentrations of Benzene have been estimated using the same method in Trondheim as in Oslo. A scaling factor of 0.78 was computed from the available Benzene observations for 2007 at Elgeseter. The resulting values at Elgeseter are presented below in Table 9, and these values reveal an extremely strong under prediction by the model. The measured value is well above the limit value, whereas the calculated value is well below; this adds doubt to the validity of the results for Benzene exposure in Trondheim.

Table 9: Measured and calculated Benzene concentration at Elgeseter for 2007.

	Mean value (µg/m3)	
	Measured	Calculated
Elgeseter	2.9	1.3

4 Discussion of uncertainties

Uncertainties linked to the various elements of the computational procedure should be kept in mind when interpreting modelling results. A brief discussion of the uncertainties that became present during this study is discussed below.

4.1 Meteorological input data

As described in Section 2.1, the wind field applied as input to the dispersion model has been calculated by the diagnostic wind field model Mathew (Sherman, 1978; Foster et al., 1995). Since these calculations are based on only one meteorological measurement site within each of the city domains, the uncertainties in the resulting wind field are relatively large, especially in the areas furthest away from the measurement site. This may lead to errors that can have a profound impact particularly on the calculations of the high concentration levels along the main road system. The reason for this is that the highest concentrations are found at the downwind side of the road, and a modest error in the calculated wind direction may shift the computed pollutant maximum to the wrong side of the road.

4.2 Area distributed emissions

There are rather large uncertainties in the area distributed emission estimates that are used as input to the air quality model (see Section 2.2). These uncertainties are connected both with the estimation of the total amount emitted (mass of pollutant), and with the spatial and temporal distribution of these emissions within the cities.

4.3 Road traffic emissions

As described in Section 2.3, the estimated road traffic emissions are based on rather detailed information on traffic amount, vehicle composition, road type, speed limit, road slope, etc. All this information is required for each road defined in the road link system in the AirQUIS model. Uncertainties in each of these input parameters greatly contribute to the overall uncertainty.

During winter and spring, road particles suspended into the air by the stirring effect of the vehicle turbulence is by far the most dominant source of ambient coarse fraction particles (i.e., the portion of the particulate matter that are larger than 2.5 micrometer in diameter, but less than 10 micrometer, $PM_{10} - PM_{2.5}$). There are huge uncertainties, however, associated with the exact estimation of the amount of road particles that are available for suspension. In order to reduce this uncertainty, the PM_{10}-simulations were first made with standard emission estimates of road particles. Then the calculated coarse fraction part, assumed to be totally dominated by suspended road particles, was compared with existing measurements. Based on this comparison, the source strength of vehicle induced particle suspension was corrected in the model so that the computed coarse fraction comes to agreement with the average levels at the measurement sites. By applying this correction method any effects of road cleaning and/or salting that clearly affect the observations will implicitly be incorporated in the results from the model simulations.

4.4 Boundary conditions

The contribution from the regional background (i.e., the concentration levels in the air entering the model domain from outside) has been estimated from measurements at the closest regional background (EMEP) station. It is to be expected that these boundary values systematically lead to a somewhat unpolluted inflow of air. The reason for this is that the air at the model boundaries will be slightly influenced by local emissions, at least in the areas where the main roads are entering into the model domain.

4.5 Dispersion modelling

The highest concentration levels in Norwegian cities are typically found in wintertime, during high pressure situations, with very low wind speeds, highly variable wind directions, and persistent temperature inversions (stable atmospheric conditions). Unfortunately, these conditions are also the most difficult to describe correctly by the wind field- and dispersion models. During such conditions, relatively small changes in the wind field can lead to rather large alterations of the computed pollutant distribution, and the inherent modelling uncertainties are therefore at its highest during these situations.

When considering the estimated exposure levels for the people living in the buildings closest to the main road system, another uncertainty should be kept in mind as well. Some of these buildings are located close to tunnel openings or near major road junctions with bridges, tunnels or steep road cuttings. However, when we estimate the concentration levels for the building points close to the main roads (i.e., within a distance of 100 - 400 meters), it is assumed that the terrain is flat, and any modifying effects due to height differences between the road and the buildings are therefore not implemented. This situation results in a systematic overestimation of the building point concentrations in such areas.

5 Results from the dispersion and exposure calculations

NILU has calculated outdoor concentration levels and the number of inhabitants exposed to exceedances of the goals defined in the ”National Air Quality Target”, which defines restrictions on the ambient concentration levels of NO_2, PM_{10} and Benzene. This target specify that during a one year period the following limits should be met: no more than 8 hours (hourly mean) of NO_2 concentration levels above 150 $\mu g/m^3$, no more than 7 days (daily mean) of PM_{10} concentration levels above 50 $\mu g/m^3$, and the yearly averaged Benzene concentration should not exceed 2 $\mu g/m^3$. These targets are to be obtained within the year 2010.

By applying the model system AirQUIS (AirQUIS, 2006), calculations have been performed for Oslo and Trondheim for 2007. Since our focus is on the higher concentration levels, and experience has shown that these levels are encountered during the winter/spring season, no calculations were made for the summer period (May 1 – September 30). Highest concentrations are found in wintertime due to the frequently occurring stable atmospheric conditions (poor dispersion conditions) and large emissions emanating from the use of studded tyres, as well as from domestic wood burning.

Ambient air concentrations and population exposure have been calculated both in the building points and in the grid squares. For these in which exceedances of the "National Air Quality Target" have been found, the relative contribution from the main source categories was estimated. When performing source apportionment calculations, only hours (NO_2) and days (PM_{10}) contributing to the exceedances have been considered, and the final estimate is the average percent contribution from the various sources. In order to present these results in a simple way, the source apportionments for all of the buildings residing within a grid cell have been averaged, and presented as the grid cell percentage source contribution. No source apportionment estimate has been done for Benzene in this study.

The concentration fields applied in the exposure calculations are presented in Appendix B. The following figures were presented for both Oslo and Trondheim:

1. The 9th highest hourly grid-value concentration of NO_2 calculated during the simulation period with all the building points experiencing exceedances are marked as black dots.
2. The 8th highest daily grid-value concentration of PM_{10}, calculated during the simulation period with all the building points experiencing exceedances are marked as black dots.
3. The estimated yearly mean grid-value concentration of Benzene with all the building points experiencing exceedances are marked as black dots.

The yearly mean Benzene values have been estimated as described in Section 3 above.

When calculating exposure, only people over the limit value are considered to experience exceedances. A small difference in the calculated concentration level, when this is close to the limit value, can hence drastically change the number of people exposed.

5.1 Oslo

5.1.1 NO_2

The gridded concentration field for the 9th highest hourly NO_2 values for Oslo is presented in Figure B1 in Appendix B. As seen in this Figure no exceedances(i.e., no values above 150 $\mu g/m^3$) were computed in the model grid. Exceedances with regards to the national target for NO_2 were only found in building points. The locations of these buildings are shown as black dots along the main road system in Figure B1. The exposure results show that 4193 inhabitants, i.e., 0.8% of the total population within the model domain, are exposed to exceedances. Their distribution within the model domain is illustrated in Figure 1.

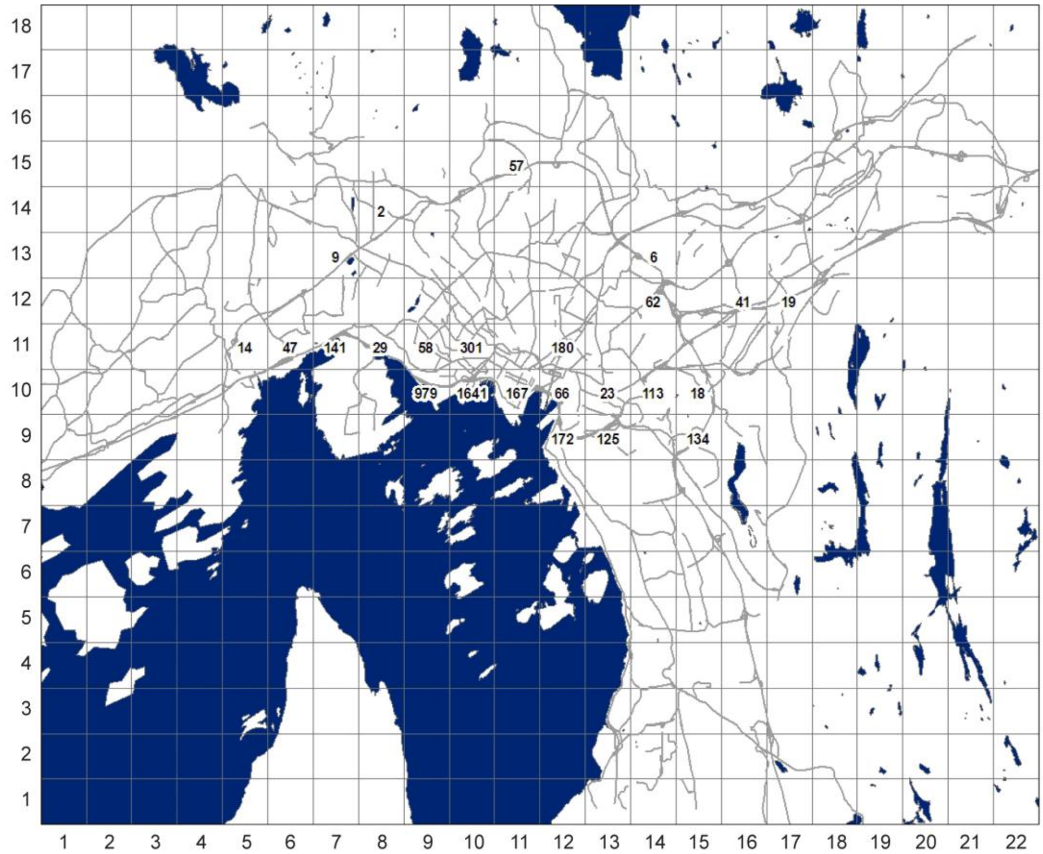

Figure 1: The number of inhabitants, and their distribution, that are exposed to exceedances of the National Air Quality Target for NO_2 in Oslo in 2007.

The main source for these exceedances is road traffic, as shown in Table 10: . The average source contributions to these exceedances within each grid square are listed in Table C1. The second most important source category is the "Other area distributed sources".

Table 10: Source contribution (in percentage) to the exceedances of the National Air Quality Target for NO_2 for Oslo in 2007.

Calculated in	Domestic wood comb.	Traffic	Other sources	Regional background
Building points	0.06	93.52	6.25	0.18

5.1.2 PM_{10}

The gridded concentration field for the 8th highest daily PM_{10} values is presented in Figure B2. As seen in this figure large areas in Oslo are experiencing exceedances on the grid square level, i.e., grid square concentration values above 50 µg/m^3. As expected, the model also predicts exceedances at numerous building points, as illustrated by the black dots along the main road system in Figure B2. In total it is estimated that 186 744 inhabitants, i.e. 35% of the population, are exposed to exceedances. Their distribution within the model domain is illustrated in Figure 2.

