NILU: OR 82/2006

NILU: OR 82/2006
REFERENCE: O-106107
DATE: DECEMBER 2006
ISBN: 82-425-1811-4 (print)
978-82-425-1876-7 (electronic)

Evaluation of abatement measures for PM_{10} in Oslo and Trondheim for the year 2010

Leiv Håvard Slørdal, Harold McInnes and Herdis Laupsa

Contents

Summary

Commissioned by the Norwegian Pollution Control Authority (SFT), NILU has performed dispersion and exposure calculations to evaluate the extent of abatement measures needed in order to fulfil the goals defined in the "National Air Quality Target for PM_{10}". This target specifies that at most 7 days during a year the inhabitants are allowed exposure levels of PM_{10} above an average value of 50 $\mu g/m^3$. This target is to be met within the year 2010.

By applying the model system AirQUIS (AirQUIS, 2006) calculations have been performed for the two cities, Oslo and Trondheim. Based on projected emissions, a Reference 2010 simulation has been performed for each city. This simulation included exposure calculations in order to indicate the exceedance levels to be expected if no abatement measures were invoked. Then a set of abatement measures was defined. By incorporating the effect of these measures on the Reference 2010 emission inventory, a series of Scenario simulations were performed.

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 referred to as grid values).

The total number of inhabitants exposed beyond the "National Target" for PM_{10} for the two reference simulations and the various scenario simulations are summarized below in Table A (Oslo) and Table B (Trondheim). In addition the maximum 8th highest calculated building and grid point concentrations are given for each simulation. To avoid exceedances these values should be below 50 $\mu g/m^3$. From the Reference 2010 results presented in these tables it is seen that a moderate decrease in the grid values are needed to get below the 50 $\mu g/m^3$ target value (a 8,5 $\mu g/m^3$ decrease in Oslo and a 3,2 $\mu g/m^3$ decrease in Trondheim). However, a substantial reduction is needed for building points close to the major road network (a 224 $\mu g/m^3$ decrease in Oslo and a 214 $\mu g/m^3$ decrease in Trondheim). These findings indicate that strong traffic-oriented measures are needed in order to reach the goal. Furthermore, tests performed in this study clearly demonstrate that all local sources apart from road traffic and domestic wood burning are of marginal importance, and the emphasize is therefore put on measures reducing the contribution from these two sources.

In summary, the traffic measures introduced in Scenario 1 (95 % un-studded vehicles) and 4 (speed limits above 60 km/h reduced to 60 km/h) are strongly recommended, and in order to further reduce the number of inhabitants exposed beyond the target value, a combination of the other measures should be applied as found necessary.

Table A: Exposure results from the various simulations for Oslo. The highest values are calculated for building 62197 in all of the scenarios. This building is located close to the Ullevål end of the Tåsen tunnel at "Ring 3". Building 8788 (maximum in the Reference 2005 simulation) is located in the same area.

Oslo	Description	No. of persons exposed
Reference 2005	76 % non-studded vehicles + emissions from wood burning scaled as shown in Appendix A	**235 849 persons** [Max build 8788: 466,4 μg/m^3] [Max grid (9,10): 88,0 μg/m^3]
Reference 2010	85 % non-studded vehicles + emissions from wood burning scaled as shown in Appendix A	**66 071 persons** [Max build 62197: 273,6 μg/m^3] [Max grid (15,12): 58,5 μg/m^3]
Scenario 1	As Reference 2010, but with 95 % non-studded vehicles	**5 930 persons** [Max build 62197: 195,1 μg/m^3] [Max grid (13,14): 46,7 μg/m^3]
Scenario 2	As Scenario 1 + exchanging all old ovens with new clean ones; the 22 % of open fireplaces are retained (corresponds to a 47 % reduction from Reference 2010 in emissions from wood burning)	**4 467 persons** [Max build 62197: 193,9 μg/m^3] [Max grid (15,12): 41,9 μg/m^3]
Scenario 3	As Scenario 1 + only new clean-burning ovens allowed (corresponds to a 62 % reduction from Reference 2010 in emissions from wood burning)	**4 023 persons** [Max build 62197: 193,5 μg/m^3] [Max grid (15,12): 40,3 μg/m^3]
Scenario 4	As Scenario 3 + all roads with speed limit above 60 km/h reduced to 60 km/h	**872 persons** [Max build 62197: 148,1 μg/m^3] [Max grid (10,12): 36,0 μg/m^3]
Scenario 5	As Scenario 4, but requiring a 90 % reduction in the emissions from wood burning (90% from Reference 2010)	**689 persons** [Max build 62197: 147,4 μg/m^3] [Max grid (5,10): 35,2 μg/m^3]
Scenario 6	As Scenario 4 + 50 % reduction in traffic volume (50 % from Reference 2010)	**56 persons** [Max build 62197: 77,8 μg/m^3] [Max grid (10,12): 28,5 μg/m^3]
Scenario 7	As Scenario 5 + 50 % reduction in traffic volume (50 % from Reference 2010)	**30 persons** [Max build 62197: 76,7 μg/m^3] [Max grid (5,10): 26,7 μg/m^3]

Table B: Exposure results from the various simulations for Trondheim. The highest values are calculated for buildings 1109 and 26924, both located at E6 Nardo/Moholt and at Building 25121 which is located at Dyre Halses gate.

