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Dispersion and exposure calculation of PM_{10}, NO_2 and benzene for Oslo and Trondheim for the year 2005

Leiv Håvard Slørdal, Harold Mc Innes, Herdis Laupsa and Sam Erik Walker

Contents

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) for the year 2005 for the two Norwegian cities Oslo and Trondheim. The calculations have been carried out by applying the model system AirQUIS (AirQUIS, 2006).

NILU has calculated outdoor concentration levels of PM_{10}, NO_2 and benzene for the winter season, i.e., from the beginning of January to the end of April, and from the beginning of October to the end of December for the year 2005. Ambient air concentrations and population exposure have been calculated both in the positions of buildings located close to the main road network (hereafter referred to as building point values), and within a domain-covering, two-dimensional grid with a quadratic 1 km^2 grid size (hereafter simply referred to as grid square values). The inhabitants of the considered buildings are assigned to building point concentrations while the rest of population are assigned to concentration values computed in the grid squares containing the location of their home address.

The exposure calculations have been performed with respect to the goals defined in the ”National Air Quality Target”. This target specifies that during a year no more than 8 hours are allowed with (hourly mean) NO_2 concentration levels above 150 $\mu g/m^3$, no more than 7 days with (daily mean) PM_{10} concentration levels above 50 $\mu g/m^3$, and, that the yearly averaged urban background benzene concentration should not exceed 2 $\mu g/m^3$. Since urban background levels are best reflected by the calculated grid square concentrations, the exposure results for benzene are based on these concentration values. The total exposure results are summarized in Table A below. The numbers in parenthesis for benzene is the one found when also considering building point concentrations in the exposure estimate.

Table A: 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 2005.

	Oslo	**Trondheim**
PM_{10}	235 849	20 914
NO_2	652	40
H_6C_6 (Benzene)	31 585 (56 547)	0 (490)

When considering the exposure estimates 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 concentration levels close to the target value are computed.

For the building points and grid squares in which exceedances of the “National Air Quality Target” have been found, the relative contribution from the main source categories have also been estimated. When performing this source

contribution calculation, only hours (NO_2) and days (PM_{10}) contributing to the exceedances have been considered, and the final estimate is the average percentual 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 is summarized below in Tables B, C, D, and E. For each compound the contributions are given separately for the building points and the grid squares. Since only buildings in the vicinity of the main roads have been treated separately as building points, the exceedances in these points will naturally be more traffic influenced than the grid squares exceedances, as clearly revealed in the tables below. No grid square exceedances are estimated for NO_2, and therefore this row is missing in Table B and D.

Table B: Source contribution (in percent) to the exceedances of the "National target" on NO_2 for Oslo in 2005.

Calculated in	Domestic wood comb.	Traffic	Regional background	Other sources
Building points	0.05	96.59	0.15	3.21

Table C: Source contribution (in percentage) to the exceedances of the "National target" on PM_{10} for Oslo in 2005.

Calculated in	Domestic wood comb.	Traffic	Regional background	Other sources
Building points	14.8	73.2	10.0	2.0
Grid squares	21.8	66.7	8.5	3.0

Table D: Source contribution (in percentage) to the exceedances of the "National target" on NO_2 for Trondheim in 2005.

Calculated in	Domestic wood comb.	Traffic	Regional background	Other sources
Building points:	0.36	97.13	0.08	2.43

Table E: Source contribution (in percentage) to the exceedances of the "National target" on PM_{10} for Trondheim in 2005.

Calculated in	Domestic wood comb.	Traffic	Regional background	Other sources
Building points:	13.9	75.3	10.4	0.4
Grid squares:	27.0	59.2	13.2	0.6

The calculations of the percentual contributions from the various sources demonstrate that road traffic is the dominant source to the exceedances of the national target for both components. For PM_{10} domestic wood combustion is clearly the second most dominant local source.

Dispersion and exposure calculation of PM_{10}, NO_2 and benzene for Oslo and Trondheim for the year 2005

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) for the year 2005 for the two Norwegian cities Oslo and Trondheim. The calculations have been carried out by applying the model system AirQUIS (AirQUIS, 2006).

NILU has calculated outdoor concentration levels of PM_{10}, NO_2 and benzene for the winter season, i.e., from the beginning of January to the end of April, and from the beginning of October to the end of December for the year 2005. Ambient air concentrations and population exposure have been calculated both in the positions of buildings located close to the main road network (hereafter referred to as building point values), and within a domain-covering, two-dimensional grid with a quadratic 1 km^2 grid size (hereafter simply referred to as grid square values). The inhabitants of the considered buildings are assigned to building point concentrations while the rest of population are assigned to concentration values computed in the grid squares containing the location of their home address.

The exposure calculations have been performed with respect to the goals defined in the ”National Air Quality Target”. This target specifies that during a year no more than 8 hours are allowed with (hourly mean) NO_2 concentration levels above 150 $\mu g/m^3$, no more than 7 days with (daily mean) PM_{10} concentration levels above 50 $\mu g/m^3$, and, finally, the target don’t allow the yearly averaged benzene concentration to exceed 2 $\mu g/m^3$.

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

2 Input data

The input data for the calculations consist of:

1. Meteorological data.
2. Consumption data on different fuel types or direct emission data from various anthropogenic activity (either defined as point sources or as grid distributed area sources).
3. Road traffic data.
4. Background concentration levels of NO_2, NO_X, ozone, PM_{10} and benzene

for application as boundary conditions at the open model boundaries during the simulation period.

5. Population distribution both in building points and in grid squares. Note that the persons assigned to the building points are subtracted from the total number in the corresponding grid square, so that all inhabitants are counted only once.

2.1 Meteorological data

The diagnostic wind field model Mathew (Sherman, 1978; Foster et al., 1995) has been used 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) and construct a three-dimensional wind field that 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 are no artificial gain or loss of air within the model domain.

For Oslo the meteorological input data have been taken from the measurement station at Valle Hovin. These data consist of hourly measurements of temperature, wind speed and direction at a height of 25 m above ground, the vertical temperature difference between the height of 25 m and 8 m above ground, relative humidity at the height of 2 m and precipitation (in mm/h).

For Trondheim meteorological observations from the measurement station Voll have been used. 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 the existing parameters and meteorological experience.

2.2 Consumption- and emission data for various fuel types

Consumption and emission data for various fuel types have been supplied by Statistics Norway (SSB).

The consumption data from SSB is divided into about 80 different source categories. In order to reduce this huge number, and thereby simplify the calculation procedure, these categories have been assembled into larger group categories (see Table 1). Group categories 1 to 6 contains SSB data. Road traffic emission (emission category 7) is treated separately and is described further in Section 2.3 below.

Table 1: Assembled emission categories employed in the calculations.

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

The consumption numbers for each of SSB's source categories are 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[1], PM_{10} and benzene for each source category. Subsequently the various source categories are assembled into the chosen group categories, and the total primary emissions are summed over all groups within each "base district" (the smallest administrative unit within the cities). When analyzing the relative source contribution to the estimated exceedances, we are basically referring to the 7 assembled categories in Table 1.

Oslo

All consumption and emission data, except for domestic wood combustion, for Oslo and Bærum are based on data from 1998. These 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 are valid for the year 2002 **(**Finstad et al., 2004 a**).** Wood consumption data for Bærum are valid for 1999, but the emission factors applied for Bærum are identical to those for Oslo, i.e. considered valid for 2002. The emission data from domestic wood combustion has then been adjusted in accordance with the expected renewal of ovens and the estimated change in wood consumption from 2002 until 2005. The applied adjustment procedure is described in detail in Slørdal et al., 2007 b.

Trondheim

Emission data on domestic wood combustion for Trondheim are valid for 2003 (Finstad et al., 2004 b). The adjustment procedure employed in Oslo has also been applied in Trondheim to estimate the emissions from this source for the year 2005 (Slørdal et al., 2007 b). All other (area distributed) data are valid for 1998 and has not been modified.

2.3 Traffic data

Road information and traffic data for Oslo and Trondheim

The emission from road traffic is mainly based on the same data (amount of traffic, vehicle composition, road classifications, speed limits, road slope, etc.) that was applied in the previous projects "Dispersion and exposure calculation of PM_{10}, NO_2, and benzene for Oslo, Trondheim and Bergen for 2003". (Laupsa et al., 2005 a) and "Calculation of PM_{10} and $PM_{2,5}$ for Oslo in 2010 and 2015" (Laupsa et al., 2005 b). The only changes are that new emission factors, valid for the year 2005, have been applied, and that some manual updates of the traffic information at some road segments have been made based on recent traffic counts. These updates also include the environmental speed limit reduction at RV4 in Oslo. Furthermore, the percentage of vehicles with studded tyres has been set to 24 % in Oslo and 38 % in Trondheim. The studded tyre season has been defined from October 15 until May 1 for Oslo and from November 1 until May 1 for Trondheim.

[1] The emission factor for NO_2 is defined as 10 % of the emission factor of NOx.

2.4 Background concentrations applied as model boundary conditions

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, measured daily background values of PM_{10} from the EMEP station 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 EMEP station at Kårvatn. This estimate is based on the following empirical relation between the concentrations of these compounds (Slørdal and Larssen, 2001).

$$[PM_{10}] = ([SO_4] + [NO_3] + [NH_4])*2.5$$

Table 2: Measurement stations applied in estimating the boundary conditions.

	NO_2	Ozone	PM_{10}
Oslo	Birkenes	Jeløya/Prestebakke	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 in the two cities. These data have been delivered by SSB and are valid for the year 2005.

The outdoor concentrations are calculated for each building that are located within a certain distance from the main road network, typically within a distance of 100 – 400 m, depending on the ADT of the road. In the exposure computations the concentration value, calculated in the geographical position of the building and estimated at a height of 2 m above ground, is assigned to all of the persons registered as inhabitants in the building. Persons living in buildings further away from the main road network are assigned to the concentration value that is 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 given in Table 3

Table 3: Population data.

	Total number of inhabitants within the model domain	Total number of persons assessed in building points
Oslo	526 228	90 885
Trondheim	151 678	11 850

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

For NO_2 and PM_{10} comparisons have been made between the measured and model calculated mean value, standard deviation and maximum hourly value. The correlation coefficient, intercept point and slope of the linear regression line have also been included in the evaluation. For benzene, however, only the model calculated mean value for 2005 has been evaluated against the measurements.

3.1 Model evaluations for Oslo

For Oslo model calculated values of NO_2 and PM_{10} have been evaluated against measurements from Kirkeveien and RV4, and calculated values of benzene have been compared with measurements at Kirkeveien. Both of these stations are located close to main roads, i.e., within a distance of 5 meter from the roadside, and are therefore termed “street stations”. Since the concentration levels decrease rapidly with increasing distance from the roadside, especially within the nearest 100 m, 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 4. As seen in this table there is a rather good agreement between the observations and the model predicted values. On average the NO_2 levels are overestimated at RV4, while there is a somewhat stronger under-prediction at Kirkeveien. At both stations rather high values of the correlation coefficient are found. Based on the statistics presented in Table 4 the best fit is found at RV4.

In Figure A1 and Figure A3 the 500 highest measured and calculated NO_2 values are plotted in descending order. The over- and under-estimation seen in the average levels in Table 4, are also evident in the curves depicted in these Figures. Note that the 9^{th} highest computed value, i.e., the value applied in the NO_2 exposure calculations, is much closer to its observed counterpart at RV4 than at Kirkeveien.

A direct comparison of the measured and calculated hourly NO_2 concentrations for a one-month period (February 2005) is presented in Figure A2 and Figure A4 for RV4 and Kirkeveien, respectively. These plots clearly reveal the high degree of correlation between the measured and calculated values.

Table 4: Statistical comparison between calculated and observed hourly values of NO_2 in Kirkeveien and RV4 for the periods 01.01.2005 to 01.05.2005 and 01.10.2005 to 01.01.2006.

	Mean value (µg/m³)		**Standard deviation (µg/m³)**		**Maximum value (µg/m³)**	
	Measured	Calculated	Measured	Calculated	Measured	Calculated
RV4	38.1	42.4	25.8	34.0	132.6	142.8
Kirkeveien	44.5	32.5	29.8	27.1	178.3	126.8
Comparison observed – calculated						
	Correlation coefficient		**Slope of linear regression line**		**Linear regression intercept point**	
RV4	0.68		0.91		8.1	
Kirkeveien	0.64		0.60		6.2	

3.1.2 PM_{10}

The statistical comparison between the measured and calculated PM_{10} values at RV4 and Kirkeveien are shown in Table 5. When compared with the statistical measures 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. This is also to be expected, since the uncertainties associated with predictions of PM_{10} are larger than those associated with NO_2 (see Section 4 for further explanation). The predicted PM_{10} concentrations are clearly overestimated at RV4, but just slightly underestimated at Kirkeveien. This feature is further illustrated in Figure A5 (RV4) and Figure A7 (Kirkeveien), where the measured and calculated daily values are plotted in descending order. From the curves plotted in Figure A5 it is evident that the model systematically over-predicts the daily PM_{10} levels at RV4. At Kirkeveien, however, the results presented in Figure A7 clearly reveal that the highest daily PM_{10} levels are very well predicted by the model.

A direct comparison of the hourly measured and calculated PM_{10} concentrations are shown in Figure A6 (RV4) and Figure A8 (Kirkeveien) for the month of February 2005. As seen from these Figures pronounced deviations are found during certain periods, while quite good correspondence are found during others. The overall impression is that the observations are reproduced reasonably well.

Table 5: Statistical comparison between calculated and observed hourly values of PM_{10} in Kirkeveien and RV4 for the periods 01.01.2005 to 01.05.2005 and 01.10.2005 to 01.01.2006.

	Mean value (µg/m³)		**Standard deviation (µg/m³)**		**Maximum value (µg/m³)**	
	Measured	Calculated	Measured	Calculated	Målt	Beregnet
RV4	31.3	43.2	30.3	53.4	260.1	416.9
Kirkeveien	29.9	25.9	25.0	30.2	220.4	273.0
Comparison observed – calculated						
	Correlation coefficient		**Slope of linear regression line**		**Linear regression intercept point**	
RV4	0.54		0.95		13.3	
Kirkeveien	0.52		0.63		7.2	

3.1.3 Benzene

Since the calculations have not been performed for the summer period (no calculations from 01.05.2005 to 01.10.2005) 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 2005 and the observed average for the calculation period. The factor used in Oslo was 0.74, and was based on the available observations of benzene. Table 6 shows that there is good agreement between the calculated and the observed yearly value of benzene at Kirkeveien.

Table 6: Measured and calculated benzene concentration at Kirkeveien for 2005.