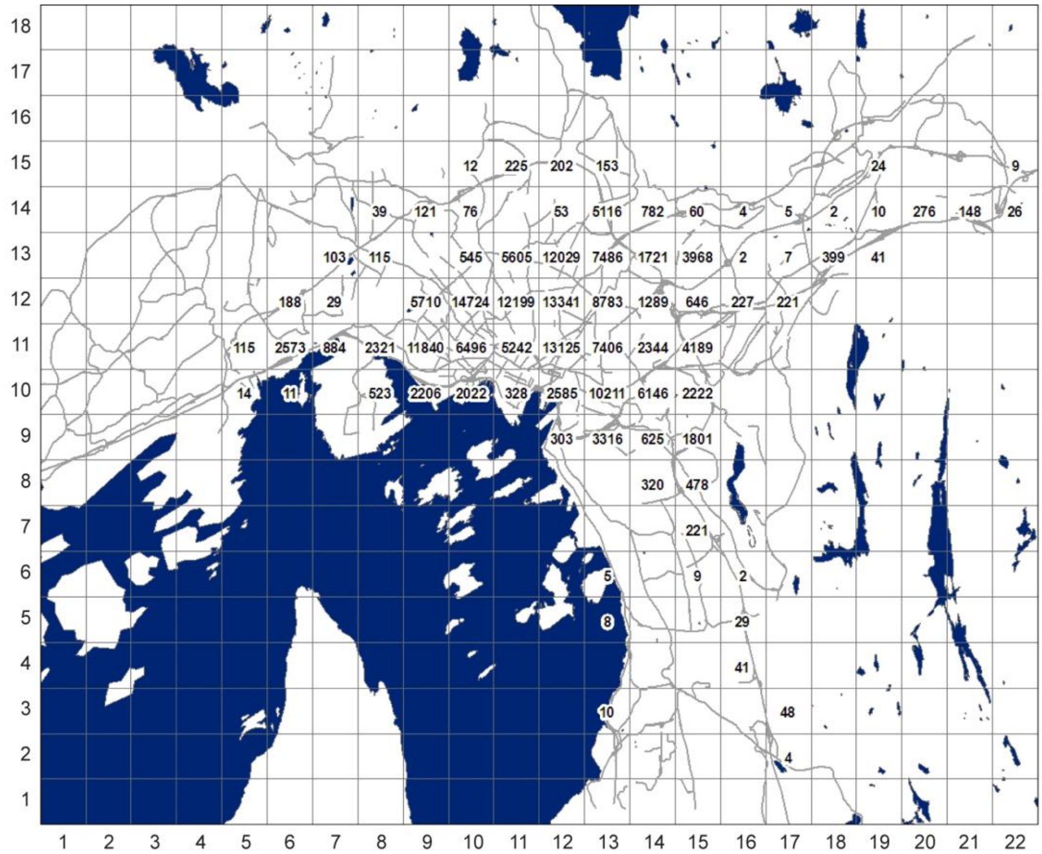

Figure 2: The number of inhabitants, and their distribution, that are exposed to exceedances of the National Air Quality Target for PM_{10} in Oslo in 2007.

The main source for these exceedances is road traffic, as shown in Table 11. The source contribution within each of the model grid squares are listed in Table C2, while the average source contribution in the buildings within each grid square is given in Table C3. Although traffic is the dominant source, domestic wood burning can contribute up to 50 % in certain areas.

Table 11: Source contribution (in percentage) to the exceedances of the National Air Quality Target for PM_{10} for Oslo in 2007.

Calculated in	Domestic wood comb.	Traffic	Regional background	Other sources
Building points	20.68	72.26	4.60	2.46
Grid squares	29.71	62.29	3.90	4.10

5.1.3 *Benzene* (H_6C_6)

The gridded concentration field for the estimated yearly mean Benzene value is presented in Figure B3. This Figure shows that some areas in Oslo are experiencing exceedances on the grid square level, i.e., grid square concentration values above 2 μg/m^3. The model also predicts exceedances in numerous building points, as illustrated by the black dots along the main road system in Figure B3.

When only including the grid value in the estimate, 6224 inhabitants, i.e., 1.2 % of the population, are exposed to exceedances. Their distribution within the model domain is illustrated in Figure 3 below.

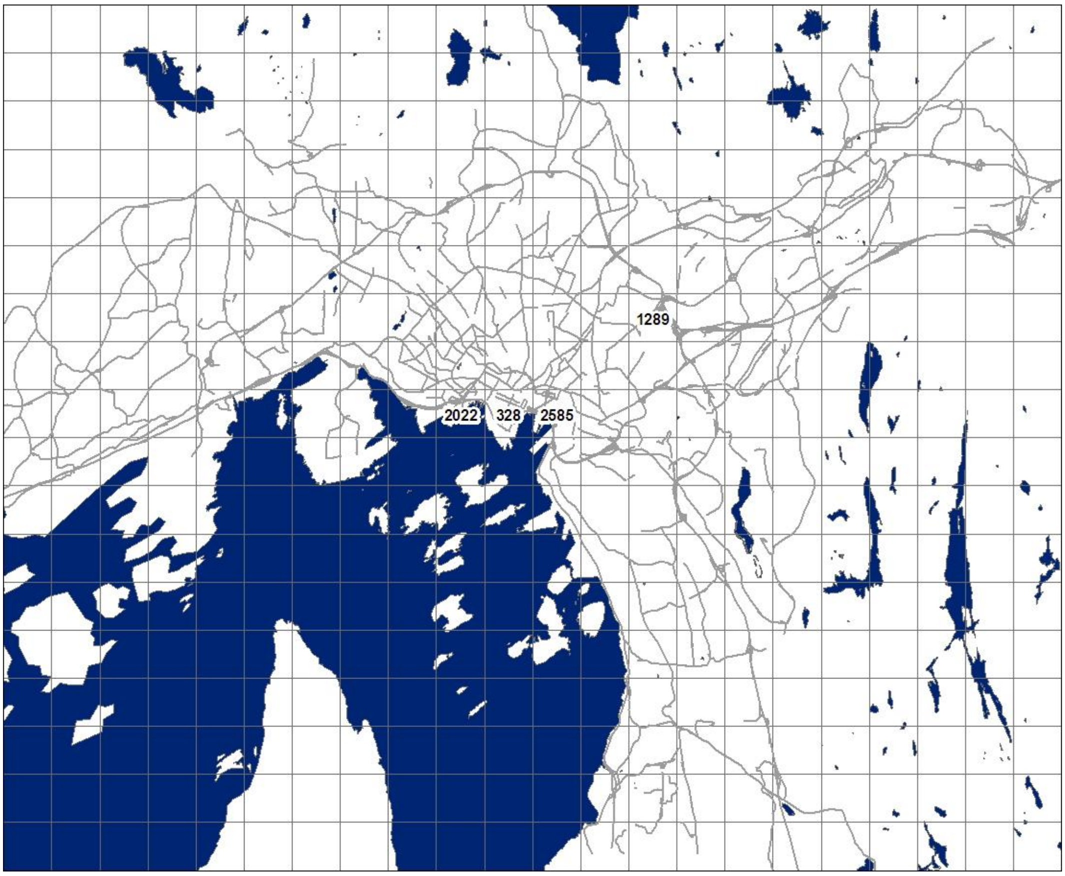

Figure 3: The number of inhabitants, and their distribution, that are exposed to exceedances of the National Air Quality Target for Benzene in Oslo in 2007. Note that this figure only shows exposure estimates with just grid values.

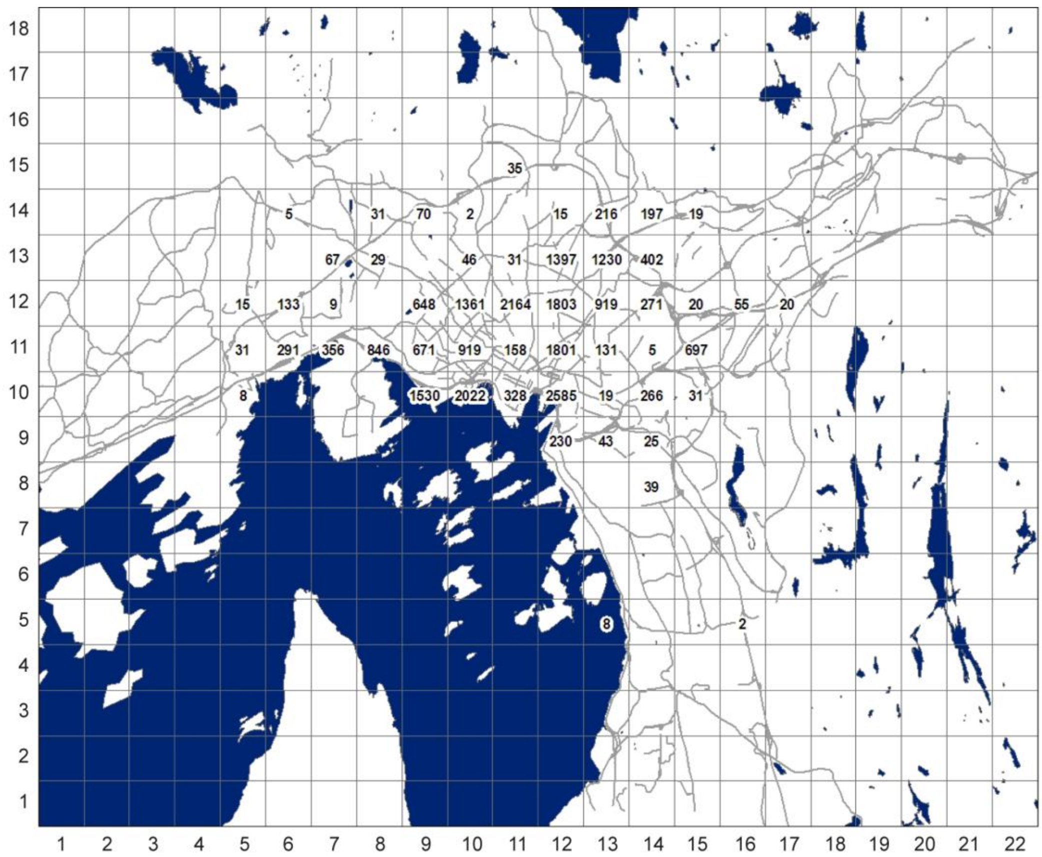

Figure 4: The number of inhabitants, and their distribution, that are exposed to exceedances of the National target for Benzene in Oslo in 2007. Note that this figure only shows exposure estimate with just the building points.

If people exposed just in building points are included, the number of people exposed to exceedances are increased to 24252, as shown in Figure 4. No calculation of source contributions has been made for Benzene, but earlier investigations (Laupsa et al., 2005) have shown that road traffic is by far the most dominant source.

5.2 Trondheim

5.2.1 NO_2

The gridded concentration field for the 9th highest hourly NO_2 values for Trondheim is presented in Figure B4. As seen in this Figure, no exceedances, i.e., no values above 150 µg/m^3, were computed from the model grid. Exceedances with regards to the national target for NO_2 were estimated in 3 building points. The locations of these buildings are shown as black dots in Figure B4. All of these exceedances are inside the grid square (7,13) as illustrated in Figure 5, giving a total of 85 persons, i.e., 0.056 % of the population within the model domain, who were exposed to exceedances.

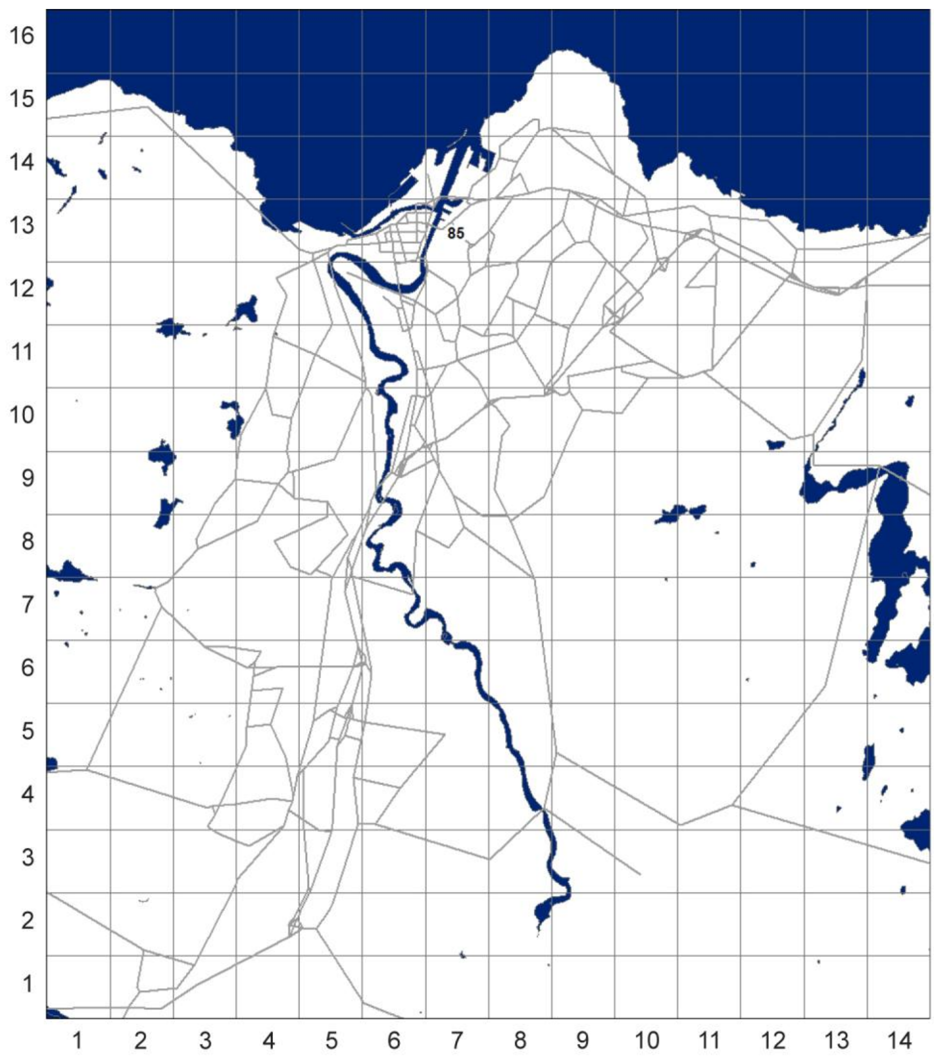

Figure 5: The number of inhabitants, and their distribution, that are exposed to exceedances of the National Air Quality Target for NO_2 in Trondheim in 2007.