Trondheim	Description	No. of persons exposed
Reference 2005	62 % non-studded vehicles + emissions from wood burning scaled as shown in Appendix A	**20 915 persons** [Max build 1109: 313,5 μg/m^3] [Max grid (6,9): 62,9 μg/m^3]
Reference 2010	75 % non-studded vehicles + emissions from wood burning scaled as shown in Appendix A	**8 555 persons** [Max build 26924: 264,3 μg/m^3] [Max grid (6,9): 53,2 μg/m^3]
Scenario 1	As Reference 2010, but with 95 % non-studded vehicles	**2 378 persons** [Max build 26924: 148,7 μg/m^3] [Max grid (7,13): 39,4 μg/m^3]
Scenario 3	As Scenario 1 + only new clean-burning ovens allowed (corresponds to a 68 % reduction from Reference 2010 in emissions from wood burning)	**1 702 persons** [Max build 26924: 145,2 μg/m^3] [Max grid (6,9): 31,7 μg/m^3]
Scenario 4	As Scenario 3 + all roads with speed limit above 60 km/h reduced to 60 km/h	**1 022 persons** [Max build 25121: 93,2 μg/m^3] [Max grid (6,9): 26,3 μg/m^3]
Scenario 5	As Scenario 4, but requiring a 90 % reduction in the emissions from wood burning (90 % from Reference 2010)	**1 002 persons** [Max build 25121: 93,0 μg/m^3] [Max grid (6,9): 25,1 μg/m^3]
Scenario 6	As Scenario 4 + 50 % reduction in traffic volume (50 % from Reference 2010)	**36 persons** [Max build 25121: 50,4 μg/m^3] [Max grid (7,13): 21,8 μg/m^3]
Scenario 7	As Scenario 5 + 50 % reduction in traffic volume (50 % from Reference 2010)	**36 persons** [Max build 25121: 50,2 μg/m^3] [Max grid (6,9): 18,2 μg/m^3]

Evaluation of abatement measures for PM_{10} in Oslo and Trondheim for the year 2010

1 Introduction

Commissioned by the Norwegian Pollution Control Authority (SFT), NILU has performed dispersion and exposure calculations to investigate the extent of abatement measures needed in order to fulfil the goals defined in the ”National Air Quality Target for PM_{10}”. This target specifies that at most 7 days during a year the inhabitants are allowed exposure levels of PM_{10} above an average value of 50 $\mu g/m^3$. This target is to be met within the year 2010.

By applying the model system AirQUIS (AirQUIS, 2006) calculations have been performed for the two cities, Oslo and Trondheim. The applied computational procedure has been defined as a sequence of separate model calculations. First, a reference simulation was made for the year 2005. 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, 1 May – 30 September. The reason why the highest PM_{10} concentrations are found in wintertime is the combination of frequently occurring stable atmospheric conditions (poor dispersion conditions) and large emissions of particulate matter emanating from the use of studded tyres and from domestic wood burning, during this season. The PM_{10} results from the Reference 2005 simulation were compared with available measurements within the cities to evaluate the model calculations. Moreover, some adjustments of the source strength of the coarse fraction particles, i.e. PM_{10} – $PM_{2.5}$, were also implemented as part of this verification/validation work. Second, the emissions were altered in accordance with expected, and already adopted regulations in technology and fuels towards 2010. Based on this updated emission inventory, a Reference 2010 simulation was performed. This simulation included exposure calculations in order to indicate the exceedance levels to be expected if no abatement measures were invoked. Third, a set of abatement measures was defined. By incorporating the effect of these measures on the Reference 2010 emission inventory, a number of Scenario simulations have been performed.

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 values).

This report describes how the modelling work has been accomplished, and gives an overview of the modelling results.

2 Description of the model calculations

2.1 Reference calculation for the year 2005

As mentioned above, the reference simulation for 2005 for the two cities were performed for the winter/spring period from January 1 to April 30, and for the autumn/winter period from October 1 to December 31. The Reference 2005 calculations and the comparison of the model results against local measurements was performed as part of the closely related project ”Dispersion and exposure calculations of PM_{10}, NO_2, and Benzene for Oslo and Trondheim for the year 2005”, and the evaluation work is documented in the project report from this project (Slørdal et al., 2007).