	Average value (µg/m3)	
	Measured	Calculated
Kirkeveien	2.3	2.5

3.2 Trondheim

Computed values of NO_2 and PM_{10} are evaluated against measurements from Elgeseter and Bakke Kirke, and 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”. Calculations at the mirror point (similar location on the opposite side of the road) were used for Elgeseter, since the computed values in this position has proved to be the most representative when being compared with measurements. The reason for this is probably that the local wind direction is influenced by local obstacles (buildings, trees, etc.) resulting in a systematic error in the calculations.

3.2.1 NO_2

The statistical evaluation of the NO_2 results at Elgeseter and Bakke Kirke is shown in Table 7. The mean values and the regression parameters indicate that there is a systematic underestimation at both stations, most pronounced at Elgeseter. Correlation coefficients of 0.54 (Elgeseter) and 0.50 (Bakke Kirke) are less than the NO_2 correlation coefficients found in Oslo, but still indicating a decent covariation between the model predicted and observed values.

The 500 highest measured and calculated hourly NO_2 values are plotted in descending order in Figure A9 (Elgeseter) and Figure A11 (Bakke Kirke). From these figures it is seen that the highest values are extremely well reproduced by the model at Bakke Kirke, while at Elgeseter the general underestimation also prevail in this high concentration regime.

Measured and calculated hourly NO_2 concentrations for the month of February 2005 are presented in Figure A10 (Elgeseter) and Figure A12 (Bakke Kirke). Again the model results from Elgeseter show clear signs of underestimation, while this tendency is less evident at Bakke Kirke. Apart from this the general impression from Figure A10 and Figure A12 is that the agreement between model predictions and observations are quite good during most of the month.

Table 7: Statistical comparison between calculated and observed hourly values of NO_2 at Elgeseter and Bakke Kirke for the periods 01.01.2005 to 01.05.2005 and 01.10.2005 to 01.01.2006.

	Mean value ($\mu g/m^3$)		**Standard deviation ($\mu g/m^3$)**		**Maximum value ($\mu g/m^3$)**	
	Measured	Calculated	Measured	Calculated	Measured	Calculated
Elgeseter	58.9	37.6	30.3	27.5	199.3	138.4
Bakke Kirke	36.7	25.0	24.0	25.5	141.5	125.4
Comparison observed - calculated						
	Correlation coefficient		**Slope of linear regression line**		**Linear regression intercept point**	
Elgeseter	0.54		0.49		8.4	
Bakke Kirke	0.50		0.52		5.7	

3.2.2 PM_{10}

The statistical evaluation of the PM_{10} results at Elgeseter and Bakke Kirke is shown in Table 8. Contrary to NO_2 a general overestimation is found at Elgeseter for PM_{10}. At Bakke Kirke the calculated mean PM_{10} level is nearly identical with the observed levels. The values of the correlation coefficients and the regression parameters, however, indicate that there are substantial deviations between model predictions and observations from hour to hour.

Despite the fact that the statistical evaluation for PM_{10} is rather disappointing, the agreement between the highest measured and computed daily values is surprisingly good. These values are shown in descending order in Figure A13 (Elgeseter) and A15 (Bakke Kirke). While there are some small deviations between the highest values at the Elgeseter station, there is almost a perfect fit at Bakke Kirke. With regards to the exposure analysis to be presented below in Section 5, these results are encouraging.

Hourly measured and calculated concentrations in February are shown in Figure A14 and A16. For this particular month the model generally overestimated the PM_{10} concentrations at both stations, except for a 3-day period from the 7^{th} to the 10^{th} of February.

Table 8: Statistical comparison between calculated and observed hourly values of PM_{10} at Elgeseter and Bakke Kirke for the periods 01.01.2005 to 01.05.2005 and 01.10.2005 to 01.01.2006.

	Mean value ($\mu g/m^3$)		**Standard deviation ($\mu g/m^3$)**		**Maximum value ($\mu g/m^3$)**	
	Measured	Calculated	Measured	Calculated	Measured	Calculated
Elgeseter	35.3	41.4	41.6	55.7	409.2	691.2
Bakke Kirke	29.6	29.3	31.8	37.4	407.5	393.7
Comparison observed – calculated						
	Correlation coefficient		**Slope of linear regression line**		**Linear regression intercept point**	
Elgeseter	0.33		0.45		26.1	
Bakke Kirke	0.26		0.30		20.4	

3.2.3 Benzene

Yearly concentrations of benzene have been estimated using the same method in Trondheim as in Oslo. A scaling factor of 0.76 was computed from the available benzene observations for 2005 at Elgeseter. The resulting values at Elgeseter are presented below in Table 9, and these values reveal a rather strong under-prediction by the model. Since the "National air quality target" for benzene is defined for the yearly mean value, and is set to 2 μg/m^3, the comparison at Elgeseter may indicate that we underestimate the number of inhabitants exposed beyond this target value.

Table 9: Measured and calculated benzene concentration at Elgeseter for 2005.

	Mean value (µg/m3)	
	Measured	Calculated
Elgeseter	2.8	2.0

4 Discussion of uncertainties

When interpreting the modelling results the uncertainties linked to the various elements of the computational procedure should be kept in mind. A brief discussion of these uncertainties is presented below.

4.1 Uncertainties in the 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 Uncertainties in the estimated 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 (mass of pollutant) emitted, and with the spatial and temporal distribution of these emissions within the cities.

4.3 Uncertainties in the estimated 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, vehicle speed, 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 contribute to the overall uncertainty.

During winter and spring, road dust particles suspended into the air by the stirring effect of the vehicle turbulence is a strong, and by far the most dominant source of ambient coarse fractions 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 dust that is available for suspension. In order to reduce this uncertainty the PM_{10}-simulations were first made with standard emission estimates of road dust particles. Then the calculated coarse fraction part, which is assumed 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 at least agrees with the average levels at the measurement sites. By applying this correction method any effects of road cleaning and/or salting, that clearly affects the observations, will implicitly be incorporated in the results from the model simulations.

4.4 Uncertainties in the estimated 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 too clean inflowing air. The reason for this is that the real air at the model boundaries will be somewhat influenced by local emissions, at least in the areas where the main roads are entering into the model domain.

4.5 Uncertainties in the 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 mouths or near major road junctions with appurtenant 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 m), it is assumed that the terrain is flat, and any modifying effects due to height differences between the road and the buildings are therefore missed. This easily leads to a systematic overestimation of the building point concentrations in such areas.

5 Results from the dispersion and exposure calculations

Since the scope of the present study has been to investigate the present exposure situation with respect to the goals defined in the ”National Air Quality Target”, our interest has mainly focused on the days and hours when the higher concentration levels are encountered. Experience has shown that these levels almost exclusively occur during the winter/spring season, and therefore no calculations have been made for the summer period, May 1. – September 30. The reason why the highest concentrations are found in wintertime is the combination of frequently occurring stable atmospheric conditions (poor dispersion conditions) and large emissions emanating from the use of studded tyres and from domestic wood burning, during this season.

Ambient air concentrations and population exposure have been calculated both in the building points and in the grid squares. Additionally, since the ”National Air Quality Target” for benzene applies for urban background concentrations, the exposure estimates for this compound have also been calculated based on the sole use of the grid square concentrations. The reasoning behind this is that the urban background concentrations are best reflected through the computed grid concentrations.

For the building points and grid squares in which exceedances of the “National Air Quality Target” have been found, we have also estimated the relative contribution from the main source categories. When performing this source apportionment calculation, only hours (NO_2) and days (PM_{10}) contributing to the exceedances have been considered, and the final estimate is the average percentual contribution from the various sources. In order to present these results in a simple way, the source contributions for all of the buildings residing within a grid cell have been averaged, and presented as the grid cell percentual source contribution. No source apportionment estimate has been made for benzene in this study.

The concentration fields applied in the exposure calculations are presented in Appendix B. For each of the two cities these figures are showing:

1. The 9^{th} highest hourly grid-value concentration of NO_2 calculated during the simulation period, and in addition, all the building points experiencing exceedances are marked as black dots.
2. The 8^{th} highest daily grid-value concentration of PM_{10}, calculated during the simulation period, and in addition, all the building points experiencing exceedances are marked as black dots.
3. The estimated yearly mean grid-value concentration of benzene, and in addition, 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. It should be noted that these buildings should not be regarded as exceedance locations if they are not residing within a grid square with a concentration value above 2 $\mu g/m^3$.

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 μg/m^3, were computed in the model grid. Exceedances with regards to the national target for NO_2 were only estimated 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 652 inhabitants, i.e., 0.12% of the total population within the model domain, are exposed to exceedances. Their distribution within the model domain is illustrated in Figure 1 below.

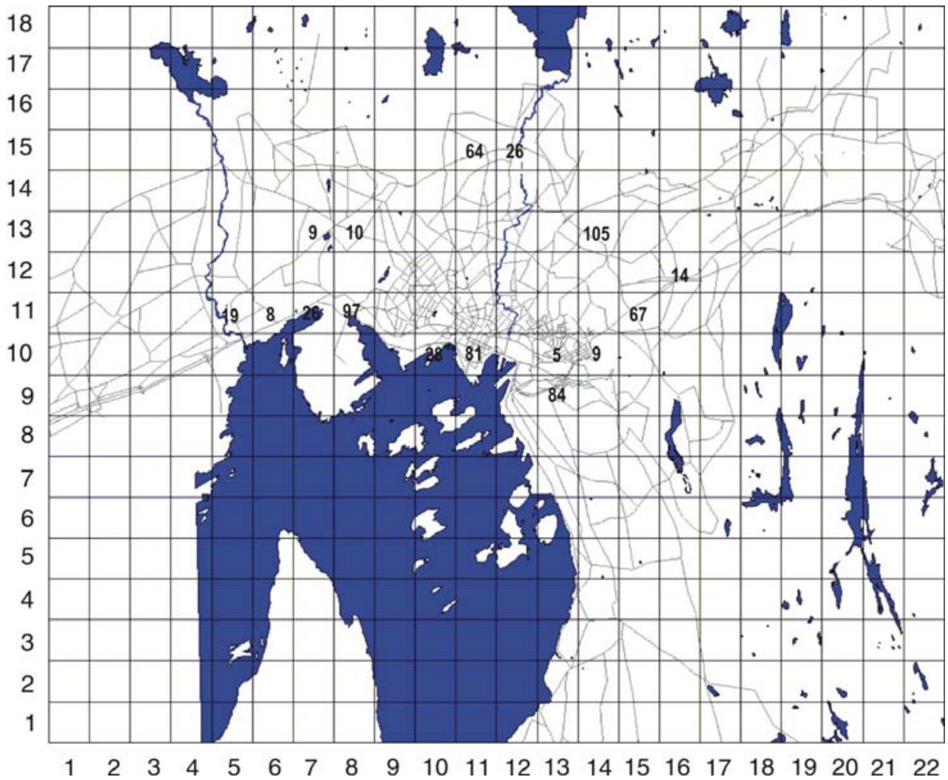

Figure 1: The number of inhabitants, and their distribution, that are exposed to exceedances of the National target for NO_2 in Oslo in 2005.

The main source for these exceedances are road traffic, as shown in Table 10 below. The average source contribution to these exceedances within each grid square is listed in Table C1 in Appendix C. The second most important source category is the “Other area distributed sources”.

Table 10: Source contribution (in percentage) to the exceedances of the “national target” on NO_2 for Oslo in 2005.

Calculated in	Domestic wood comb.	Traffic	Regional background	Other sources
Building points	0.05	96.59	0.15	3.21

5.1.2 PM_{10}

The gridded concentration field for the 8th highest daily PM_{10} values is presented in Figure B2 in Appendix B. As seen in this Figure large areas in Oslo are experiencing exceedances on the grid square level, i.e., grid squares concentration values above 50 μg/m^3 are estimated. As expected the model also predict exceedances in lots of building points, as illustrated by the black dots along the main road system in Figure B2. In total it is estimated that 235 849 inhabitants, i.e., 44.8 % of the population, are exposed to exceedances. Their distribution within the model domain is illustrated in Figure 2 below.

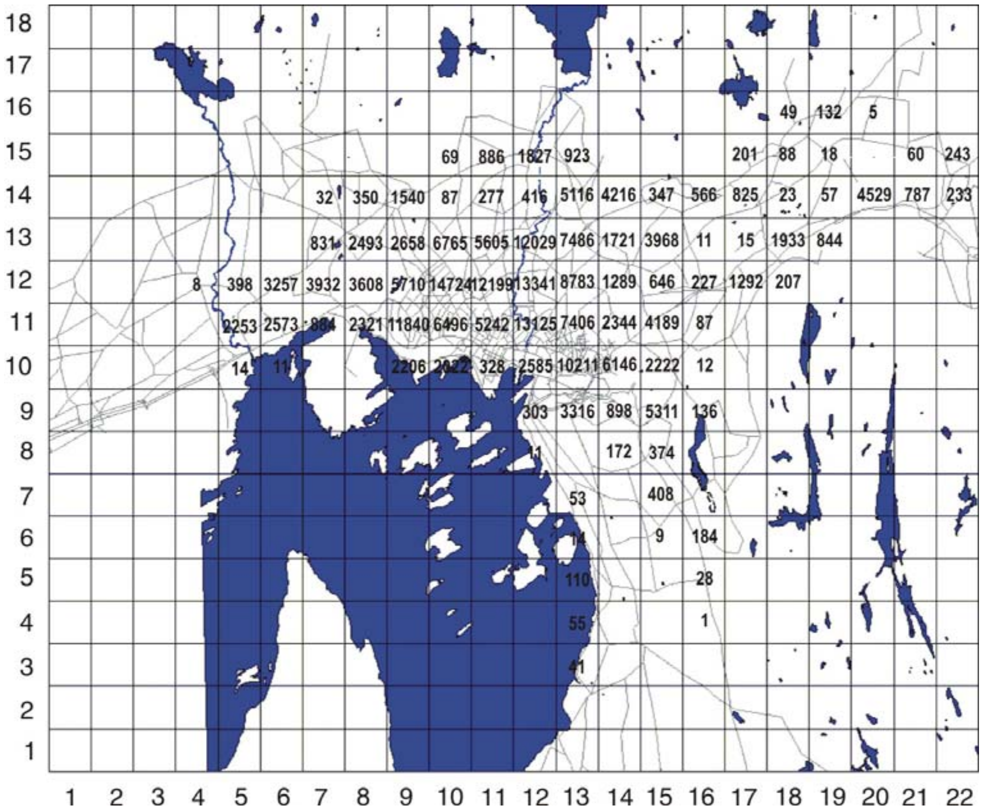

Figure 2: The number of inhabitants, and their distribution, that are exposed to exceedances of the National target for PM_{10} in Oslo in 2005.

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 (Appendix C). Even though traffic is the dominant source, domestic wood burning can contribute up to 44 % in certain areas.

Table 11: Source contribution (in percentage) to the exceedances of the "national target" on PM_{10} for Oslo in 2005.