The main source for the exceedances is road traffic, as shown in Table 12.

Table 12: Source contribution (in percentage) to the exceedances of the National Air Quality Target for NO_2 for Trondheim in 2007.

Calculated in	Domestic wood comb.	Traffic	Regional background	Other sources
Building points:	0.02	98.88	0.32	0.78

5.2.2 PM_{10}

The gridded concentration field for the 8th highest daily mean for PM_{10} values is presented in Figure B5. As seen in this Figure, no area is experiencing exceedances on the grid square level, i.e., grid square concentration values above 50 $\mu g/m^3$. The model does predict exceedances in numerous building points, as illustrated by the black dots along the main road system in Figure B4. It is estimated that 4994 inhabitants, i.e., 3.3 % of the total population within the model domain, are exposed to exceedances. Their distribution within the model domain is illustrated in Figure 6.

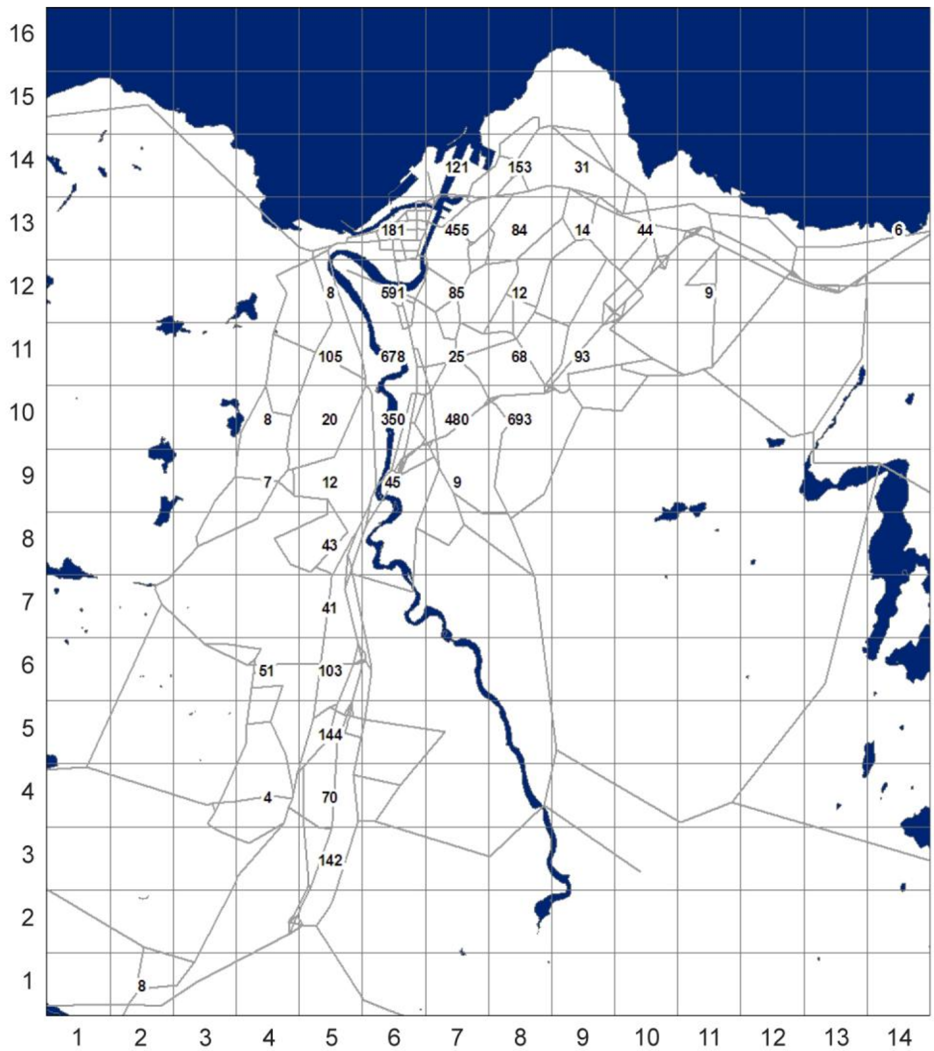

Figure 6: The number of inhabitants, and their distribution, that are exposed to exceedances of the National Air Quality Targetfor PM_{10} in Trondheim in 2007.

The main source for these exceedances is road traffic, as shown in Table 13. The average source contribution in the buildings within each grid square is given in Table C5. The maximum contribution from domestic wood burning was found to be up to 33 % in one area.

Table 13: Source contribution (in percentage) to the exceedances of the National Air Quality Target for PM_{10} for Trondheim in 2007.

Calculated in	Domestic wood comb.	Traffic	Regional background	Other sources
Building points:	10.10	83.50	5.95	0.45

5.2.3 Benzene (H6C6)

The gridded concentration field for the estimated yearly mean Benzene value is presented in Figure B6. As seen in this Figure, no exceedances, i.e., no values above 2 μg/m^3, were computed in the model grid. Exceedances with regards to the national target for Benzene were only estimated in building points. The locations of these buildings are shown as black dots along the main road system in Figure B6. The exposure results show that 87 inhabitants, i.e., 0.06 % of the total population within the model domain, are exposed to exceedances. Their distribution within the model domain is illustrated in Figure 7 below.

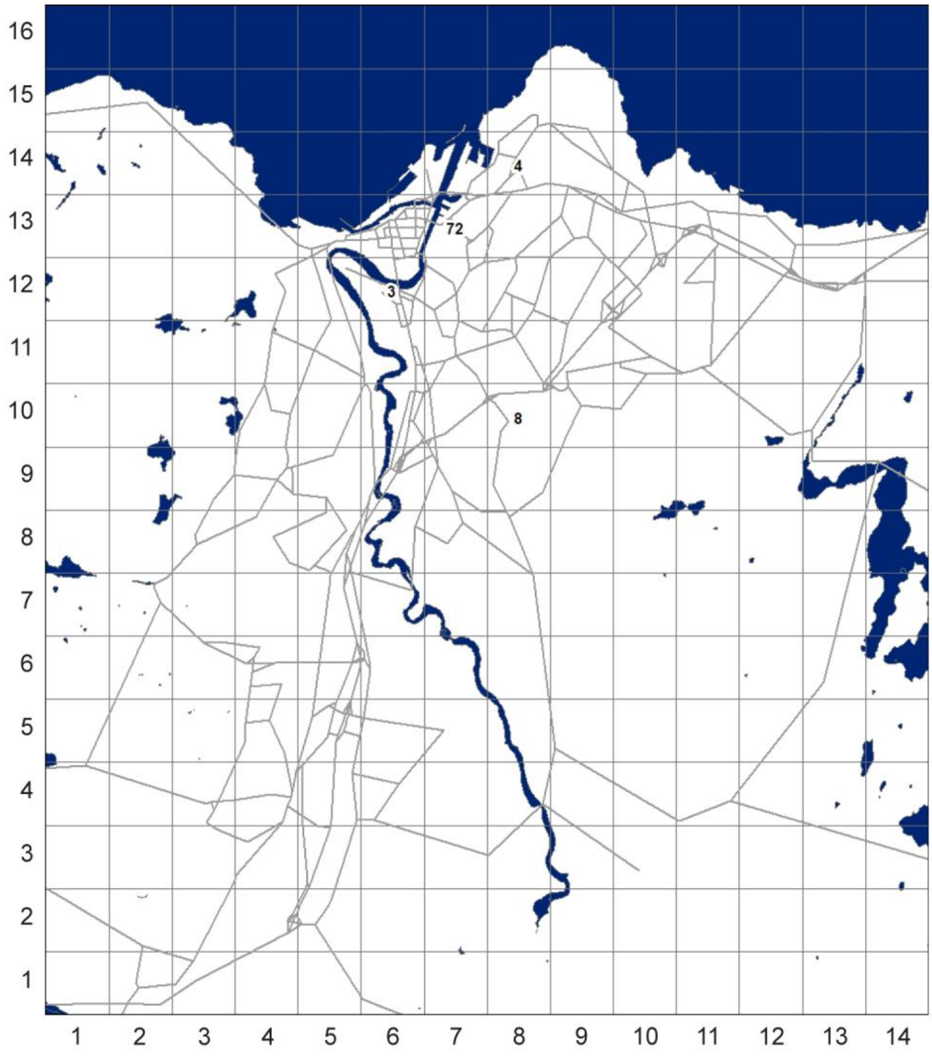

Figure 7: The number of inhabitants, and their distribution, that are exposed to exceedances of the National Air Quality Targetfor Benzene in Trondheim in 2007.

6 Concluding remarks

The total exposure results reported in Section 5 are summarized in Table 14 below. The model predictions show that a higher percentage of the population in Oslo are exposed to exceedances than in Trondheim. Most exceedances are found for PM_{10}, which affect as much as 35 % of the population in Oslo and 3.3 % in Trondheim. The main source for PM_{10} and NO_2 in both cities is road traffic. Meteorology and the background concentrations are the factors with the largest influence on variations from year to year. It is therefore often difficult to draw any conclusion on the quantative effect of changes in emissions. It is however shown in the scenario study for 2010, that the new emission factors applied in this study do increase the NO_2 levels (Tønnesen, D. and Sundvor, I., 2008).

Table 14: Number of inhabitants exposed to exceedances of the goals defined in the National Air Quality Target for PM_{10}, NO_2 and benzene in Oslo and Trondheim during 2007. Results from a similar calculation for the year 2005 (Slørdal et al., 2007) are shown in parenthesis for comparison.

	Oslo	Trondheim
PM_{10}	186 744 (235 849)	4 994 (20 914)
NO_2	4 193 (652)	85 (40)
H_6C_6 (Benzene)	6 224 (31 585)	0 (0)

When considering the exposure estimates in Table 14 it should be noted that relatively small changes in the calculated concentration levels can result in large changes in the numbers of inhabitants exposed to exceedances. This is especially the case when grid square concentrations levels close to the target value are computed. In Section 5 the average source contributions (in percent) to the exceedances were presented in Table 10 - Table 13.

6.1 Oslo

PM_{10} is by far the component which affects the largest number of people in Oslo. Compared to 2005, there is a reduction in the number of people exposed to levels above the limit value of a daily mean of 50 µg/m^3. Exceedances are found both on grid squares and in building points. The main source is road traffic, but wood combustion makes up a larger percentage in 2007 than in 2005. This could be due to reduced speed limits along some of the major roads in Oslo together with the decrease in use of studded tyres (24 % in 2005 to 19.5% 2007). Both of these measures are expected to decrease the suspension of PM_{10}. A noticeable change in PM_{10} compared to 2005 is seen at RV4. Looking at Figure A5 and its counterpart figure from 2005, the daily means are significant lower. The PM_{10} background concentration has also a lower level in 2007 than in 2005. From the model evaluation it is concluded that values are underestimated at Kirkeveien but overestimated at RV4 .