The Reference 2005 simulation was also carried out in order to adjust the estimated contribution of traffic induced suspension of PM_{10}. 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 Reference 2005 simulation was 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.

Data employed in the 2005 reference calculation

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) 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 are 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. 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.

At the boundaries if the model domains regional background levels have been specified. 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 compounds (Slørdal and Larssen, 2001).

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

Consumption data for fossil fuels, except of road traffic consumption, has been supplied by Statistics Norway (SSB). The emissions from these fuels are mostly emitted at roof level, and have therefore been distributed in the 1 km^2 model grid as area sources. The consumption of fossil fuels, except of wood for domestic heating, is based on information from 1998. Emission data from domestic wood burning in Oslo are valid for 2002, while the corresponding wood burning emissions for Trondheim are valid for 2003. For Oslo the wood burning emissions are scaled from 2002 to 2005 based on given assumptions on changes in wood consumption and on the continuous replacement of old ovens with new clean-burning ones. The method applied for this scaling procedure is described in detail in Appendix A. In this Appendix all model assumptions on the percentage distribution of the different oven-types together with the expected changes in wood consumption, are specified.

The emission from road traffic is mainly based on the same data 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., 2005a) and ”Calculation of PM_{10} and $PM_{2,5}$ for Oslo in 2010 and 2015” (Laupsa et al., 2005b). The only changes are that new emission factors, valid for the year 2005, has 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 speed reduction at RV4 in Oslo. Furthermore, the percentage of vehicles with un-studded tyres has been changed to 76 % in Oslo and 62 % in Trondheim for the Reference 2005 simulation.

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

2.2 Reference projection (prognosis, prediction, calculation) for 2010

With the Reference 2005 model setup as starting point, the emissions have been projected towards 2010. A Reference 2010 dispersion- and population exposure simulation has been performed for the two cities to estimate the PM_{10} levels to be expected if no abatement measures are applied. Ambient concentration values and exposure estimates are calculated both in building points along the main road network (i.e., buildings within a distance of 100 – 500 m from each road depending on traffic volume) and in the domain covering grid system. The inhabitants living in buildings some distance away from the main road network are assigned to the value of the grid cell covering their home address. The exposure calculations apply the PM_{10} limit value specified in the ”National Air Quality Target for PM_{10}”, i.e., at most 7 days during a year the inhabitants are allowed exposure levels of PM_{10} above an average value of 50 μg/m^3. Accordingly, in the model simulations the 8th highest daily average PM_{10} concentration has been computed both in the grid network as well as in the positions of the selected buildings. If this 8th highest value is above 50 μg/m^3 the persons assigned to this value are considered as exposed to exceedances, i.e., exposed beyond the limit defined in the “National Target”.

Data employed in the 2010 reference calculation

In the “Reference 2010” calculation identical meteorological and regional background data have been applied as in the Reference 2005 simulation. With regard to the emissions, however, expected changes in emissions from both the wood burning and the road traffic have been incorporated in the projected emission inventory for the Reference 2010 simulation. All of the other sources have been assumed unaltered.

In the project ”Tiltaksutredning i Osloregionen etter forskrift om lokal luftkvalitet med forslag til handlingspakker”, projected traffic data was constructed for 2010 (Oslo kommune/Statens vegvesen Region øst, 2004). These traffic projections have been applied in the Reference 2010 simulation for Oslo. Moreover, a growth in vehicles with un-studded tyres has been expected, so this portion has been increased from 76 % to 85 %.

For Trondheim the traffic emissions have been changed based on an expected traffic growth of 9 % from 2005. In addition, the percentage of vehicles with un-studded tyres has been expected to increase from 62 % to 75 %.

The emissions from domestic wood combustion for the Reference 2010 simulation are scaled as described in Appendix A.

3 Description of the calculated abatement scenarios

Each of the abatement scenarios that have been simulated for Oslo and Trondheim are described separately in the list below. Note that Scenario 0 was only included for demonstrative purposes, and are not discussed further in Sections 4 to 6. Moreover, Scenario 2 was only performed for Oslo.

Scenario 0: In order to demonstrate that domestic wood burning and road traffic are the main local sources for PM_{10}, a scenario simulation has been performed for 2010 for both cities in which these two sources have been excluded. In addition, the contribution from the regional background has also been ignored. These two simulations show that the 8th highest daily PM_{10} concentration from all of these other sources maximum amounts to:

4.9 μg/m^3 in Oslo [grid square (12,12)], and
1.9 μg/m^3 in Trondheim [grid square (8, 14)].

Scenario 1: As Reference 2010, but with 95 % non-studded vehicles.