Calculated in	Domestic wood comb.	Traffic	Regional background	Other sources
Building points	14.8	73.2	10.0	2.0
Grid squares	21.8	66.7	8.5	3.0

5.1.3 Benzene (H_6C_6)

The gridded concentration field for the estimated yearly mean benzene value is presented in Figure B3 in Appendix B. As seen in this Figure some central grid squares in Oslo are experiencing exceedances, i.e., grid square concentration values above 2 μg/m^3 are estimated. As expected the model also predict exceedances in lots of building points, as illustrated by the black dots along the main road system in Figure B3. When only considering the grid square concentrations 31 585 inhabitants, i.e. 6.0 % of the total population, are exposed to exceedances. Their distribution within the model domain is illustrated in Figure 3.

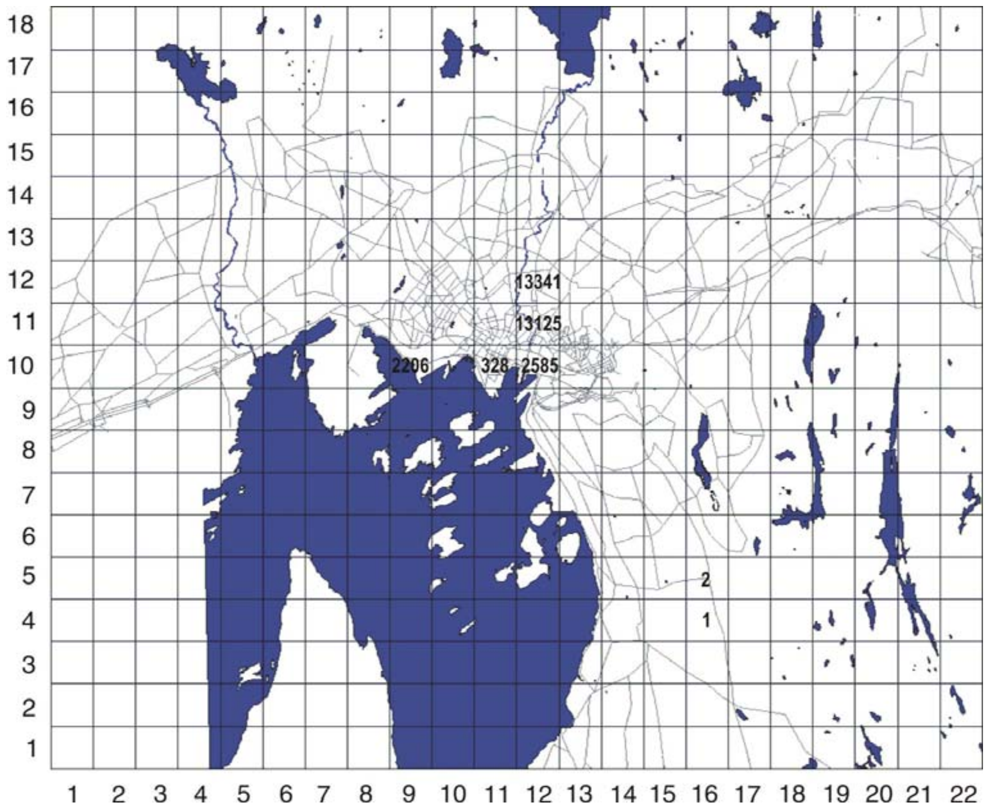

Figure 3: The number of inhabitants, and their distribution, that are exposed to exceedances of the National target for benzene in Oslo in 2005, when only the grid square concentrations (i.e., urban background) are included in the exposure estimate.

If the building points are also included in the exposure estimate, the exceedance number increase to 56 547 inhabitants, i.e., 10.7 % of the total population, and their distribution is shown in Figure 4.

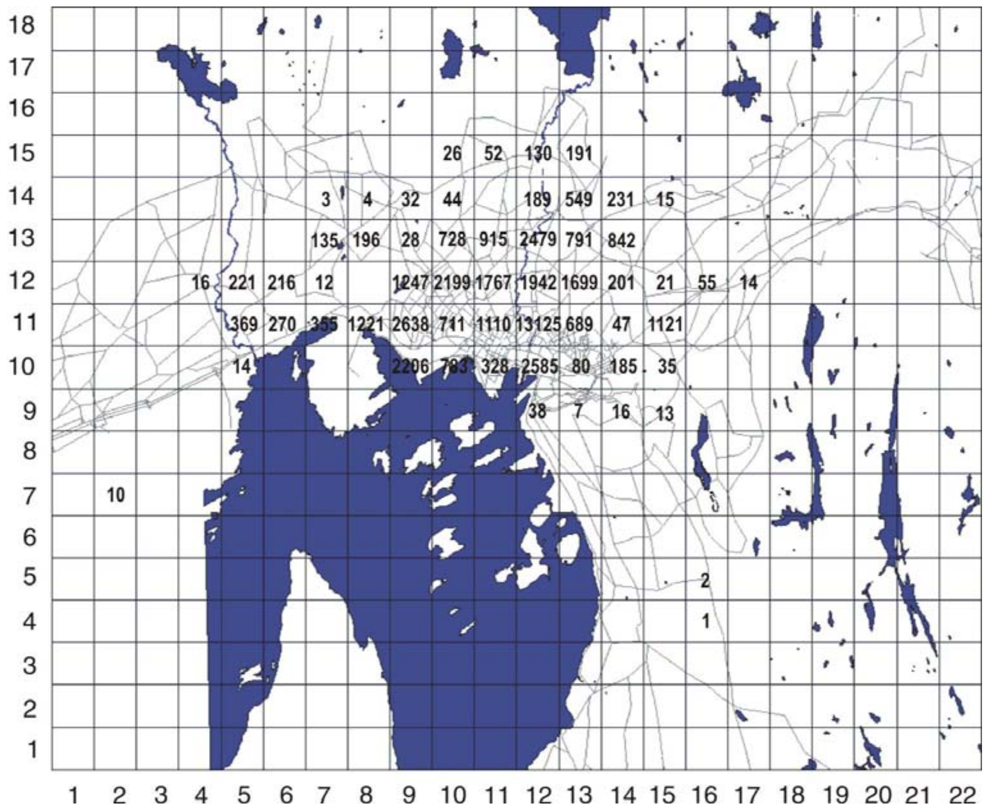

Figure 4: The number of inhabitants, and their distribution, that are exposed to exceedances of the National target for benzene in Oslo in 2005 when the near road building points are also included in the exposure estimate.

No calculation of source contributions has been made for benzene, but earlier investigations (Laupsa et al., 2005 a) 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 in Appendix B. As seen in this Figure no exceedances, i.e., no values above 150 μg/m^3, were computed in the model grid. Exceedances with regards to the national target for NO_2 were only estimated in 2 building points. The locations of these buildings are shown as black dots in Figure B4. The exposure results show that only 40 persons, i.e., 0.026 % of the total population within the model domain, are exposed to exceedances. Their distribution within the model domain is illustrated in Figure 5 below.

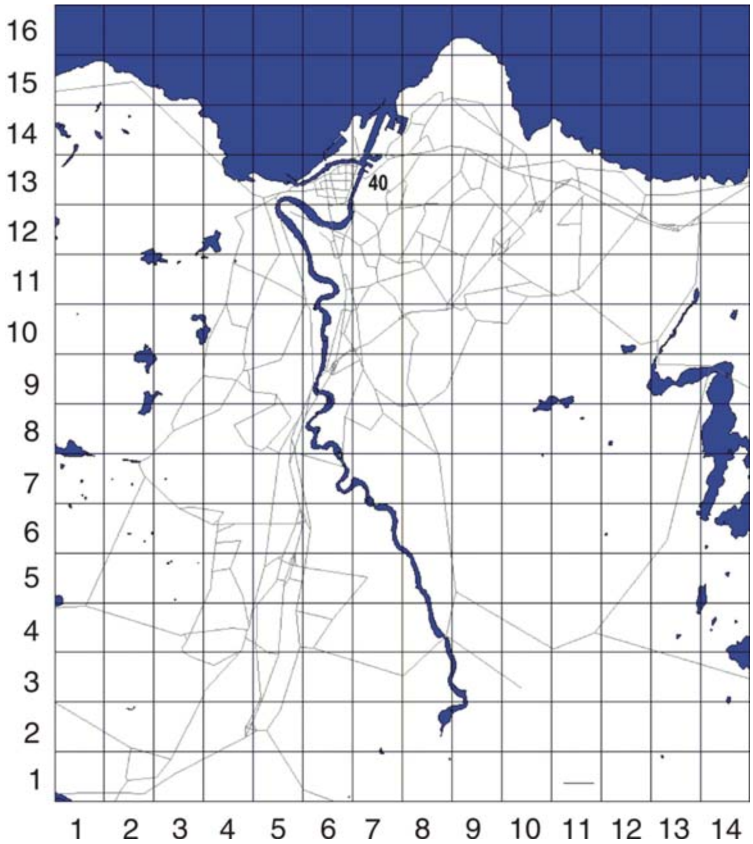

Figure 5: The number of inhabitants, and their distribution, that are exposed to exceedances of the National target for NO_2 in Trondheim in 2005.

The main source for the exceedances is road traffic, as shown in Table 12. Since both of these buildings are located in the same grid square, the results shown in Table 12 is identical with the result presented in Table C4 in Appendix C.

Table 12: Source contribution (in percentage) to the exceedances of the "national target" on NO_2 for Trondheim in 2005.

Calculated in	Domestic wood comb.	Traffic	Regional background	Other sources
Building points:	0.36	97.13	0.08	2.43

5.2.2 PM_{10}

The gridded concentration field for the 8th highest daily PM_{10} values is presented in Figure B5 in Appendix B. As seen in this Figure the areas along the main road entering the city center from the south are experiencing exceedances on the grid square level, i.e., grid square concentration values above 50 $\mu g/m^3$ are estimated. As expected the model also predict exceedances in lots of building points, as illustrated by the black dots along the main road system in Figure B5. In total it is estimated that 20 914 inhabitants, i.e., 13.8 % of the total population within the model domain, are exposed to exceedances. Their distribution within the model domain is illustrated in Figure 6 below.

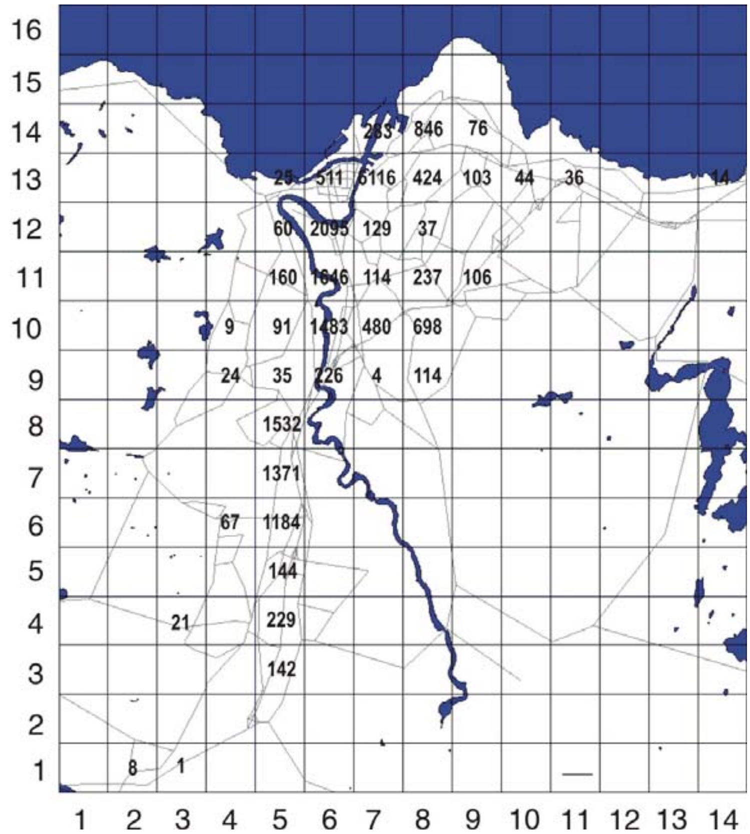

Figure 6: The number of inhabitants, and their distribution, that are exposed to exceedances of the National target for PM_{10} in Trondheim in 2005.

The main source for these exceedances is road traffic, as shown in Table 13. The source contribution within each of the model grid squares are listed in Table C5 while the average source contribution in the buildings within each grid square is given in Table C6 (Appendix C). Even though traffic is the dominant source, domestic wood burning can contribute up to 56 % in certain areas.

Table 13: Source contribution (in percentage) to the exceedances of the "national target" on PM_{10} for Trondheim in 2005.

Calculated in	Domestic wood comb.	Traffic	Regional background	Other sources
Building points:	*13.9*	*75.3*	*10.4*	*0.4*
Grid squares:	*27.0*	*59.2*	*13.2*	*0.6*

5.2.3 Benzene (H_6C_6)

The gridded concentration field for the estimated yearly mean benzene value is presented in Figure B6 in Appendix B. As seen in this Figure no exceedances, i.e., no urban background 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 located close to the main road network. The locations of these buildings are shown as black dots along the main road system in Figure B6. If the building points are included in the exposure estimate, 490 inhabitants, i.e., 0.32 %

of the total population within the model domain, are exposed to exceedances. Their distribution within the model domain is illustrated in Figure 7 below.

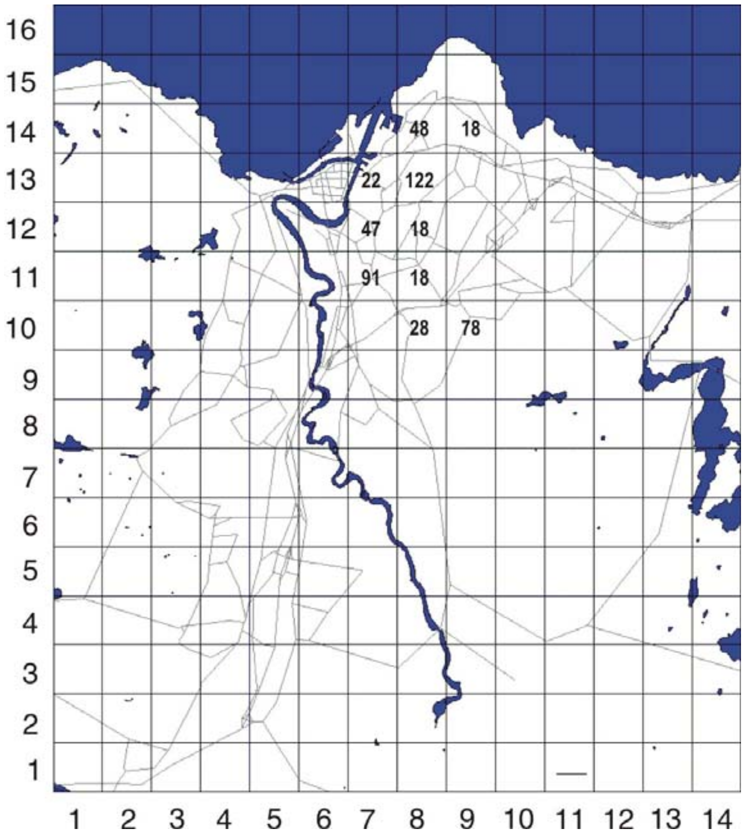

Figure 7: The number of inhabitants, and their distribution, that are exposed to exceedances of the National target for benzene in Trondheim in 2005 when the near road building points are also included in the exposure estimate.