An increase in number of exceedances is found for NO_2. The increase could be attributed to the new emission factors for road traffic, but the model evaluation shows a general underestimation of the NO_2 levels, so it is likely that the actual number of people exposed to exceedances is underestimated. The total number of people exposed for NO_2 levels above the limit value is nonetheless modest compared to the situation for $PM_{10.}$

There is a large reduction in number of people exposed to Benzene concentrations above the limit value of a yearly mean of 2 µg/m^3 in 2007 compared to 2005. The reduction is a consequence of a change in number of grid squares above the limit, with 5 in 2005 and 3 in 2007. From the model evaluation in Section 3, the values found at Kirkeveien were very close to the limit value with the calculated value being just below, and the measured value being just above the limit. It is therefore highly probable that the number of exceedances found from the model is too low.

6.2 Trondheim

Traffic is the also the dominant source in Trondheim, and similar to Oslo there is a reduction in the exposure estimate for PM_{10}, and an increase in NO_2 . For $PM_{10,}$we only find exceedances in building points. The number of people exposed is therefore largely reduced compared to the 2005 numbers when also exceedances on grid squares were found. Compared to 2005 results, a larger percentage of the exceedances in building points is due to traffic, whereas the percentages from domestic wood combustion and regional background are lower.

The main difference in the traffic emission data for Trondheim affecting the PM_{10} is the decrease in percentage of studded tires which went from 38 % in 2005 to 30.4% in 2007. This should result in a reduction of the PM_{10} suspension and the calculated concentration values at Bakke kirke and Elgeseter give the maximum and mean values to be lower in 2007. This reduction is not seen in the measurements. The measured values at the two stations show approximately the same mean value for the two years, but the maximum value is actually higher in 2007. The model evaluation concludes there is an underestimate of PM_{10} levels, especially the highest concentration values, and as a consequence the exposure result is likely to be underestimated.

The new emission factors increase the basic emissions of NO_2. The number of people which experience exceedances has increased in 2007, but it is a relatively small percentage of the greater Trondheim population. No direct comparison with measured and modelled values was done for NO_2 in Trondheim.

For Benzene we have no inhabitants exposed to concentration levels above the limit value on grid. When including the building points it is estimated that 87 people are affected, which is a lower number than the 2005 results (712 people). In the model evaluation a large underestimation of the annual mean value at Elgeseter is found. The measured value is well above the limit value and the calculated value is far below so the exposure result is likely to be underestimated.

7 References

AirQUIS (2006). URL: www.airquis.com

Finstad, A., Flugsrud, K., Haakonsen, G. og Aasestad, K. (2004) Vedforbruk, fyringsvaner og svevestøv. Resultater fra Folke- og boligtellingen 2001. Levekårsundersøkelsen 2002 og undersøkelse om vedforbruk og fyringsvaner i Oslo 2002. Oslo-Kongsvinger (SSB-rapport 2004/5) (In Norwegian).

Foster, F., Walker, H., Duckworth, G., Taylor, A. and Sugiyama, G. (1995) User's guide to the CG-MATHEW/Adpic models, Version 3.0. Lawrence Livermore National Laboratory (Report UCRL-MA-103581 Rev. 3).

Laupsa, H., Tønnesen, D.A., Krognes, T., Bruno, M. and Walker, S.E. (2005) Dispersion and exposure calculation of PM_{10}, NO_2 and benzene for Oslo, Trondheim and Bergen for the year 2003. Kjeller (NILU OR 10/2005). (In Norwegian).

Laupsa, H (2002) Dispersion and exposure calculation of PM_{10}, NO_2 and benzene for Oslo and Trondheim for the year 2001. (Note; HEL/Bka/O-102022/B). (In Norwegian).

Sherman, C.A. (1978) A mass consistent model for wind fields over complex terrain. *J. Appl. Meteorol.*, *17*, 312-319.

Slørdal, L.H. and Larssen, S. (2001) Indoor wood burning and airborne particles. Model calculations for Oslo for the winter of 1998-1999. Kjeller (NILU OR 37/2001). (In Norwegian).

Slørdal, L.H., McInnes, H., Laupsa, H. and Walker, S.E. (2007) Dispersion and exposure calculation of PM_{10}, NO_2 and benzene for Oslo and Trondheim for the year 2005 Kjeller (NILU OR 90/2006).

Statens forurensningstilsyn (1998) Veiledning til forskrift om grenseverdier for lokal luftforurensning og støy. Oslo (SFT Veiledning 98:03).

Tønnesen, D. and Sundvor, I. (2008) Scenario dispersion and exposure calculation of NO_2 for 2010, 2015 and 2020 for Oslo. Kjeller (NILU OR 59/2008).