No calculation of source contributions has been made for benzene, but earlier investigations (Laupsa et al., 2005 a) have shown that road traffic is by far the most dominant source.

6 Concluding remarks

The total exposure results reported in Section 5 are summarized in Table 14 below. The model predictions indicate that a higher percentage of the population in Oslo are exposed to exceedances than in Trondheim. When relating the exposure numbers in Table 14 with the total number of inhabitants within the model domains (see Table 3), we find that 0.12 %, 44.8 %, and 6.0 % of the Oslo population are exposed to exceedances of the National air quality target for NO_2, PM_{10} and benzene, respectively. The corresponding numbers for Trondheim are, 0.026 %, 13.8 %, and 0 %.

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 2005. Results from a similar calculation for the year 2003 (Laupsa et al., 2005 a) are shown in parenthesis for comparison.

	Oslo	**Trondheim**
PM_{10}	235 849 (239 595)	20 914 (8 065)
NO_2	652 (6 893)	40 (708)
H_6C_6 (Benzene)	31 585 (114 873)	0 (712)

When considering the exposure estimates in Table 14 it should be noted that relatively small changes in the calculated concentration levels could 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 above the average source contribution (in percent) to the exceedances were presented in Table 4, 5, 6, and 7. For each compound the contributions were given separately for the building points and the grid squares. Since only buildings in the vicinity of the main roads have been treated separately as building points, the exceedances in these points will naturally be more traffic influenced than the grid squares exceedances, as clearly revealed in the tables.

6.1 Oslo

As expected the model predictions show that road traffic is by far the most important source for the modest exceedances with respect to NO_2 in Oslo. Compared with the previous exposure levels estimated for the year 2003 (Laupsa et al., 2005 a) there is a rather marked reduction, from 6 893 inhabitants in 2003 to 652 in 2005, as seen in Table 14. The main reason for this large reduction is that the exposure calculations for 2003 produced grid square exceedances in two grid cells in the harbour area, leading to exceedances for more than 4000 persons. The 9^{th} highest hourly NO_2 concentrations computed in these grid cells did not reach 150 µg/m^3 in 2005, partly as a consequence of a small reduction in the road traffic emissions and, probably more important, as a result of natural variations in the meteorological conditions.

The model results for PM_{10} reveal a modest reduction in exposure levels between 2003 and 2005 (Table 14).

As for NO_2, also the benzene results show a marked reduction in exposure levels from 2003 to 2005. Again the main reason is that a slight reduction in the calculated concentration levels have brought some of the grid cells below the target level. In addition, the exposure estimate for 2003 did not relate to the urban background levels, but included the extra contribution from the building points. Nevertheless, the 2005 exposure estimate is still lower, even when the building points are included, i.e., 56 547 inhabitants in 2005 versus 114 873 in 2003.

6.2 Trondheim

The model evaluation indicates that there is a systematic underestimation of the observed NO_2 levels in Trondheim. When considering the higher concentrations, however, the predictions at Bakke Kirke (see Figure A11) seem to be rather well represented while at Elgeseter the underestimation is evident also in this regime (Figure A9). This under-prediction might mean that the low number of exceedances for NO_2 (49 persons) can be somewhat too low exposure estimate. In 2003 a slightly higher number of persons experiencing exceedances were calculated (708 inhabitants). Again traffic was estimated as the dominant source.

As for NO_2 also the average PM_{10} levels are underestimated at the observation sites at Elgeseter and Bakke Kirke. However, when comparing the highest daily concentration levels (see Figure A13 and A15) quite equal levels are found. This indicate that the confidence in the exposure estimates is better than expected from the general statistical analysis reported in Table 8. The model predicts that a total of 20 914 inhabitants are exposed to exceedances for PM_{10}. This is a marked increase from the estimated 8 065 inhabitants that was estimated in 2003. When comparing these numbers, one should note that a different wind field model, i.e., the prognostic weather forecast model MM5, was applied for the 2003 calculations in Trondheim. This may explain why a much stronger underestimation of the highest daily PM_{10} concentrations were found at Elgeseter in 2003 than in 2005. The source apportionment study again show that road traffic and domestic wood combustion are the major local sources of PM_{10}, with road traffic being the most dominant of the two.

For benzene the model estimates that there are no exceedances with regards to the grid square, i.e. urban background, concentrations. However, if the near road building points are also included a total of 490 inhabitants experience exceedances. As mentioned in Section 3 the model tend to underestimate somewhat the benzene observation at Elgeseter. However, even if the estimated gridded yearly concentration field is up-scaled according to the Elgeseter observations, the resulting grid square concentrations are still below 2 $\mu g/m^3$. Nevertheless, a considerable number of buildings experienced exceedances as a result of this up-scaling, leading to a total of 2 395 inhabitants (1.58 %) being exposed. This example serves to illustrate the consequences of the uncertainties inherent in the present calculations.

7 References

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Appendix A

Figures applied in the evaluation of the model calculations

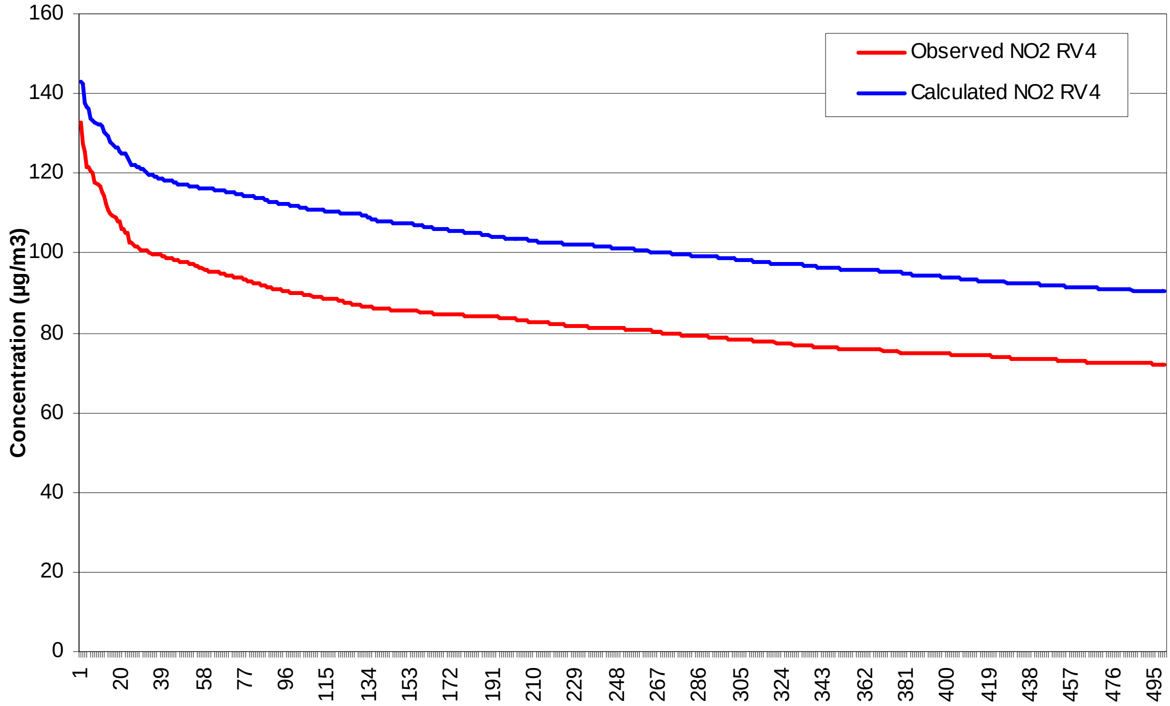


Figure A1: The 500 highest hourly values of NO_2 at RV4 sorted descending.

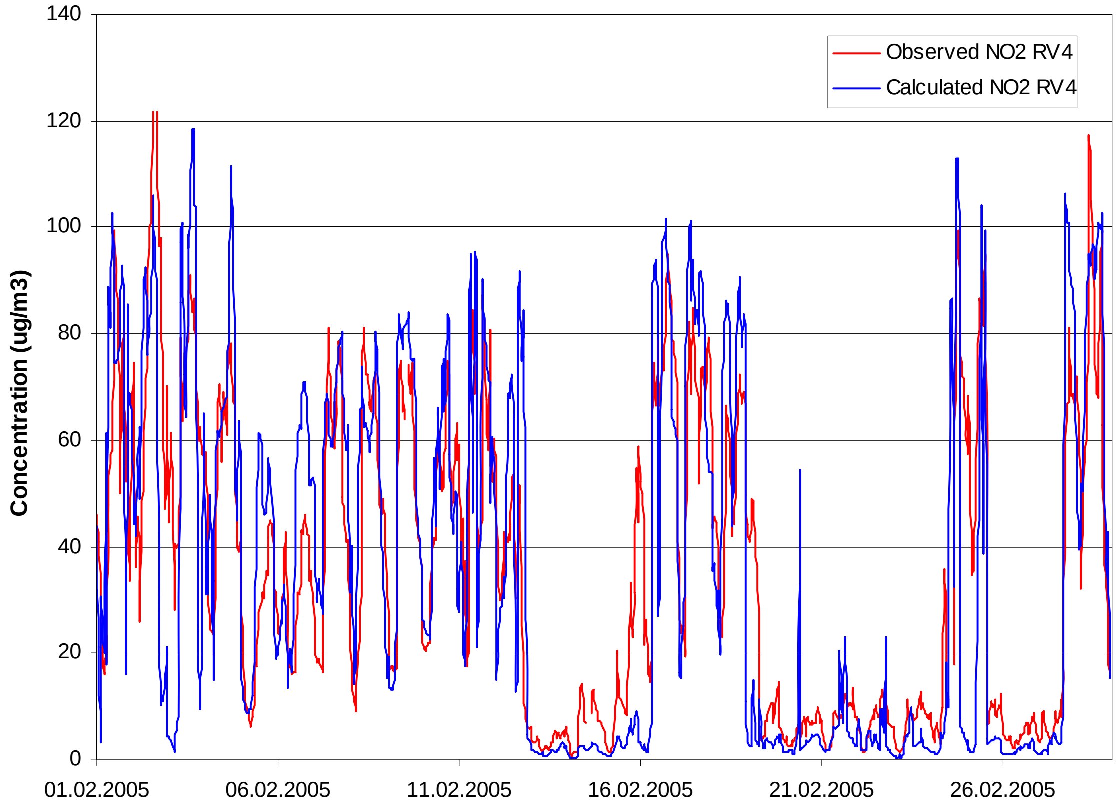


Figure A2: Hourly values of NO_2 at RV4 in february 2005.

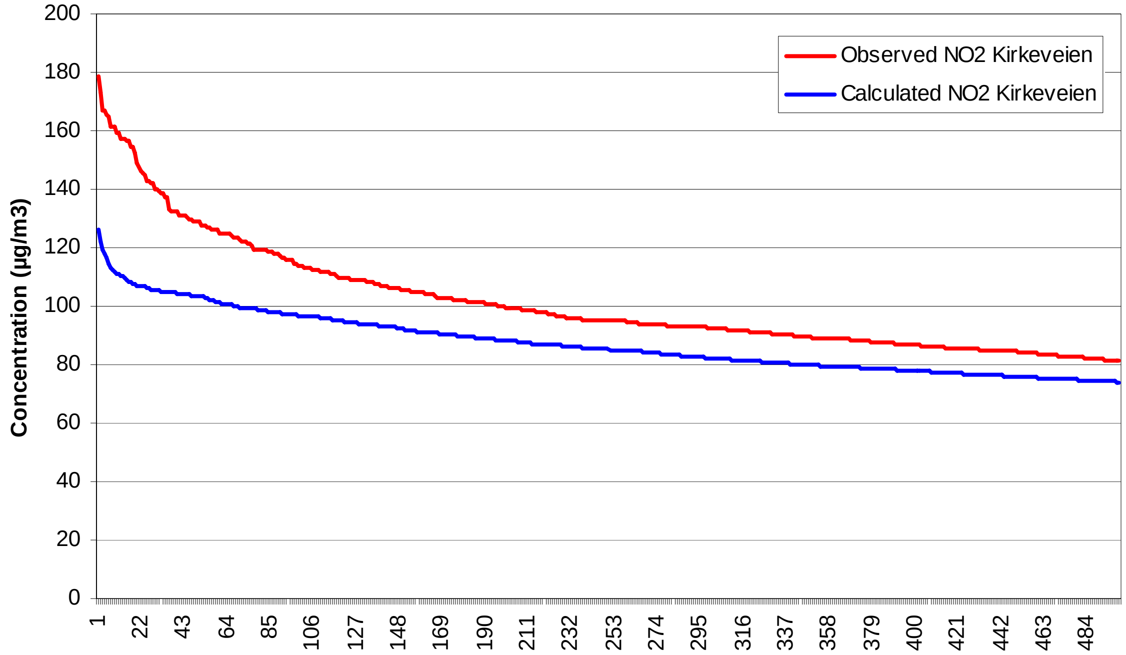


Figure A3: The 500 highest hourly values of NO_2 at Kirkeveien sorted descending.

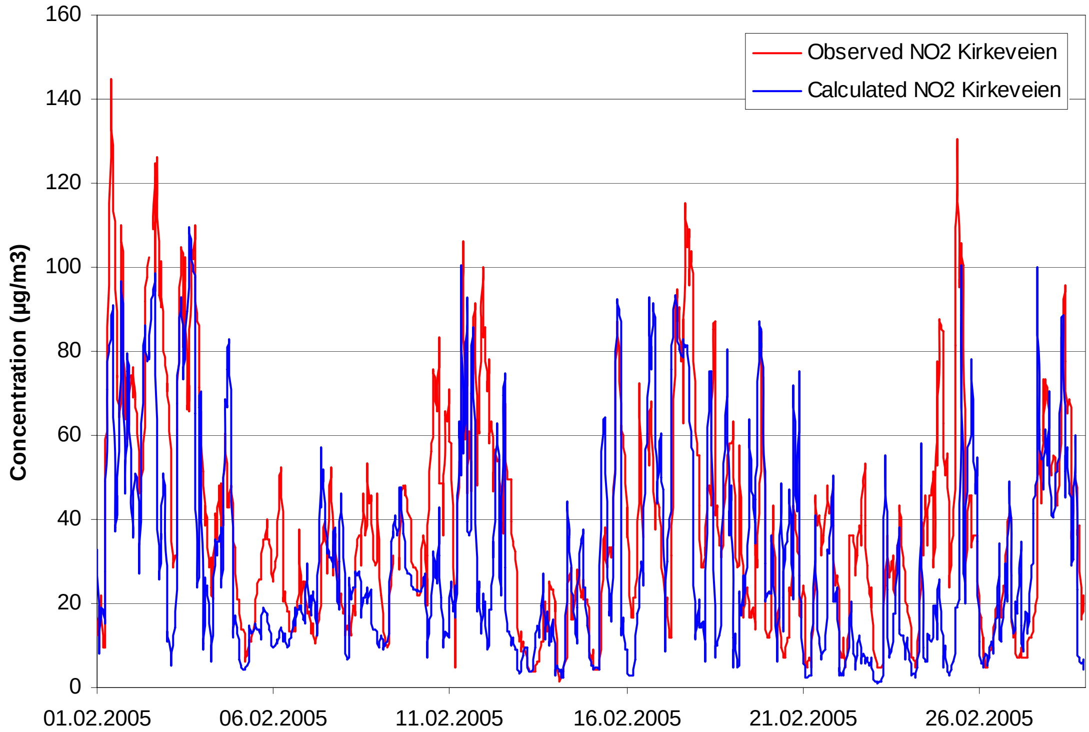
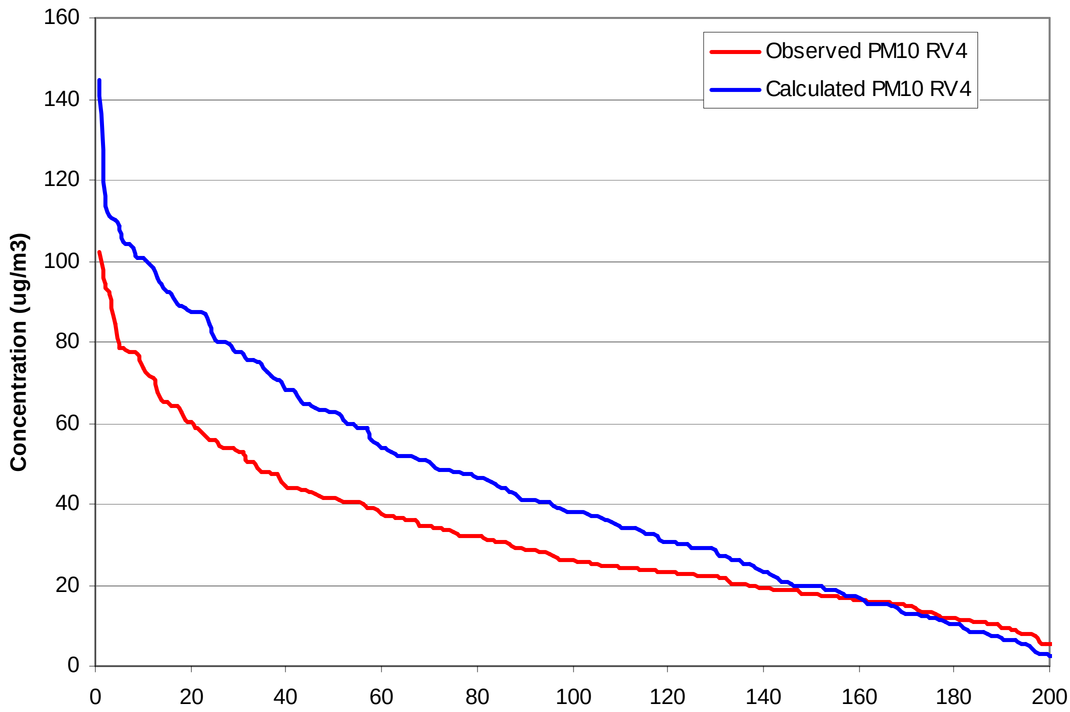


Figure A4: Hourly values of NO_2 at Kirkeveien in february 2005.



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

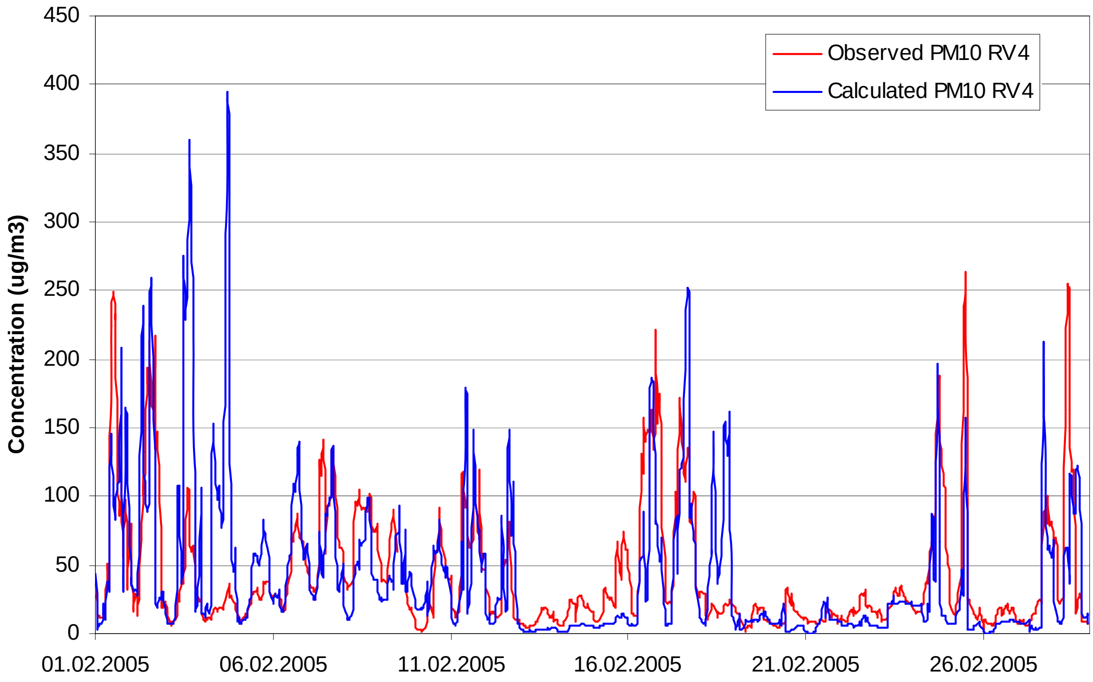
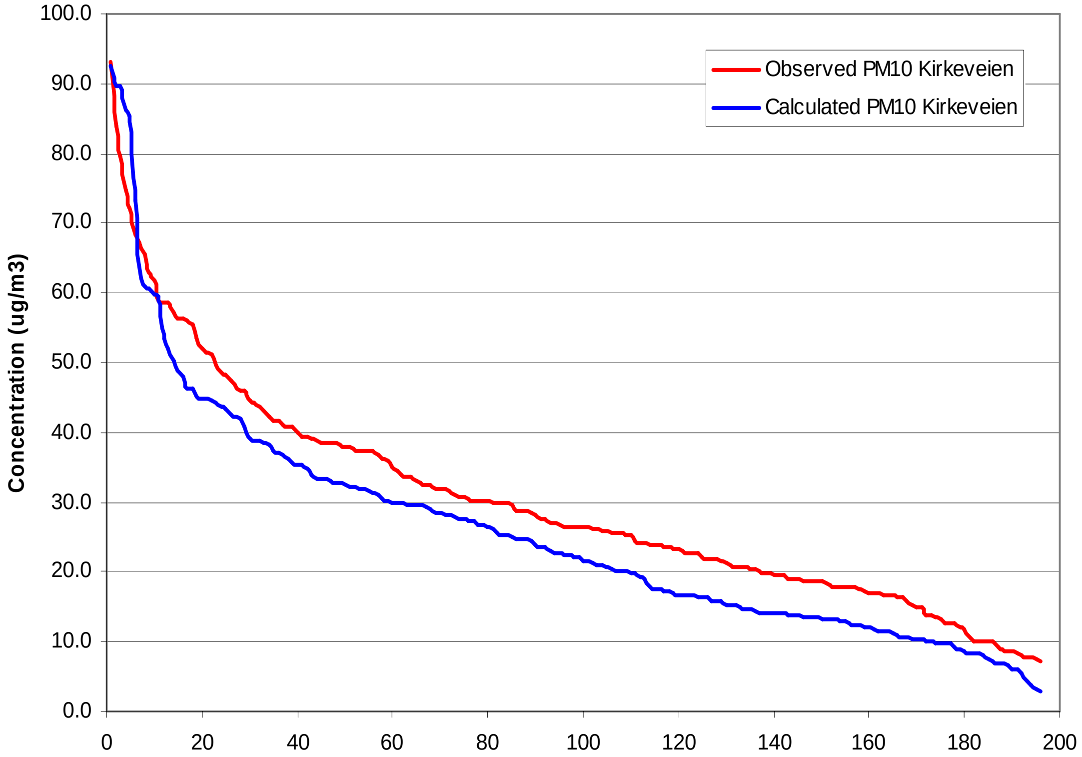


Figure A6: Hourly values of PM_{10} at RV4 in february 2005.



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

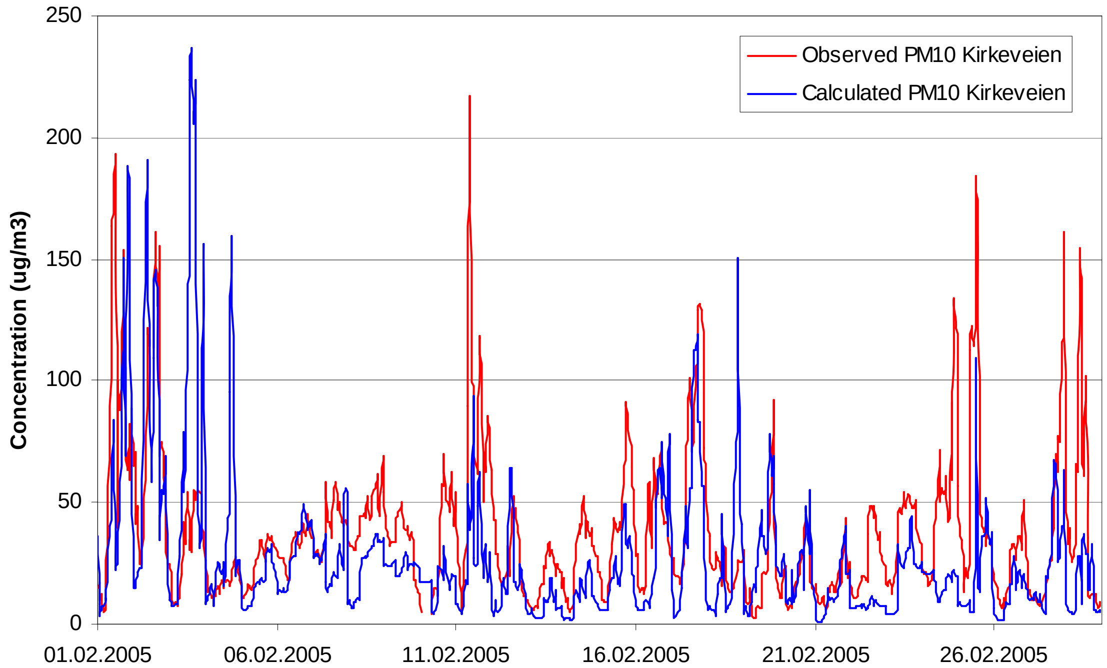


Figure A8: Hourly values of PM_{10} at Kirkeveien in february 2005.

Trondheim

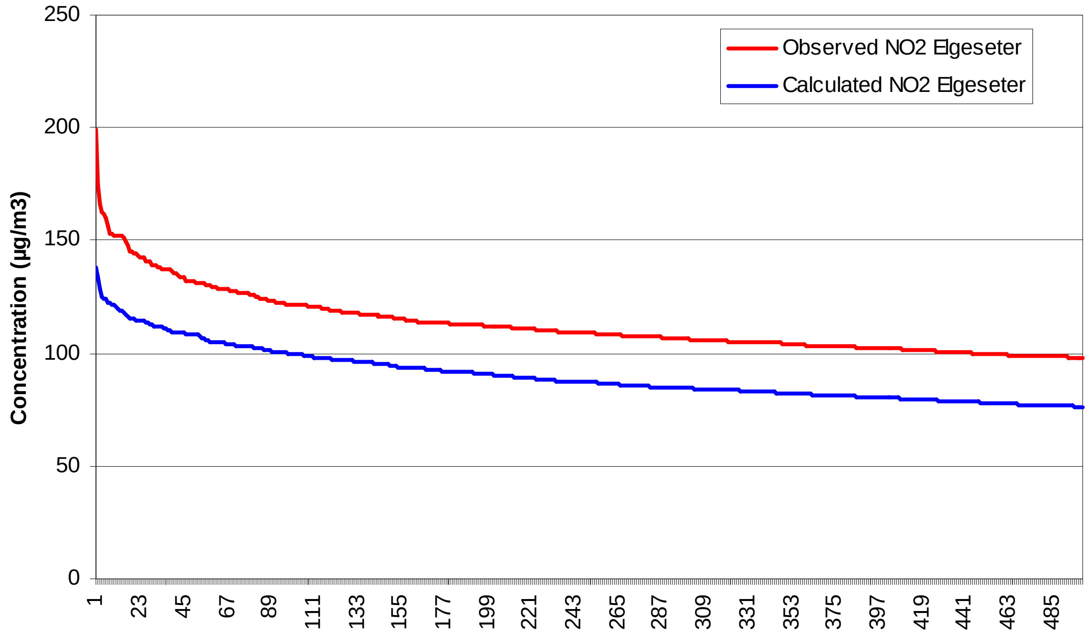


Figure A9: The 500 highest hourly values of NO_2 at Elgeseter sorted descending.