Appendix A

Figures applied in the evaluation of the model calculations

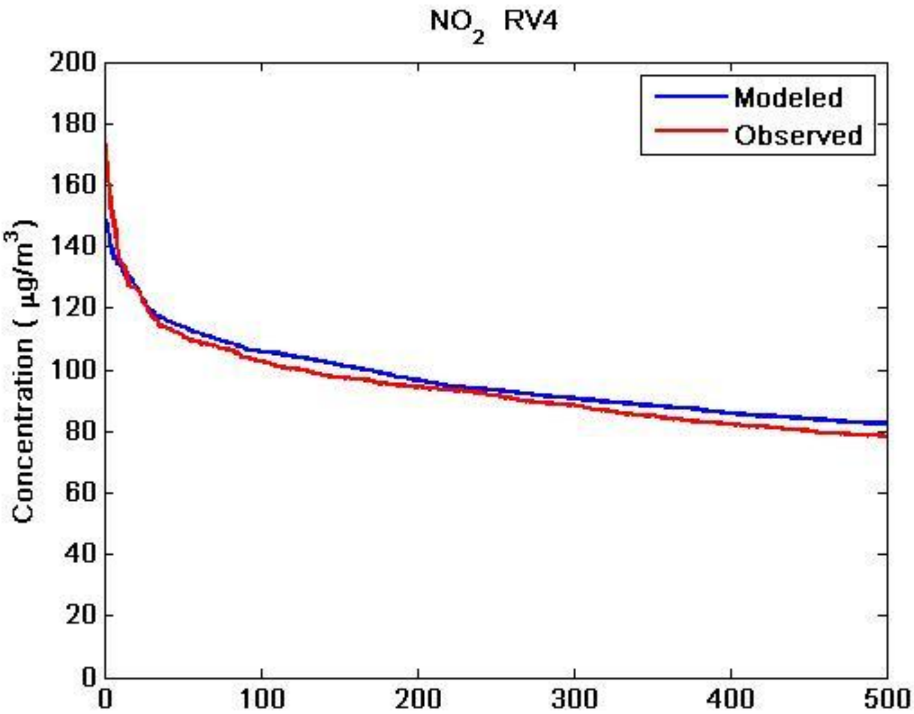

Figure A1: The 500 highest hourly values of NO_2 at RV4 sorted descending

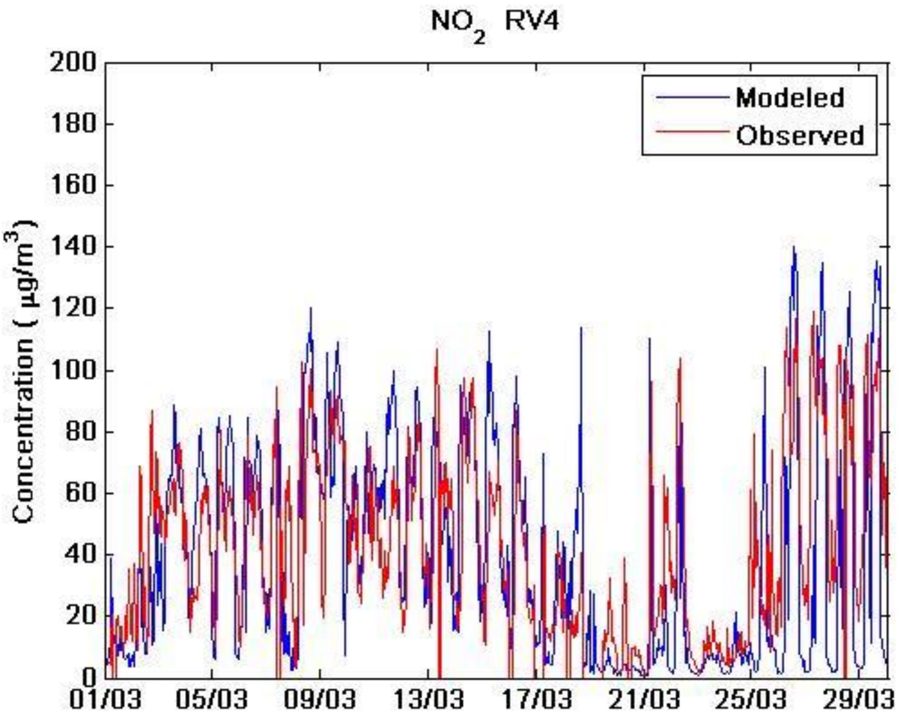

Figure A2: Hourly values of NO_2 at RV4 in March 2007

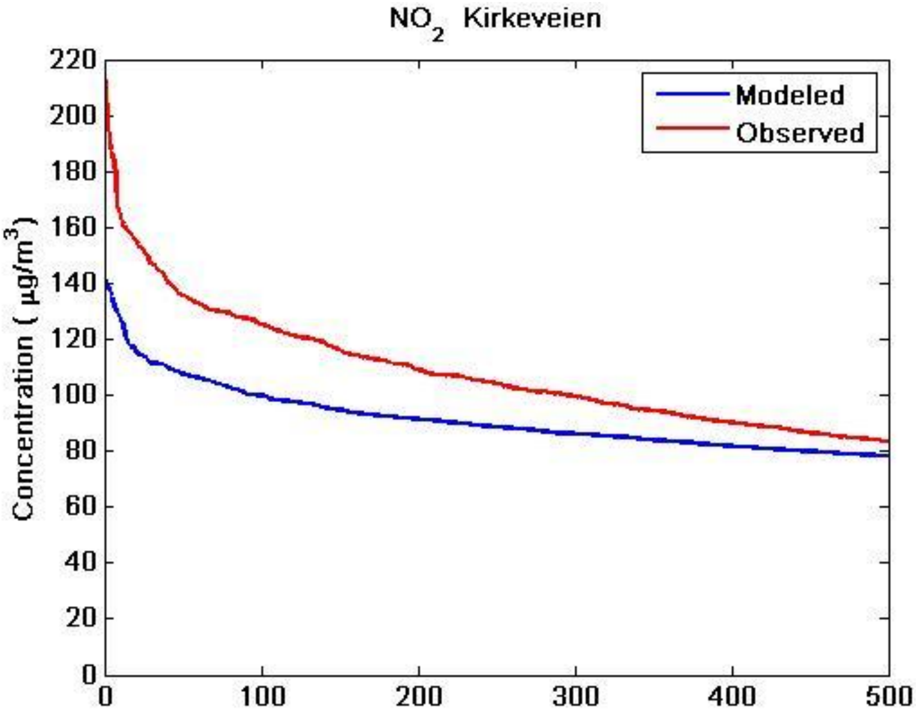

Figure A3: The 500 highest hourly values of NO_2 at Kirkeveien sorted descending

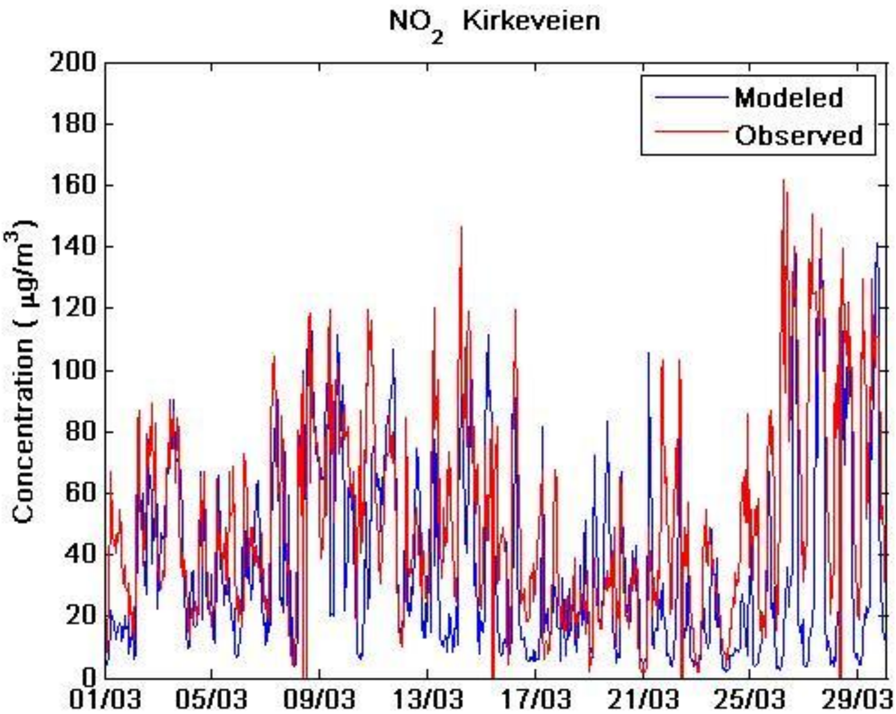

Figure A4: Hourly values of NO_2 at Kirkeveien in March 2007

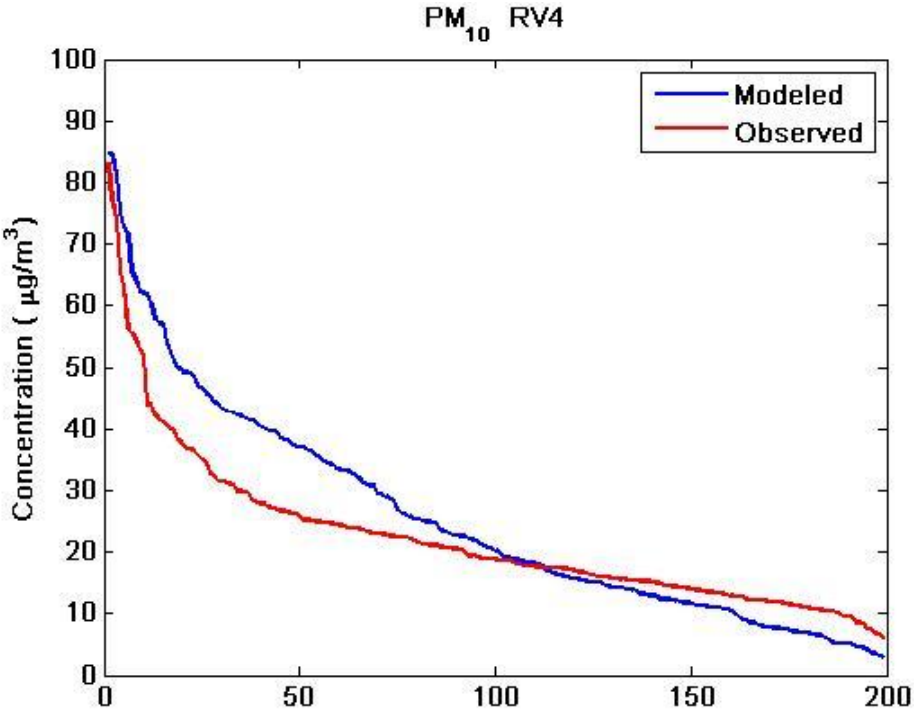

Figure A5: Daily values of PM_{10} at RV4 sorted descending

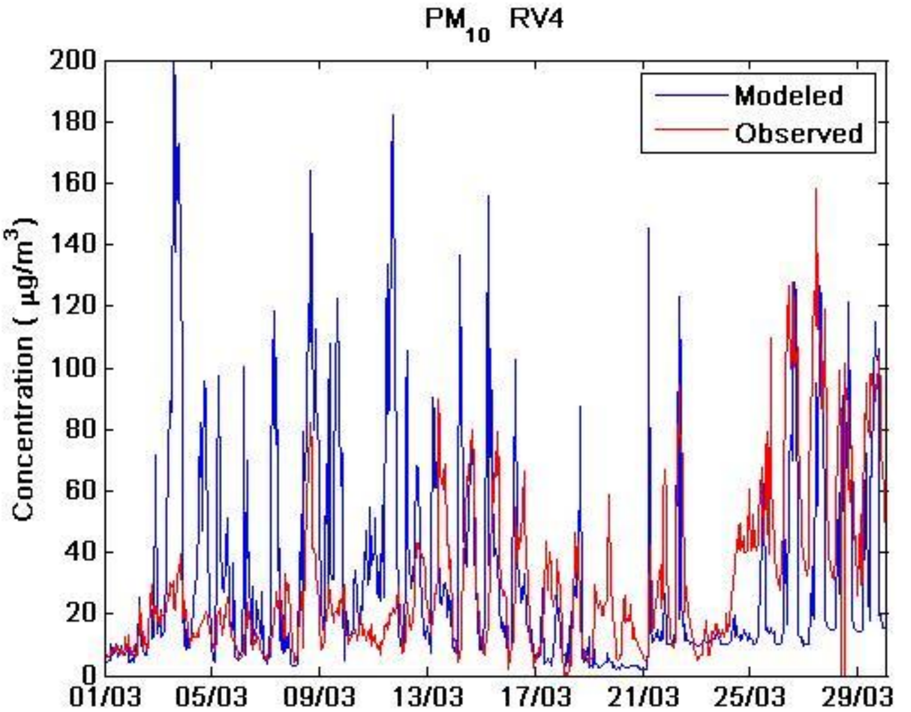

Figure A6: Hourly values of PM_{10} at RV4 in March 2007

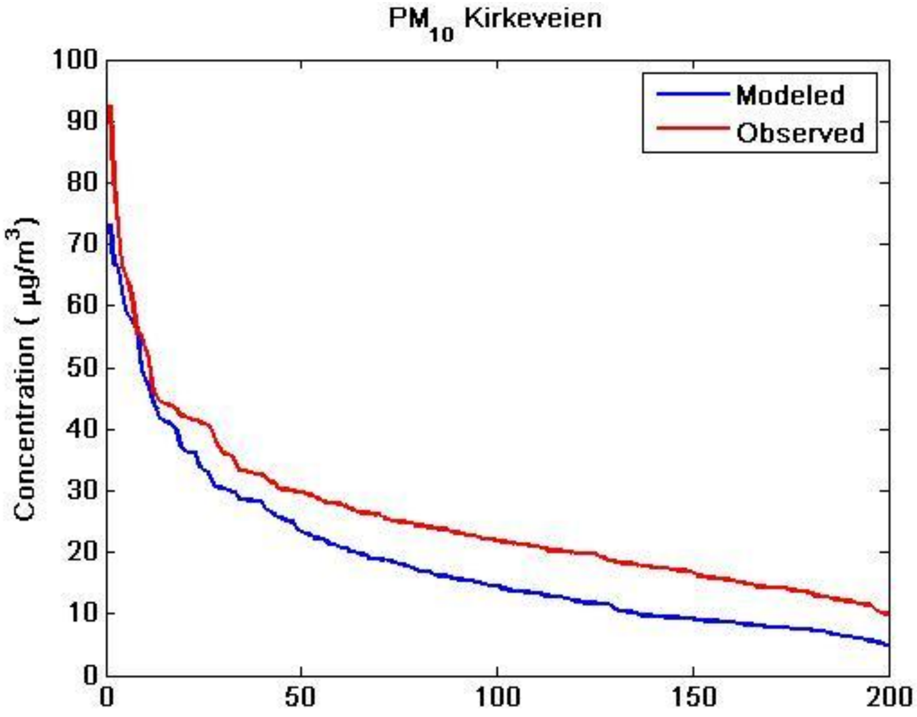

Figure A7: Daily values of PM_{10} at Kirkeveien sorted descending

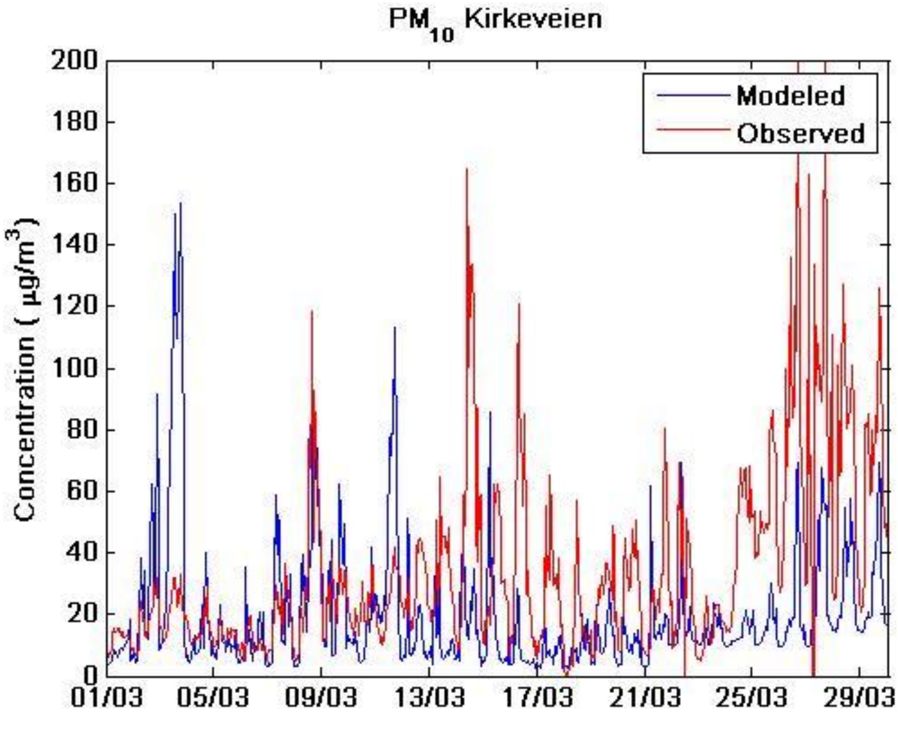

Figure A8: Hourly values of PM_{10} at Kirkeveien in March 2007

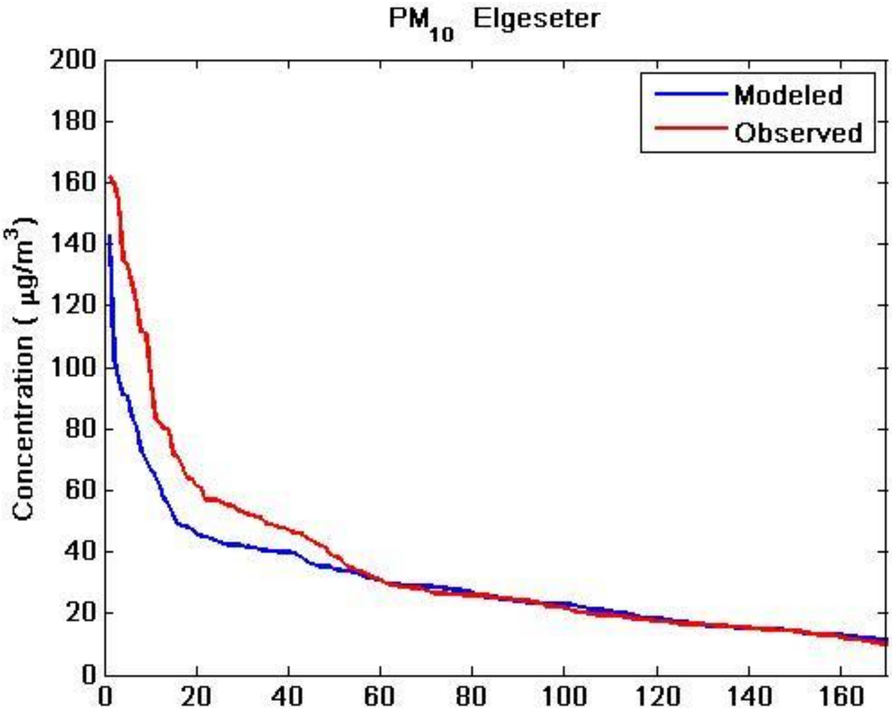

Figure A9: Daily values of PM_{10} at Elgeseter sorted descending

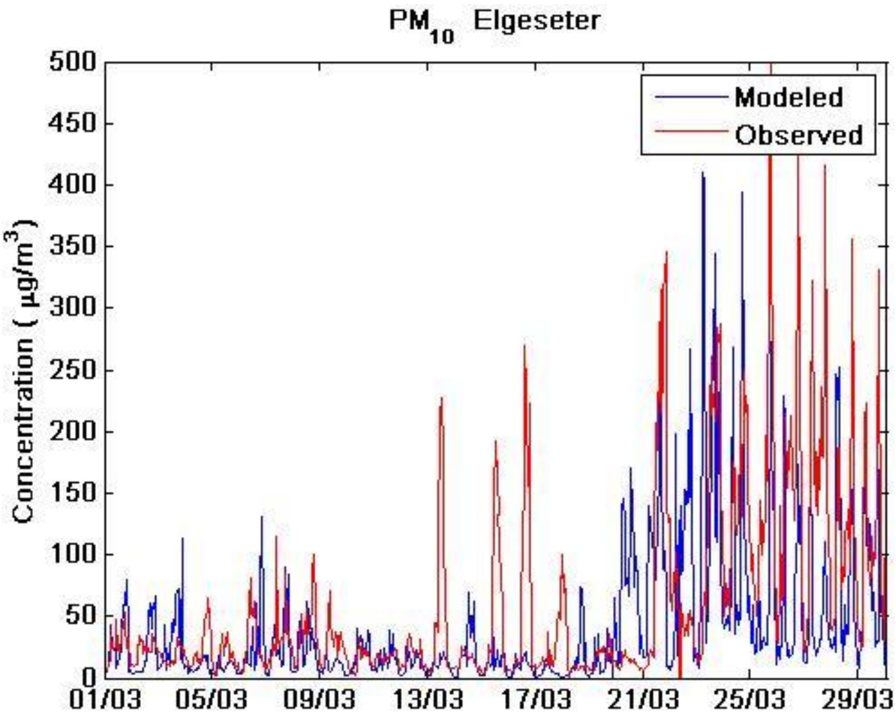

Figure A10: Hourly values of PM_{10} at Elgeseter in March 2007

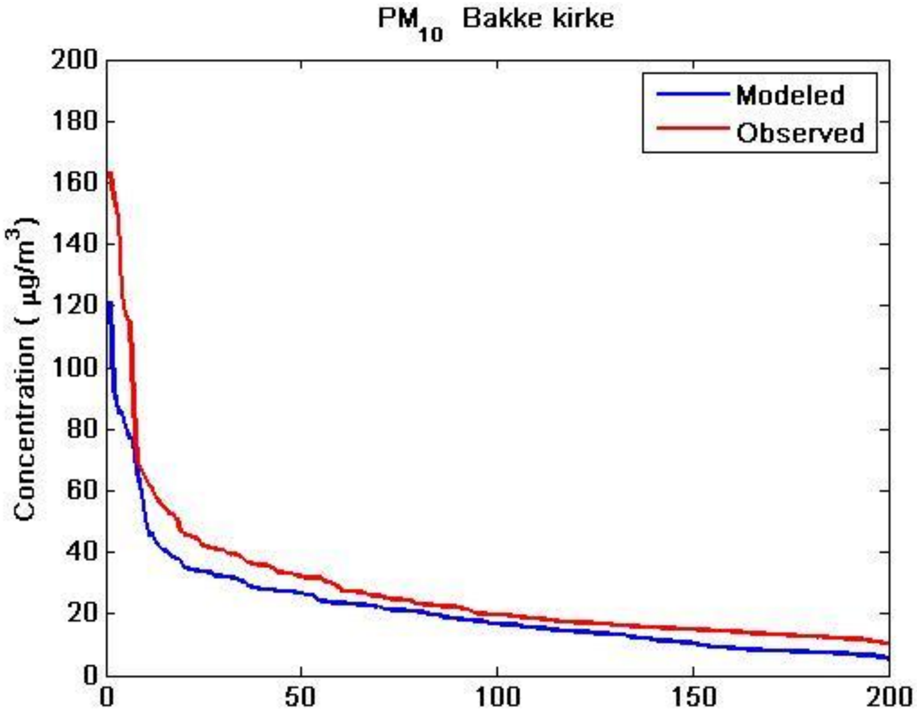

Figure A11: Daily values of PM_{10} at Bakke kirke sorted descending

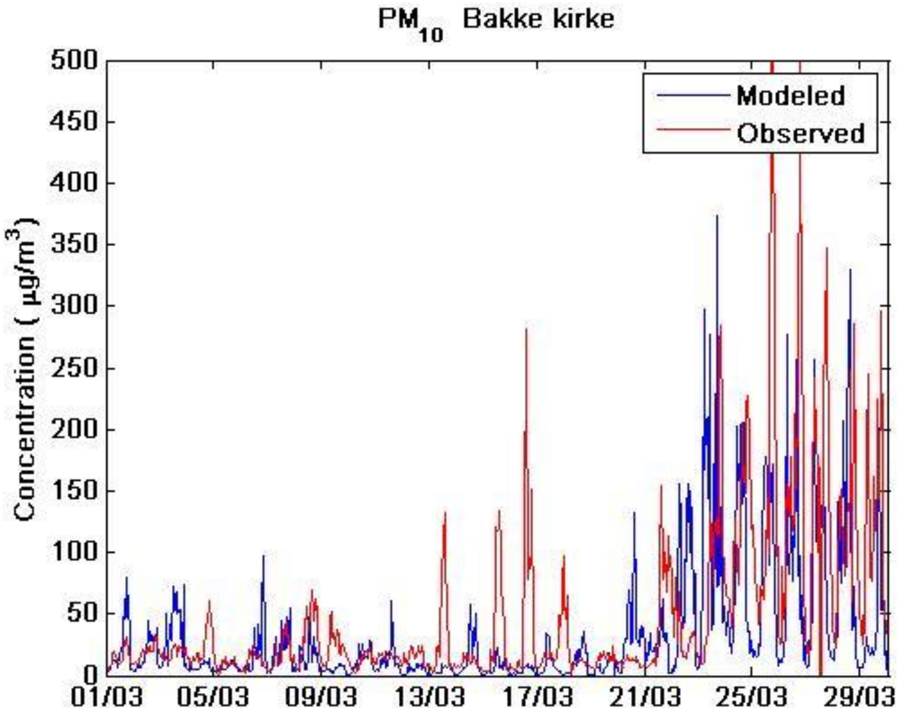

Figure A12: Hourly values of PM_{10} at Bakke kirke in March 2007

Appendix B

Model predicted concentration fields related to the national air quality targets

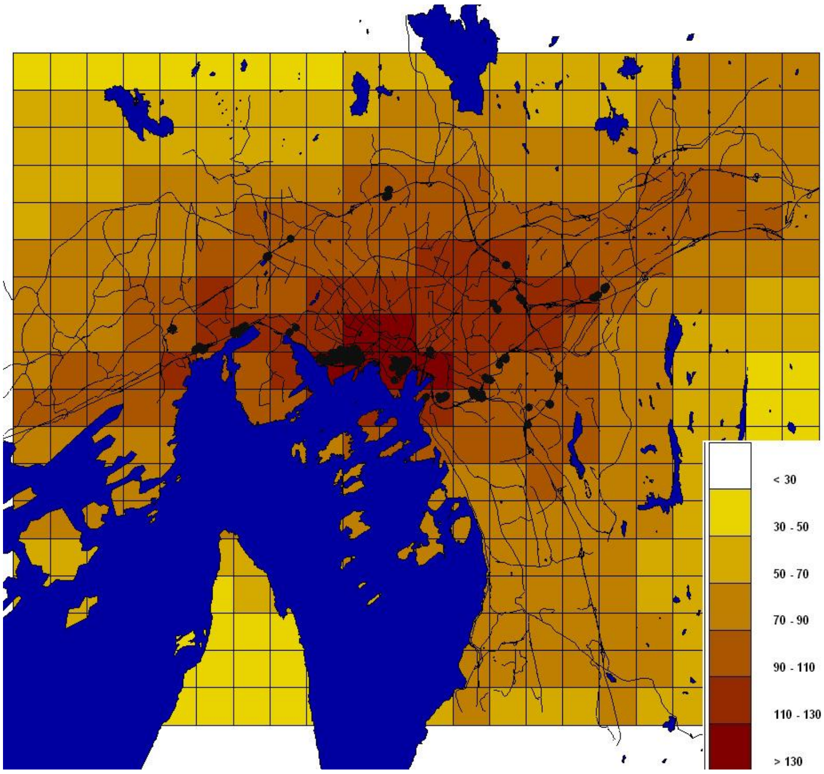

Figure B1: The 9th highest hourly grid value of NO_2 ($\mu g/m^3$) for Oslo in 2007. The black dots are illustrating the building points where the 9th highest hourly NO_2 value is above the national target of 150 $\mu g/m^3$.

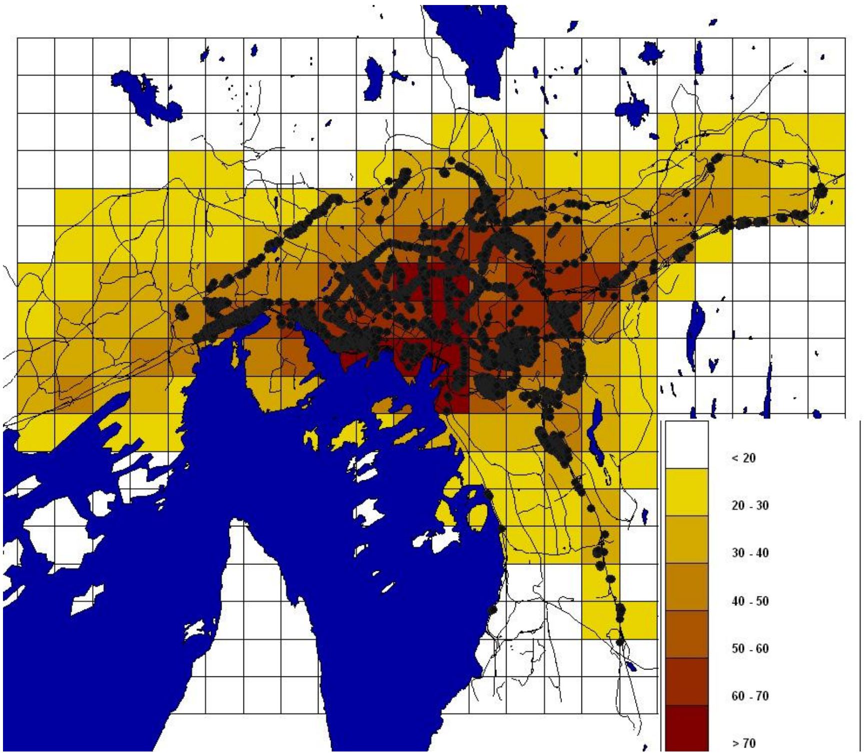

Figure B2: The 8th highest daily grid value of PM_{10} ($\mu g/m^3$) for Oslo in 2007. The black dots are illustrating the building points where the 8th highest daily PM_{10} value is above the national target of 50 $\mu g/m^3$.