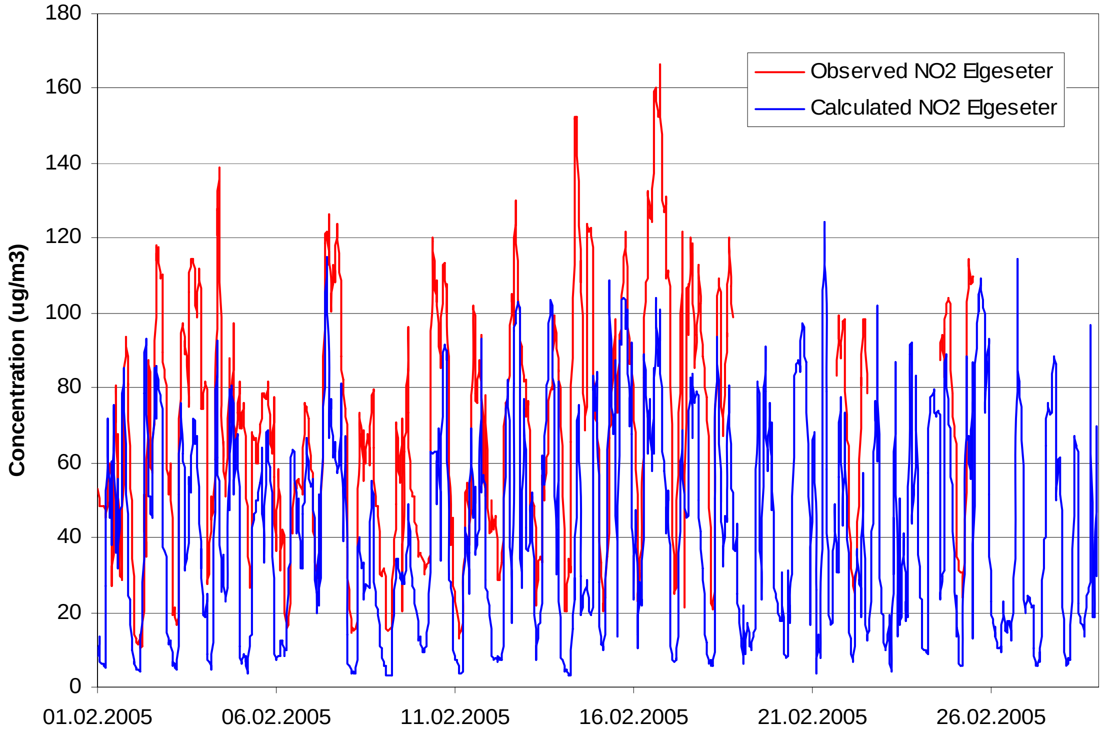


Figure A10: Hourly values of NO_2 at Elgeseter in february 2005.

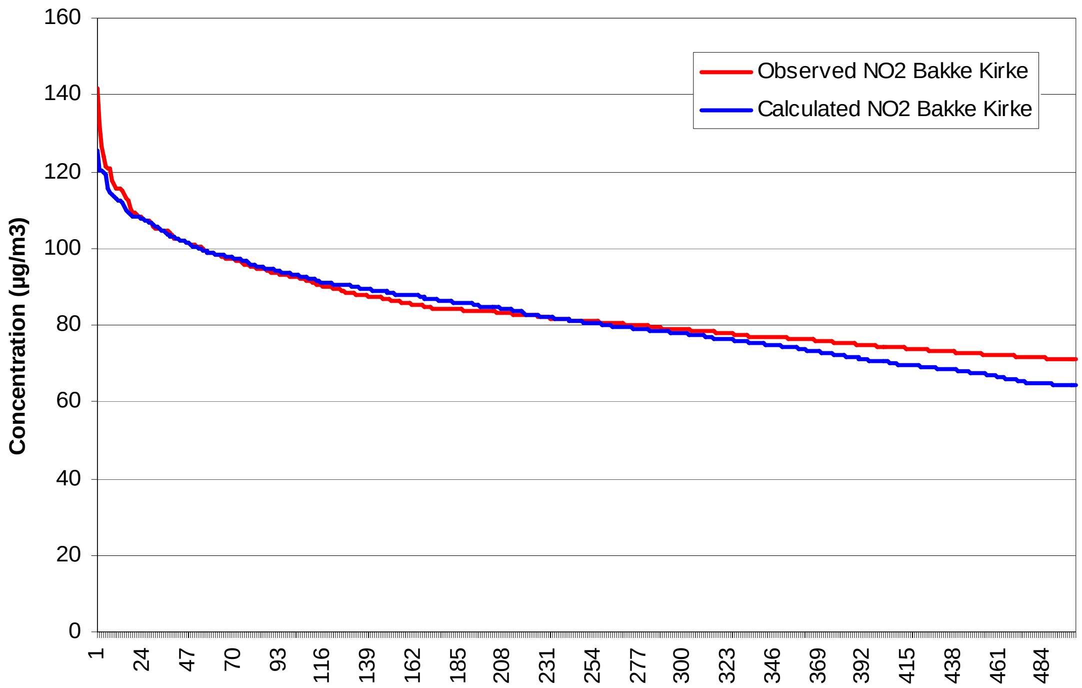


Figure A11: The 500 highest hourly values of NO_2 at Bakke Kirke sorted descending.

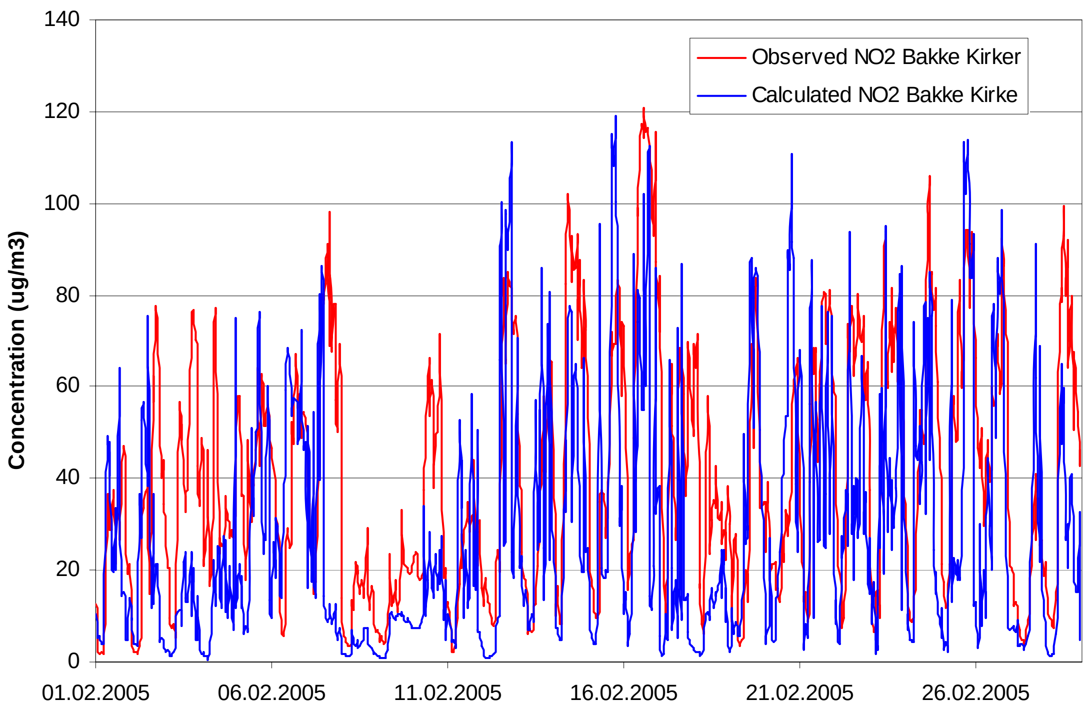
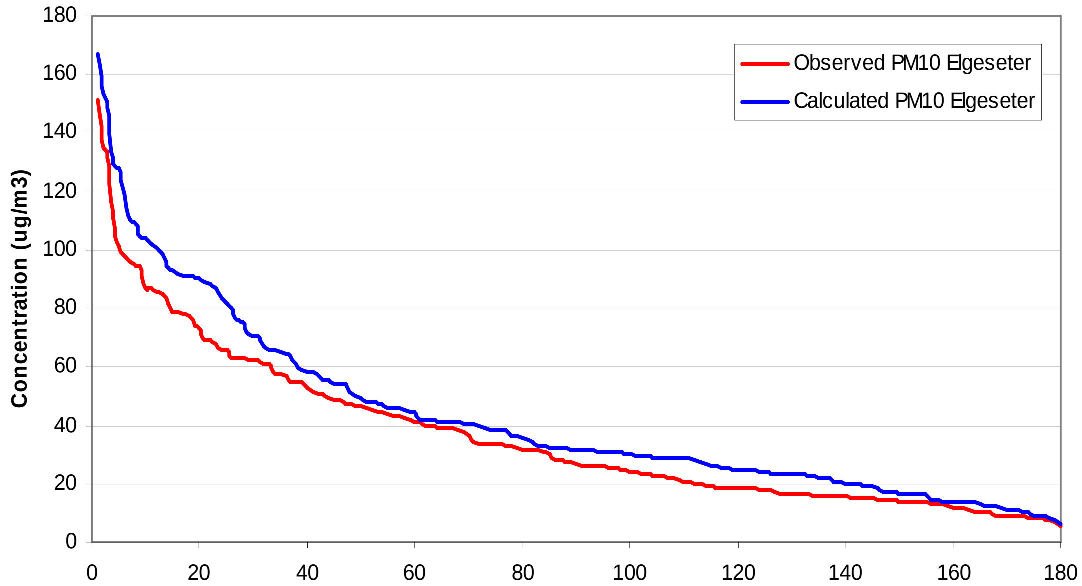


Figure A12: Hourly values of NO_2 at Bakke Kirke in february 2005.



Figur A13: Daily values of PM_{10} at Elgeseter sorted descending.

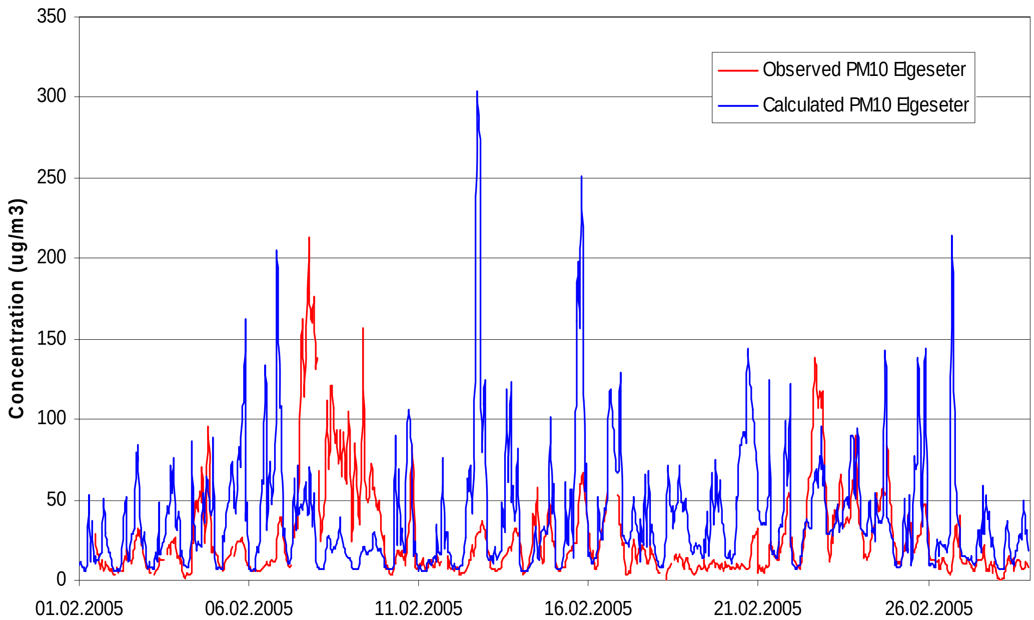
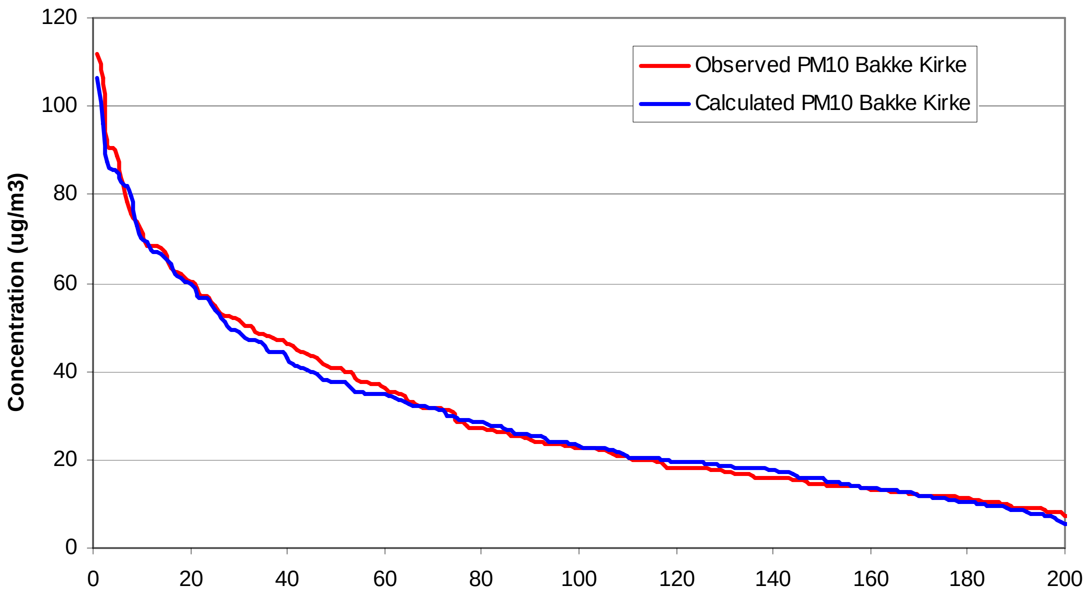


Figure A14: Hourly values of PM_{10} *at Elgeseter in february 2005.*



Figur A15: Daily values of PM_{10} at Bakke Kirke sorted descending.

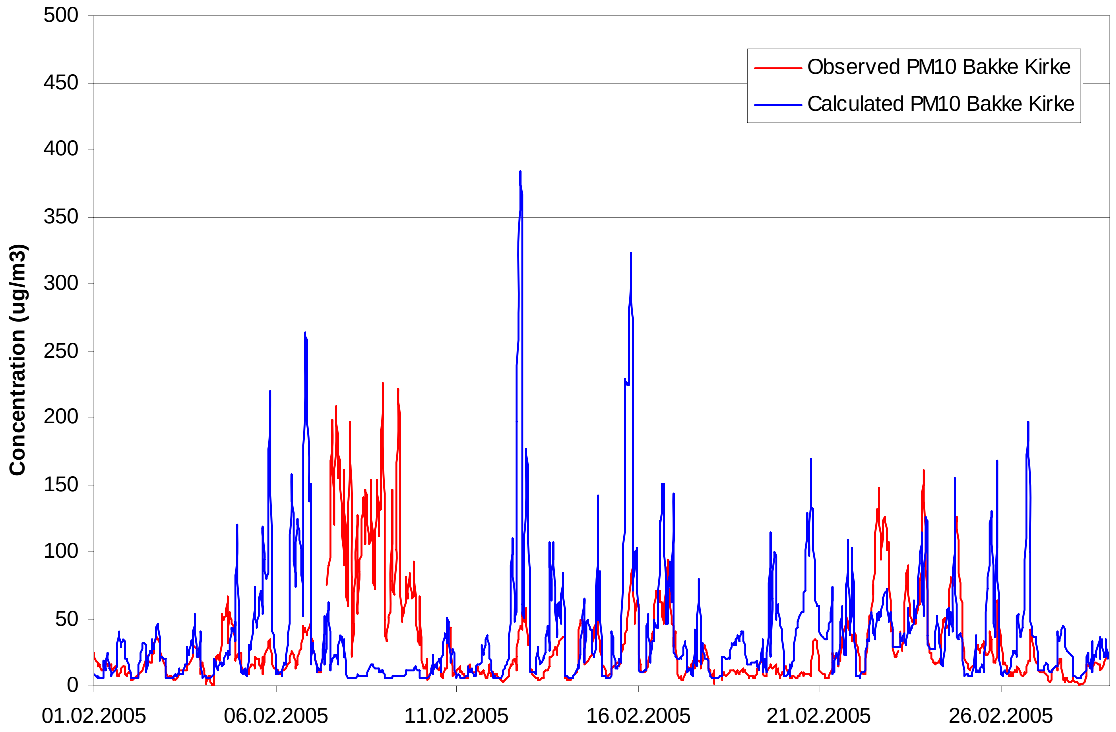


Figure A16: Hourly values of PM_{10} *at Bakke Kirke in february 2005.*

Appendix B

Model predicted concentration fields related to the national air quality targets

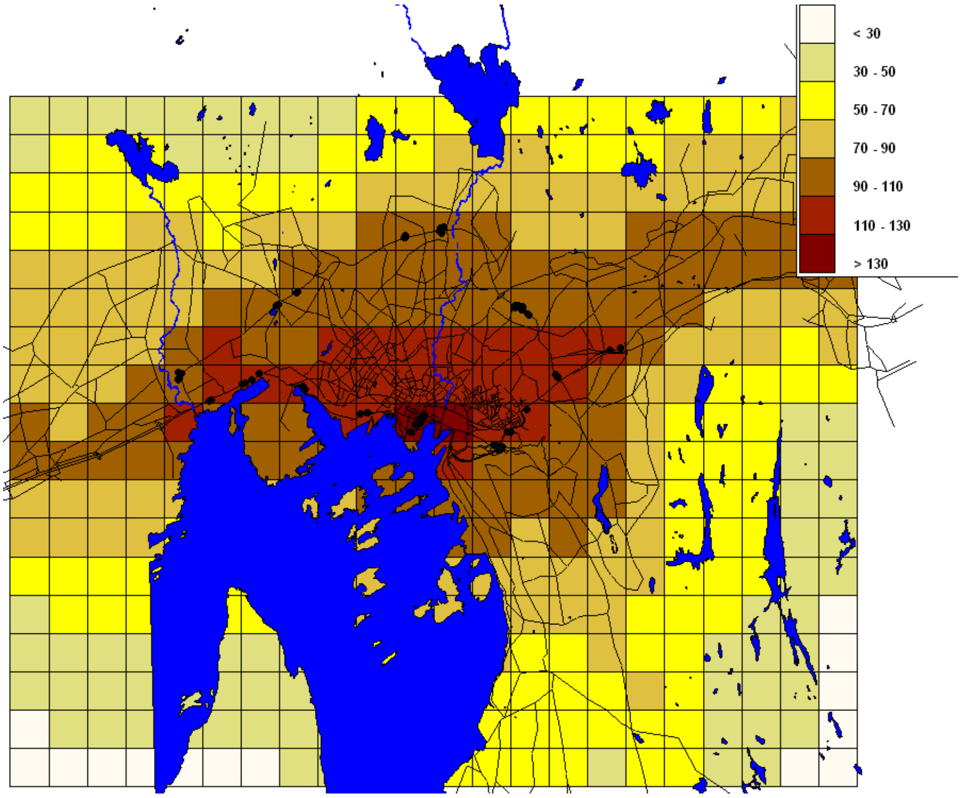


Figure B1: The 9th highest hourly grid value of NO_2 ($\mu g/m^3$) for Oslo in 2005. The black dots are illustrating the building points where the 9th highest hourly NO_2 value is above the national target of 150 $\mu g/m^3$.

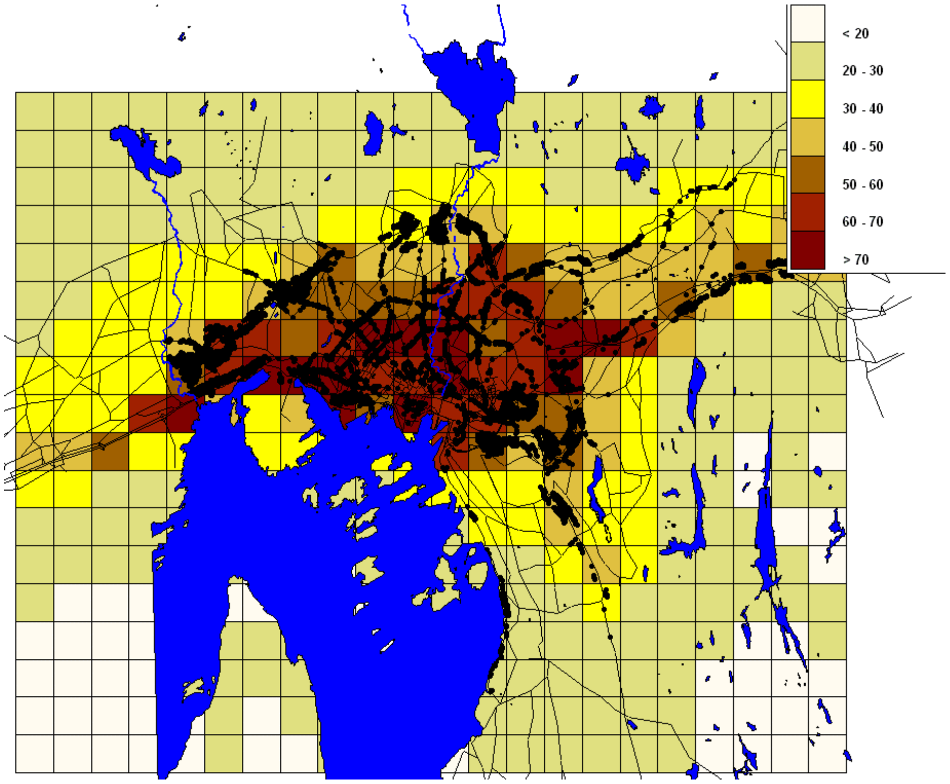


Figure B2: The 8th highest daily grid value of PM_{10} ($\mu g/m^3$) for Oslo in 2005. The black dots are illustrating the building points where the 8th highest daily PM_{10} value is above the national target of 50 $\mu g/m^3$.

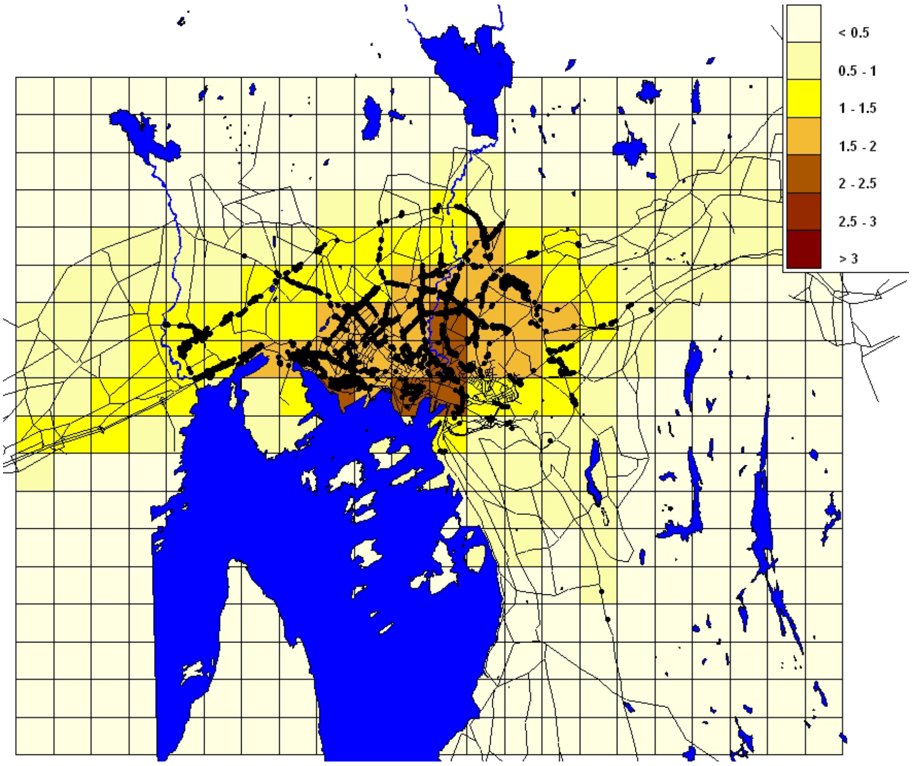


Figure B3: The yearly mean grid value of benzene (μg/m³) for Oslo in 2005. The black dots are illustrating the building points where the yearly mean benzene value is above the national target of 2 μg/m³.

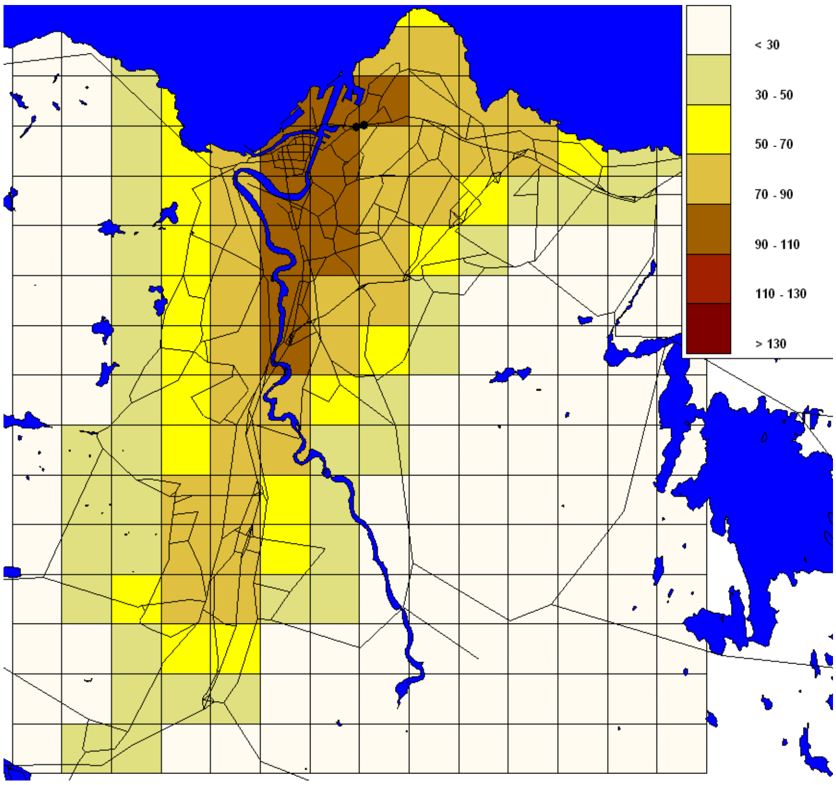


Figure B4: The 9th highest hourly grid value of NO_2 (μg/m³) for Trondheim in 2005. The black dots are illustrating the building points where the 9th highest hourly NO_2 value is above the national target of 150 μg/m³.

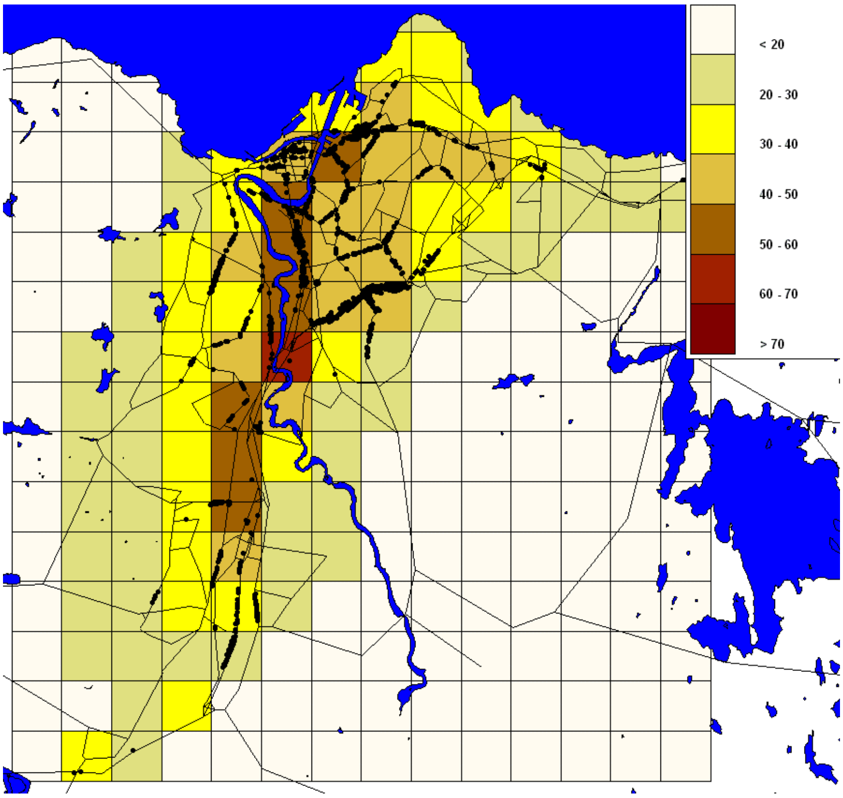


Figure B5: The 8th highest daily grid value of PM_{10} ($\mu g/m^3$) for Trondheim in 2005. The black dots are illustrating the building points where the 8th highest daily PM_{10} value is above the national target of 50 $\mu g/m^3$.