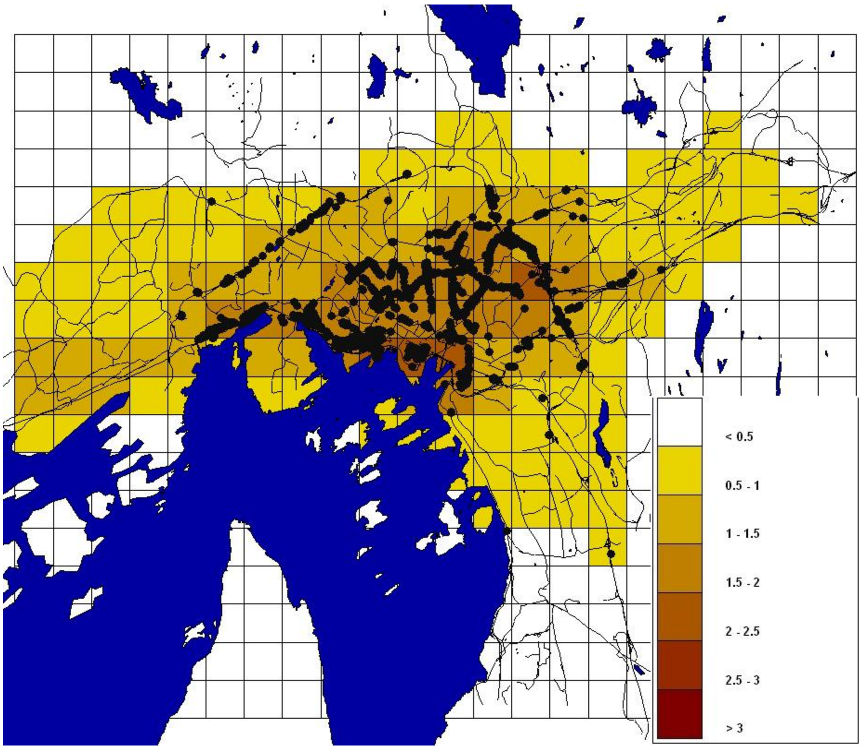

Figure B3: The yearly mean grid value of Benzene ($\mu g/m^3$) for Oslo in 2007. The black dots are illustrating the building points where the yearly mean Benzene value is above the national target of 2 $\mu g/m^3$.

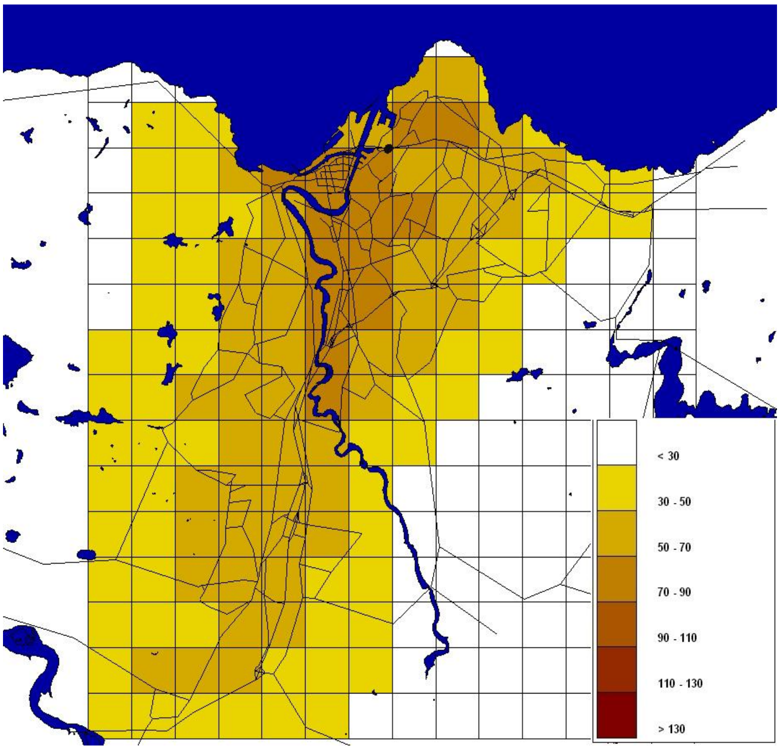

Figure B4: The 9th highest hourly grid value of NO_2 ($\mu g/m^3$) for Trondheim in 2007. The black dots are illustrating the building points where the 9th highest hourly NO_2 value is above the national target of 150 $\mu g/m^3$.

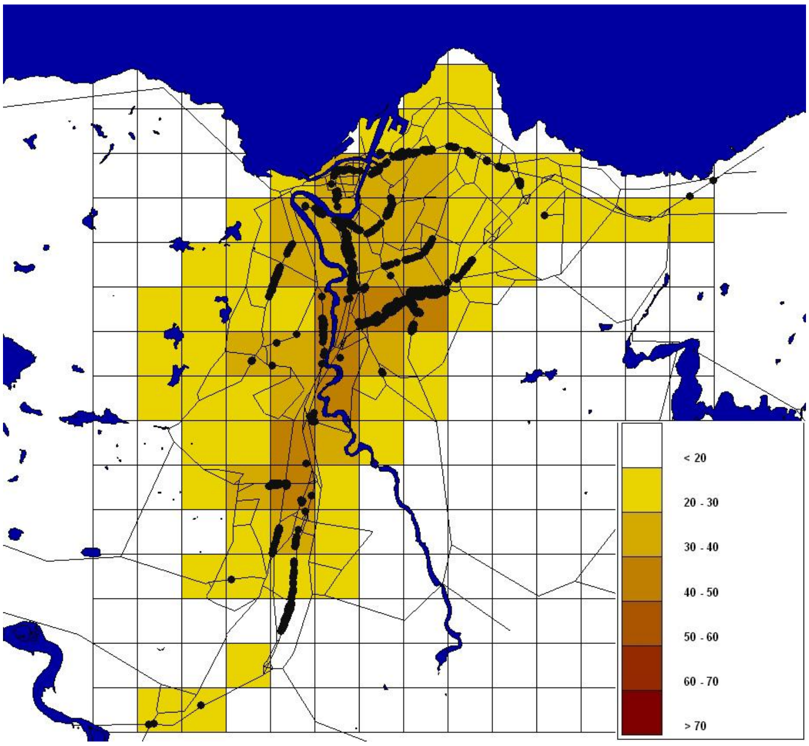

Figure B5: The 8^{th} highest daily grid value of PM_{10} ($\mu g/m^3$) for Trondheim in 2007. The black dots are illustrating the building points where the 8^{th} highest daily PM_{10} value is above the national target of 50 $\mu g/m^3$.

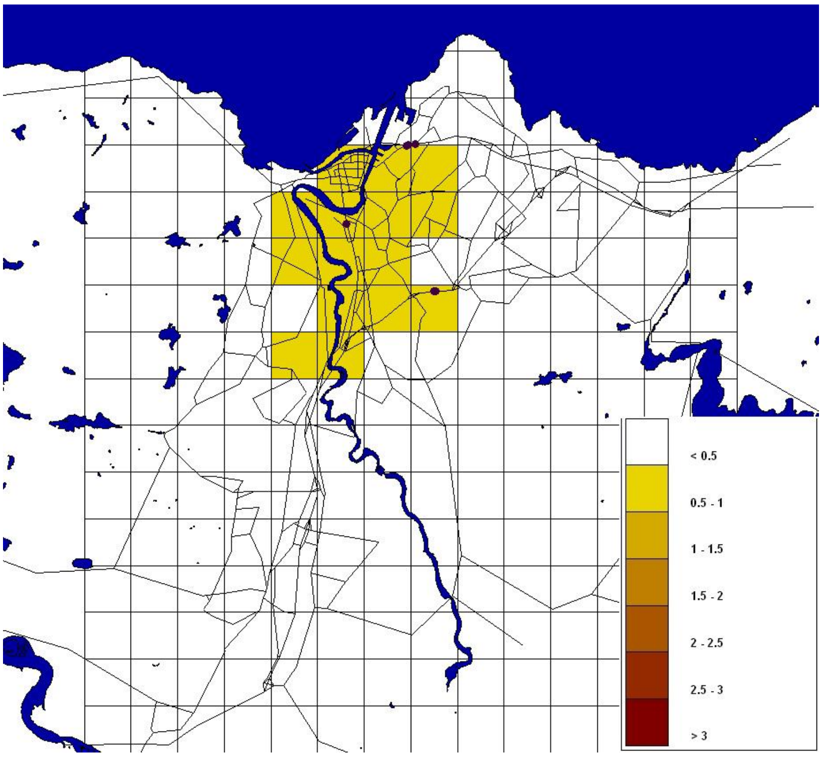

Figure B6: The yearly mean grid value of Benzene ($\mu g/m^3$) for Trondheim in 2007. The black dots are illustrating the building points where the yearly mean Benzene value is above the national target of 2 $\mu g/m^3$.

Appendix C

Percentual source contribution to the exceedances of the National Target

Table C1: Average source contribution to exceedances of the National Target for NO_2 in building points in Oslo. Values given in percent.

Grid index I	Grid index J	Domestic wood combustion	Traffic	Regional background	Other sources
12	9	0,07	93,01	0,09	6,83
13	9	0,07	97,78	0,08	2,07
15	9	0,05	96,38	0,22	3,35
9	10	0,06	88,30	0,20	11,44
10	10	0,03	91,89	0,18	7,89
11	10	0,04	90,43	0,13	9,40
12	10	0,05	85,82	0,12	14,01
13	10	0,03	95,49	0,14	4,34
14	10	0,03	95,84	0,24	3,89
15	10	0,05	97,42	0,17	2,36
5	11	0,06	96,72	0,32	2,90
6	11	0,07	95,45	0,12	4,36
7	11	0,08	93,64	0,14	6,14
8	11	0,21	86,79	0,21	12,79
9	11	0,09	89,35	0,08	10,48
10	11	0,08	90,27	0,19	9,46
12	11	0,07	83,88	0,20	15,85
14	12	0,07	95,07	0,16	4,70
16	12	0,06	93,28	0,18	6,48
17	12	0,03	98,76	0,16	1,05
7	13	0,05	98,27	0,28	1,40
14	13	0,08	94,14	0,16	5,62
8	14	0,03	98,00	0,35	1,62
11	15	0,04	98,40	0,10	1,46

Table C2: Source contribution to exceedances of the National Target for PM_{10} in grid squares in Oslo. Values given in percent.

Grid index I	Grid index J	Domestic wood combustion	Traffic	Regional background	Other sources
12	9	13,28	81,57	3,12	2,03
13	9	19,09	74,65	4,35	1,91
9	10	18,19	73,42	4,06	4,33
10	10	12,74	79,07	4,82	3,37
11	10	11,04	81,72	4,02	3,22
12	10	13,89	79,84	3,14	3,13
13	10	21,57	71,82	3,5	3,11
14	10	20,4	72,74	4,07	2,79
15	10	20,62	72,86	4,31	2,21
6	11	28,96	62,72	4,63	3,69
7	11	28,77	62,78	4,18	4,27
8	11	30,22	60,95	3,86	4,97
9	11	38,37	52,28	3,8	5,55
10	11	34,88	55,39	4,22	5,51
11	11	30,44	59,75	4,04	5,77
12	11	26,95	64,38	3,41	5,26
13	11	26,05	66,21	3,54	4,2
14	11	21,94	71,67	3,41	2,98
15	11	18,84	75,5	3,53	2,13
9	12	46,93	42,95	4,16	5,96
10	12	51,82	38,57	3,82	5,79
11	12	48,45	41,9	4,06	5,59
12	12	44,06	46,1	3,72	6,12
13	12	36,42	54,36	3,65	5,57
14	12	24,08	69,16	3,52	3,24
15	12	18,73	75,06	3,51	2,7
16	12	15,42	78,91	3,59	2,08
11	13	49,83	40,43	4,26	5,48
12	13	52,93	38,21	3,62	5,24
13	13	42,69	48,51	3,87	4,93
14	13	34,61	57,08	4,09	4,22
15	13	32,18	59,51	4,79	3,52
13	14	46,03	45,59	4,00	4,38

Table C3: Average source contribution to exceedances of the National Target for PM_{10} in building points in Oslo. Values given in percent.

Grid index I	Grid index J	Domestic wood combustion	Traffic	Regional background	Other sources
17	2	2,15	91,68	6,03	0,14
13	3	5,03	86,56	8,04	0,37
17	3	2,62	90,38	6,7	0,3
16	4	6,79	87,99	4,9	0,32
13	5	3,75	90,02	5,88	0,35
16	5	6,62	87,41	5,62	0,35
13	6	14,6	80,55	3,68	1,17
15	6	15,55	79,76	3,73	0,96
16	6	8,87	85,85	4,84	0,44
15	7	13,8	80,87	4,52	0,81
14	8	9,94	84,15	5,14	0,77
15	8	14,65	79,65	4,71	0,99
12	9	6,68	88,95	3,20	1,17
13	9	13,68	80,59	4,24	1,49
14	9	17,74	75,92	4,82	1,52
15	9	18,64	75,5	4,49	1,37
5	10	20,42	72,11	4,87	2,60
6	10	21,82	71,49	3,83	2,86
9	10	15,07	76,74	4,55	3,64
10	10	7,80	85,56	4,37	2,27
11	10	7,28	86,79	3,61	2,32
12	10	12,73	81,03	3,31	2,93
13	10	19,84	73,75	3,52	2,89
14	10	17,73	75,95	4,07	2,25
15	10	16,67	77,39	4,11	1,83
5	11	21,16	71,47	4,89	2,48
6	11	26,31	66,14	4,4	3,15
7	11	21,89	70,90	4,24	2,97
8	11	28,18	63,80	3,88	4,14
9	11	35,13	55,96	3,85	5,06
10	11	30,88	59,89	4,27	4,96
11	11	29,51	60,89	4,04	5,56
12	11	25,60	65,91	3,50	4,99
13	11	25,12	67,35	3,47	4,06
14	11	20,90	72,78	3,46	2,86
15	11	13,06	81,27	4,02	1,65
6	12	27,55	64,89	4,96	2,6
7	12	31,53	59,88	4,73	3,86
9	12	44,09	46,25	4,19	5,47

Grid index I	Grid index J	Domestic wood combustion	Traffic	Regional background	Other sources
10	12	50,02	40,62	3,89	5,47
11	12	46,54	44,28	3,87	5,31
12	12	42,52	47,94	3,69	5,85
13	12	34,19	57,05	3,69	5,07
14	12	19,00	74,41	3,87	2,72
15	12	14,68	79,08	4,01	2,23
16	12	12,28	82,03	3,92	1,77
17	12	13,11	81,05	4,41	1,43
7	13	18,97	73,42	5,64	1,97
8	13	21,77	71,22	4,79	2,22
10	13	44,39	46,62	4,43	4,56
11	13	47,23	43,52	4,09	5,16
12	13	50,04	41,26	3,66	5,04
13	13	37,42	54,58	3,84	4,16
14	13	26,21	66,28	4,00	3,51
15	13	28,93	63,37	4,48	3,22
16	13	20,56	72,50	4,36	2,58
17	13	16,06	77,50	4,72	1,72
18	13	7,02	87,17	4,89	0,92
19	13	3,90	91,21	4,29	0,60
8	14	20,80	71,76	5,56	1,88
9	14	19,95	72,38	5,81	1,86
10	14	38,35	53,76	4,77	3,12
12	14	50,88	39,60	4,66	4,86
13	14	39,46	52,76	3,93	3,85
14	14	35,94	56,23	4,39	3,44
15	14	28,92	63,97	4,42	2,69
16	14	18,89	73,67	4,89	2,55
17	14	16,59	77,10	4,31	2,00
18	14	8,77	84,88	5,25	1,10
19	14	4,99	89,88	4,51	0,62
20	14	5,75	88,05	5,56	0,64
21	14	5,95	86,69	6,70	0,66
22	14	3,05	88,55	7,96	0,44
10	15	20,58	73,43	4,28	1,71
11	15	12,93	81,72	4,21	1,14
12	15	24,43	68,42	4,93	2,22
13	15	26,69	66,11	4,74	2,46
19	15	8,91	85,07	5,05	0,97
22	15	5,62	85,84	7,91	0,63

Table C4: Average source contribution to exceedances of the National Target for NO_2 in building points in Trondheim. Values given in percent.

Grid index I	Grid index J	Domestic wood combustion	Traffic	Regional background	Other sources
7	13	0,02	98,88	0,32	0,78

Table C5: Average source contribution to exceedances of the National Target for PM_{10} in building points in Trondheim. Values given in percent.

Grid index I	Grid index J	Domestic wood combustion	Traffic	Regional background	Other sources
2	1	0,54	94,43	4,89	0,14
5	3	2,05	92,66	5,04	0,25
4	4	12,72	79,73	6,72	0,83
5	4	5,05	90,06	4,51	0,38
5	5	8,11	85,64	5,70	0,55
4	6	8,47	86,52	4,58	0,43
5	6	4,54	91,76	3,41	0,29
5	7	12,04	78,99	8,43	0,54
5	8	9,09	86,06	4,43	0,42
4	9	8,89	83,83	6,76	0,52
5	9	16,00	76,91	6,41	0,68
6	9	9,29	85,59	4,58	0,54
7	9	27,37	62,11	9,86	0,66
4	10	6,97	87,16	5,50	0,37
5	10	7,03	86,4	6,13	0,44
6	10	11,86	82,06	5,64	0,44
7	10	12,82	81,78	5,06	0,34
8	10	9,21	85,25	5,28	0,26
5	11	12,21	80,89	6,4	0,5
6	11	11,52	82,87	5,08	0,53
7	11	18,14	74,69	6,63	0,54
8	11	13,79	78,10	7,68	0,43

Grid index I	Grid index J	Domestic wood combustion	Traffic	Regional background	Other sources
9	11	9,35	83,19	7,07	0,39
5	12	6,88	86,82	5,80	0,50
6	12	16,86	76,73	5,66	0,75
7	12	33,24	58,07	7,97	0,72
8	12	30,68	60,18	8,58	0,56
11	12	4,13	89,84	5,78	0,25
6	13	5,53	87,55	6,10	0,82
7	13	15,00	79,91	4,41	0,68
8	13	12,76	81,95	4,89	0,40
9	13	4,67	88,31	6,67	0,35
10	13	2,67	91,38	5,66	0,29
14	13	1,38	91,9	6,58	0,14
7	14	1,83	93,6	4,22	0,35
8	14	7,64	87,35	4,70	0,31
9	14	2,66	89,92	7,17	0,25

Appendix D Appendix D

Procedure for the estimation of boundary values

General procedure

Observations of daily averaged values of NO_2 and hourly values of Ozone measured at the closest regional background stations have been applied as boundary conditions on the open boundaries of the model domain (see Table 2). For the Oslo domain daily means of PM_{10} measured at Birkenes were applied, whereas the background PM_{10} levels in Trondheim were estimated from measurements of SO_4, NO_3 and NH_4 at the regional station Kårvatn. Based on an empirical relation found between the concentrations of these compounds and the measured PM_{10} levels at Birkenes in 2007 an estimate is calculated for Kårvatn by the formula:

$$[PM_{10}] = ([SO_4] + [NO_3] + [NH_4])*3.5$$

Table D2: Measurement stations applied in estimating the boundary conditions.

	NO_2	Ozon	PM_{10}
Oslo	Birkenes	Birkenes/Prestebakke/Hurdal	Birkenes
Trondheim	Kårvatn	Kårvatn	Kårvatn

Average background values for the simulation period are applied when a background value is missing.

Ozon

- For Oslo the hourly values from Birkenes,Prestebakke and Hurdal are considered. The largest values from these stations are applied.
- For Trondheim hourly values from Kårvatn are applied.

NO_2

- For Oslo daily means of NO_2 from Birkenes are applied.
- For Trondheim daily means of NO_2 from Kårvatn are applied.

Note: Since the values in the NILUdb are given as NO2_N, the values are converted from N to NO2 by use of the following relation: NO_2=NO_2-N*(46/14).

Daily means are applied directly as hourly values for the hours in which they are valid, i.e., from (an including) 07 AM until 07AM the next day.

PM_{10}:

- For Oslo actual measurements of PM_{10} from Birkenes are applied.
- For Trondheim data on SO_4A, SumNO_3 and SumNH_4 from Kårvatn are applied to estimate the background PM_{10} levels.

Note: Since the values in the NILUdb are given as SO4A, SumNO3 and SumNH4, the values are converted to PM_{10} by use of the following relation:
PM10=((SO4A*3)+(SumNO3*4.43)+(SumNH4*1.29))*3.5

Since the values in the NILUdb are given as SO_4A-S, the values are converted from S to SO_4 by use of the following relation: SO_4A=SO_4A-S* (96/32).

Daily values are applied directly as hourly values for the hours in which they are valid, i.e., from (an including) 07 AM until 07AM the next day.

NO:
Backgrond values of NO are set equal to zero.

Benzene:
Backgrond values of Benzene are set equal to zero.

Appendix E Appendix E

Norwegian Summary

Sammendrag

På oppdrag fra Statens forurensningstilsyn (Sft) har Norsk institutt for luftforskning (Nilu) utført sprednings og eksponerings beregninger for PM_{10}, NO_2 og Benzen (C_6H_6) i Oslo og Trondheim for 2007. Beregningene har blitt gjort med Nilus modellsystem AirQUIS (AirQUIS, 2006).

Nilu har beregnet utendørs konsentrasjoner av PM_{10}, NO_2 og Benzen (C_6H_6) i Oslo og Trondheim for vintermånedene i 2007, dvs. fra januar til og med april og fra oktober til og med desember. Antall personer utsatt for overskridelser etter de "Nasjonale mål for luftkvalitet" er beregnet i både bygningspunkt langs de største veiene og på gridruter(1 km^2).

De nasjonale mål setter grense på maks 8 timer over 150 $\mu g/m^3$ for NO_2 og maks 7 døgn med døgnmiddel over 50 $\mu g/m^3$ for PM_{10} per år. For Benzen er grensen at årsmiddelet ikke skal overskride 2 $\mu g/m^3$. Antall personer i Oslo og Trondheim som er utsatt for overskridelser er vist i Tabell A under. Så mye som 35 % av Oslos befolkning er beregnet utsatt for overskridelser av PM_{10} i 2007 i motsetning til kun 3.3 % i Trondheim. Dette er en nedgang fra 2005 mens man for NO_2 ser en økning.

Tabell A: Antall mennesker utsatt for overskridelser i følge de "Nasjonale mål" for PM_{10}, NO_2 og Benzen i Oslo og Trondheim i 2007. Resultat for 2005 er gitt i parentes.

	OSLO	**TRONDHEIM**
PM_{10}	186 744 (235 849)	4994 (20 914)
NO_2	4193 (652)	85 (40)
Benzen	6224 (31585)	0 (0)

Antall eksponerte personer som vist i tabell A kan variere mye selv ved små forandringer i beregnet konsentrasjon. Dette er spesielt utslagsgivende når konsentrasjonsnivået i en gridrute er i nærhet av grenseverdien.

I de bygningspunkt og gridruter man har overskridelser blir de prosentvise bidragene fra hver kildegruppe beregnet. Denne "skyldfordelingen" ble ikke gjort for Benzen. De gjennomsnittelige kildebidragene er vist i tabell B, C, D og E. Hovedkilden for både PM_{10} og NO_2 er vegtrafikk. Vedfyring er for PM_{10} også en ganske stor kilde og som enkelte steder bidrar med opptil 50 % av overskridelsen.

Tabell B: Kildebidrag til overskridelser i prosent" for NO2 for Oslo i 2007.

Beregnet i	**Vedfyring**	**Trafikk**	**Bakgrunn**	**Andre kilder**
Bygningspunkt	0.06	93.52	0.18	6.25

Tabell C: Kildebidrag til overskridelser i prosent" for PM_{10} for Oslo i 2007.

Beregnet i	**Vedfyring**	**Trafikk**	**Bakgrunn**	**Andre kilder**
Bygningspunkt	20.68	72.26	4.60	2.46
Gridruter	29.71	62.29	3.90	4.10

Tabell D: Kildebidrag til overskridelser i prosent" for NO_2 for Trondheim i 2007.

Beregnet i	Vedfyring	Trafikk	Bakgrunn	Andre kilder
Bygningspunkt	0.02	98.88	0.32	0.78

Tabell E: Kildebidrag til overskridelser i prosent" for PM_{10} for Trondheim i 2007.

Beregnet i	Vedfyring	Trafikk	Bakgrunn	Andre kilder
Bygningspunkt	10.10	83.50	5.95	0.45

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The Norwegian Institute for Air research (NILU) has preformed dispersion and exposure calculation of PM10, NO2 and benzene for Oslo, Trondheim and Bergen for 2003. Population exposure estimates has been related to national guidelines.</td></tr>
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Norsk institutt for luftforskning (NILU) har på oppdrag fra Statens forurensningstilsyn (SFT) gjennomført spredning- og eksponeringsberegninger for PM10, NO2 og benzen for Oslo, Trondheim og Bergen for 2003. Antall personer utsatt for overskridelser av nasjonalt mål av PM10, NO2 og benzen ble beregnet i bygningspunkter og i ruter.</td></tr>
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