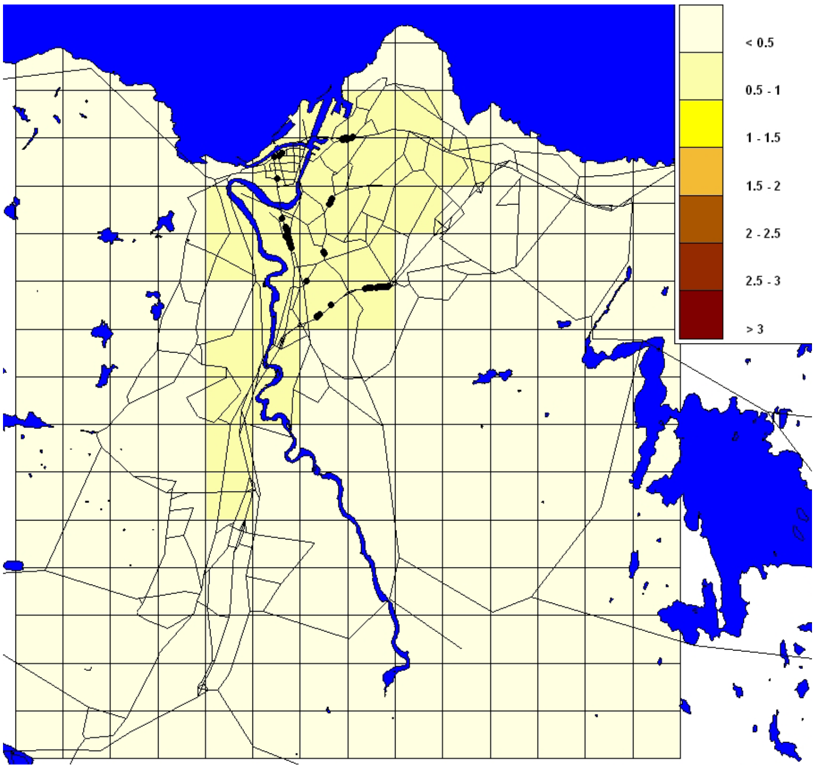


Figure B6: The yearly mean grid value of benzene ($\mu g/m^3$) for Trondheim in 2005. The black dots are illustrating the building points where the yearly mean benzene value is above the national target of 2 $\mu g/m^3$.

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
13	9	0.04	98.79	0.05	1.12
10	10	0.02	92.8	0.18	7
11	10	0.01	93.49	0.16	6.34
13	10	0.02	95.18	0.11	4.69
14	10	0.02	95.54	0.21	4.23
5	11	0.03	99.17	0.09	0.71
6	11	0.08	97.67	0.15	2.1
7	11	0.09	95.34	0.19	4.38
8	11	0.06	98.16	0.17	1.61
15	11	0.07	95.57	0.23	4.13
16	12	0.04	95.68	0.17	4.11
7	13	0.06	98.08	0.14	1.72
8	13	0.05	98.51	0.15	1.29
14	13	0.09	93.86	0.12	5.93
11	15	0.04	98.33	0.11	1.52
12	15	0.02	99.27	0.09	0.62

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 backgroun	Other sources
3	9	13.71	74.14	11.26	0.89
12	9	11.72	79.63	6.75	1.9
13	9	16.44	74.22	7.41	1.93
15	9	13.53	75.55	9.70	1.22
4	10	18.09	70.57	10.20	1.14
5	10	14.37	75.40	9.12	1.11
9	10	10.60	78.76	8.28	2.36
10	10	18.56	68.34	9.10	4
11	10	16.17	73.23	6.80	3.8
12	10	12.54	75.41	8.95	3.1
13	10	18.01	70.45	8.72	2.82
14	10	20.40	68.69	7.93	2.98
15	10	17.17	69.86	10.82	2.15
5	11	20.07	68.82	9.64	1.47
6	11	15.08	73.35	10.23	1.34
7	11	16.19	74.09	7.98	1.74
8	11	14.00	75.59	8.33	2.08
9	11	19.22	69.21	8.63	2.94
10	11	26.45	61.43	7.78	4.34
11	11	25.03	61.88	7.96	5.13
12	11	25.14	62.32	7.48	5.06
13	11	22.80	66.88	6.20	4.12
14	11	19.84	69.69	7.02	3.45
15	11	14.47	74.78	8.85	1.9
6	12	15.92	72.33	10.46	1.29
7	12	17.70	71.67	8.83	1.8

8	12	20.50	67.17	9.91	2.42
9	12	27.80	60.20	8.50	3.5
10	12	37.04	50.17	7.79	5
11	12	39.66	48.59	6.22	5.53
12	12	39.06	48.67	6.15	6.12
13	12	34.17	53.81	6.38	5.64
14	12	19.62	67.75	9.10	3.53
15	12	12.60	75.54	9.44	2.42
16	12	9.82	79.49	9.02	1.67
17	12	10.48	77.73	10.43	1.36
8	13	23.78	66.04	7.77	2.41
9	13	28.65	59.74	8.37	3.24
10	13	35.20	52.71	7.65	4.44
11	13	37.68	50.79	6.84	4.69
12	13	44.13	44.36	6.21	5.3
13	13	35.91	53.28	6.06	4.75
14	13	28.74	60.39	6.74	4.13
15	13	27.02	60.62	8.44	3.92
18	13	10.81	75.29	12.25	1.65
9	14	15.19	72.03	10.70	2.08
13	14	35.41	53.75	6.69	4.15
14	14	31.26	56.82	7.94	3.98
20	14	7.80	78.54	12.52	1.14

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
13	3	1.38	83.48	15	0.14
13	4	2.94	81.66	15.15	0.25
13	5	3.55	85.16	10.99	0.3
14	5	5.85	81.67	12.13	0.35
16	5	8.58	79.54	11.42	0.46
13	6	5.66	82.81	11.01	0.52
15	6	8.79	84.18	6.25	0.78
16	6	12.76	78.72	7.63	0.89
13	7	6.68	79.35	13.28	0.69
15	7	8.47	82.14	8.77	0.62
12	8	5.43	82.23	11.46	0.88
14	8	10.76	81.21	6.99	1.04
15	8	7.27	82.3	9.81	0.62
12	9	8.65	83.13	6.8	1.42
13	9	12.31	79.4	6.83	1.46
14	9	14.96	74.11	9.35	1.58
15	9	10.23	79.47	9.35	0.95
16	9	15.95	72.36	10.44	1.25
5	10	5.42	84.94	9	0.64
6	10	10.32	82.01	6.7	0.97
9	10	6.9	82.35	8.91	1.84
10	10	14.25	73.11	9.34	3.3
11	10	10.89	77.9	8.27	2.94
12	10	10.59	78.04	8.69	2.68

13	10	16.5	71.61	9.23	2.66
14	10	17.14	71.42	8.91	2.53
15	10	10.62	78.5	9.43	1.45
16	10	15.26	73.32	9.84	1.58
5	11	14.53	74.2	10.22	1.05
6	11	11.19	78.08	9.59	1.14
7	11	10.62	78.28	9.57	1.53
8	11	9.86	80.17	8.34	1.63
9	11	17.18	71.54	8.5	2.78
10	11	24.81	62.68	8.37	4.14
11	11	23.63	63.41	8.13	4.83
12	11	21.7	65.81	7.86	4.63
13	11	20.79	67.76	7.53	3.92
14	11	19.14	70.34	7.22	3.3
15	11	9.32	80.86	8.4	1.42
16	11	16.03	70.66	11.41	1.9
4	12	22.64	61.49	14.65	1.22
5	12	19.23	67.5	11.95	1.32
6	12	12.93	76.31	9.62	1.14
7	12	12.28	78.29	8.15	1.28
8	12	19.77	67.05	10.88	2.3
9	12	24.35	62.19	10.21	3.25
10	12	34.65	52.08	8.43	4.84
11	12	35.93	51.19	7.7	5.18
12	12	36.15	51.29	6.76	5.8
13	12	29.03	58.22	7.66	5.09
14	12	13.85	74.65	8.85	2.65
15	12	12.74	75.73	9.23	2.3
16	12	5.39	85.1	8.52	0.99
17	12	7.9	81.23	9.81	1.06
18	12	9.51	77.12	12.24	1.13
7	13	11.98	77.44	9.22	1.36
8	13	19.2	70.28	8.54	1.98
9	13	25.26	62.65	9.25	2.84
10	13	32.21	55.82	8.06	3.91
11	13	34.43	53.23	7.93	4.41
12	13	39.86	47.91	7.19	5.04
13	13	26.5	62.35	7.27	3.88
14	13	14.28	74.24	8.96	2.52
15	13	23.34	64.56	8.66	3.44
16	13	17.04	69.15	11.05	2.76
17	13	12.34	73.91	11.73	2.02
18	13	8.48	79.91	10.3	1.31
19	13	6.43	81.94	10.74	0.89
7	14	18.16	65.71	14.17	1.96
8	14	10.28	79.18	9.35	1.19
9	14	10.17	78.74	9.71	1.38
10	14	23.71	63.9	9.63	2.76
11	14	37.46	49.05	8.86	4.63
12	14	39.19	47.26	8.28	5.27
13	14	24.6	63.84	8.24	3.32
14	14	26.15	61.92	8.64	3.29
15	14	22.13	65.54	9.44	2.89
16	14	14.3	73.13	10.45	2.12

17	14	9.03	79.3	10.33	1.34
18	14	9.27	78.44	10.92	1.37
19	14	6.4	80.46	12.11	1.03
20	14	5.69	83.69	9.84	0.78
21	14	5.24	80.5	13.56	0.7
22	14	2.78	84.7	12	0.52
10	15	11.61	74.55	12.25	1.59
11	15	14.98	73.38	9.77	1.87
12	15	19.05	69.76	8.8	2.39
13	15	17.36	69.52	10.69	2.43
17	15	6.6	77.85	14.54	1.01
18	15	9.45	74.73	14.2	1.62
19	15	9.8	74.88	13.71	1.61
21	15	6.17	80.46	12.36	1.01
22	15	3.77	82.28	13.35	0.6
18	16	5.52	80.59	13.01	0.88
19	16	6.64	78.24	14	1.12
20	16	7.19	76.08	15.39	1.34

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	0.36	97.13	0.08	2.43

Table C5: Source contribution to exceedances of the National Target for PM_{10} in grid squares in Trondheim. Values given in percent.

Grid index I	Grid index J	Domestic wood combustion	Traffic	Regional background	Other sources
5	6	14.64	70.65	14.4	0.31
5	7	11	76.74	12.01	0.25
5	8	12.04	76.21	11.42	0.33
6	9	17.32	70.37	11.93	0.38
6	10	26.51	58.5	14.41	0.58
6	11	37.47	44.68	16.97	0.88
6	12	40.57	45.73	12.7	1
7	13	56.11	30.82	11.7	1.37

Table C6: 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	0.4	93.06	6.5	0.04
5	3	1.11	92.26	6.57	0.06
3	4	3.69	84.43	11.72	0.16
5	4	4.38	85.39	10.1	0.13
5	5	5.52	85.73	8.6	0.15
4	6	5.6	84.42	9.83	0.15
5	6	4.6	87.58	7.69	0.13
5	7	8.11	81.04	10.64	0.21
5	8	10.95	78.49	10.28	0.28
4	9	12.97	75.41	11.33	0.29
5	9	23.06	64.8	11.66	0.48
6	9	6.49	85.52	7.78	0.21
8	9	4.29	85.48	10.06	0.17
4	10	12.68	72.76	14.28	0.28
5	10	19.2	69.05	11.31	0.44
6	10	9.47	81.61	8.62	0.3
7	10	12.95	77.69	9.07	0.29
8	10	9.61	82.41	7.78	0.2
5	11	12.72	77.02	9.83	0.43
6	11	12.89	77.61	9.06	0.44
7	11	30.74	54.33	14.3	0.63
8	11	17.37	69.53	12.75	0.35
9	11	6.15	83.11	10.52	0.22
5	12	13.68	72.85	12.85	0.62
6	12	20.84	68	10.51	0.65
7	12	34.32	50.27	14.68	0.73
8	12	27.38	56.67	15.37	0.58
5	13	8.73	81.23	9.59	0.45
6	13	22.83	65.25	10.82	1.1
7	13	34.2	53.78	11.07	0.95
8	13	30.45	56.87	12.03	0.65
9	13	29.49	57.15	12.82	0.54
10	13	4.89	87.59	7.35	0.17
11	13	2.82	88.33	8.7	0.15
14	13	0.54	89	10.41	0.05
7	14	16.33	72.45	10.19	1.03
8	14	29.17	59.21	10.01	1.61
9	14	17.37	72.55	9.45	0.63

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 D1). For the Oslo domain measured daily background values of PM_{10} from 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. This estimate is based on the following empirical relation between the concentrations of these compunds (Slørdal and Larssen, 2001).

$$[PM_{10}] = ([SO_4] + [NO_3] + [NH_4])*2.5$$

Table D1: Measurement stations applied in estimating the boundary conditions.

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

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

Negative background values means that the concentration is below the detection limit. In these situations we apply a background value which is equal to the absolute value multiplied by 2.

Ozon

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

NO_2

- For Oslo daily values of NO_2 from Birkenes are applied.
- For Trondheim daily values 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: $NO_2=NO_2\text{-}N*(46/14)$.

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.

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))*2.5

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: $SO_4A=SO_4A\text{-}S*(96/32)$.

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.

Norwegian Institute for Air Research (NILU)

P.O. Box 100, N-2027 Kjeller, Norway

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REPORT PREPARED FOR:
Statens forurensningstilsyn
Postboks 8100 Dep
0032 OSLO

ABSTRACT
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) for the year 2005 for the two Norwegian cities Oslo and Trondheim. The number of inhabitants exposed to exceedances of the National Air Quality Target for the three compounds have been computed both in building points and in the model grid squares. The calculations show that 0.12 % , 44.8 % , and 6.0 % of the Oslo population are exposed to exceedances of the National air quality target for NO_2 , PM_{10} , and benzene, respectively. The corresponding numbers for Trondheim are, 0.026 % , 13.8 % , and 0 %. The calculations of the percentual contributions from the various sources demonstrate that road traffic is the dominant source to the exceedances of the national target for both NO_2 and PM_{10}. For PM_{10} domestic wood combustion is clearly the second most dominant local source. No calculations of source contributions has been made for benzene, but earlier investigations (Laupsa et al., 2005 a) have shown that raod traffic is by far the most dominant source for the exceedances with regards to this compound as well.

NORWEGIAN TITLE

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ABSTRACT (in Norwegian)
Norsk institutt for luftforskning (NILU) har på oppdrag fra Statens forurensningstilsyn (SFT) gjennomført spredning- og eksponeringsberegninger for PM_{10}, NO_2 og benzen for Oslo og Trondheim for 2005. Antall personer utsatt for overskridelser av nasjonalt mål for disse tre komponentene er blitt beregnet i bygningspunkter og i ruter. Beregningene viser at 0.12 % , 44.8 % og 6.0 % av Oslos befolkning eksponeres for overskridelser av henholdsvis NO_2, PM_{10} og benzen. De tilsvarende tallene for Trondheim er 0.026 % , 13.8 % og 0 %. Beregninger av de prosentvise kildebidragene viser at vegtrafikk er den dominerende kilden til overskridelsene for både NO_2 og PM_{10}. For PM_{10} er vedfyring den nest mest dominerende lokale kilden. For benzen er det denne gangen ikke blitt gjennomført beregninger av kildebidraget, men tidligere undersøkelser, (Laupsa et al., 2005 a) har vist at veg-trafikk er den klart dominerende kilden til overskridelser for denne komponenten også.

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