For Oslo the following additional scenario (Scenario 2) has been performed:

Scenario 2: As Scenario 1, but in addition all old ovens are exchanged with new clean ones; the 22 % of open fireplaces in Oslo are retained (corresponds to a 47 % reduction from Reference 2010 in emissions from wood burning).

Scenario 3: As Scenario 1, but only new clean-burning ovens allowed [corresponds to a 62 % (Oslo) and 68 % (Trondheim) reduction from Reference 2010 in emissions from wood burning].

Scenario 4: As Scenario 3, but for all roads where the speed limit is above 60 km/h, this limit is reduced to 60 km/h.

Scenario 5: As Scenario 4, but requiring a 90 % reduction in the emissions from wood burning (90 % reduction from Reference 2010).

Scenario 6: As Scenario 4, but with a 50 % reduction in traffic volume (50 % from Reference 2010).

Scenario 7: As Scenario 5, but with a 50 % reduction in traffic volume (50 % from Reference 2010).

4 Exposure results for all simulations for Oslo and Trondheim

The total number of inhabitants exposed beyond the "National Target" for PM_{10} for the two reference simulations and the various scenario simulations are summarized below in Table 4.1 (Oslo) and Table 4.2 (Trondheim). In addition the maximum 8th highest calculated building and grid point concentrations are given for each simulation. To avoid exceedances these values should be below 50 μg/m^3. A more detailed discussion of these results is given below in Section 6.

Table 4.1: Exposure results from the various simulations for Oslo. The highest values are calculated for building 62197 in all of the scenarios. This building is located close to the Ullevål end of the Tåsen tunnel at "Ring 3". Building 8788 (maximum in the Reference 2005 simulation) is located in the same area.

Oslo	**Description**	**No. of persons exposed**
Reference 2005	76 % non-studded vehicles + emissions from wood burning scaled as shown in Appendix A	235 849 persons [Max build 8788: 466,4 μg/m^3] [Max grid (9,10): 88,0 μg/m^3]
Reference 2010	85 % non-studded vehicles + emissions from wood burning scaled as shown in Appendix A	66 071 persons [Max build 62197: 273,6 μg/m^3] [Max grid (15,12): 58,5 μg/m^3]
Scenario 1	As Reference 2010, but with 95 % non-studded vehicles	5 930 persons [Max build 62197: 195,1 μg/m^3] [Max grid (13,14): 46,7 μg/m^3]
Scenario 2	As Scenario 1 + exchanging all old ovens with new clean ones; the 22 % of open fireplaces are retained (corresponds to a 47 % reduction from Reference 2010 in emissions from wood burning)	4 467 persons [Max build 62197: 193,9 μg/m^3] [Max grid (15,12): 41,9 μg/m^3]
Scenario 3	As Scenario 1 + only new clean-burning ovens allowed (corresponds to a 62 % reduction from Reference 2010 in emissions from wood burning)	4 023 persons [Max build 62197: 193,5 μg/m^3] [Max grid (15,12): 40,3 μg/m^3]
Scenario 4	As Scenario 3 + all roads with speed limit above 60 km/h reduced to 60 km/h	872 persons [Max build 62197: 148,1 μg/m^3] [Max grid (10,12): 36,0 μg/m^3]
Scenario 5	As Scenario 4, but requiring a 90 % reduction in the emissions from wood burning (90% from Reference 2010)	689 persons [Max build 62197: 147,4 μg/m^3] [Max grid (5,10): 35,2 μg/m^3]
Scenario 6	As Scenario 4 + 50 % reduction in traffic volume (50 % from Reference 2010)	56 persons [Max build 62197: 77,8 μg/m^3] [Max grid (10,12): 28,5 μg/m^3]
Scenario 7	As Scenario 5 + 50 % reduction in traffic volume (50 % from Reference 2010)	30 persons [Max build 62197: 76,7 μg/m^3] [Max grid (5,10): 26,7 μg/m^3]

Table 4.2: Exposure results from the various simulations for Trondheim. The highest values are calculated for buildings 1109 and 26924, both located at E6 Nardo/Moholt and at Building 25121 which is located at Dyre Halses gate.

Trondheim	**Description**	**No. of persons exposed**
Reference 2005	62 % non-studded vehicles + emissions from wood burning scaled as shown in Appendix A	20 915 persons [Max build 1109: 313,5 μg/m^3] [Max grid (6,9): 62,9 μg/m^3]
Reference 2010	75 % non-studded vehicles + emissions from wood burning scaled as shown in Appendix A	8 555 persons [Max build 26924: 264,3 μg/m^3] [Max grid (6,9): 53,2 μg/m^3]
Scenario 1	As Reference 2010, but with 95 % non-studded vehicles	2 378 persons [Max build 26924: 148,7 μg/m^3] [Max grid (7,13): 39,4 μg/m^3]
Scenario 3	As Scenario 1 + only new clean-burning ovens allowed (corresponds to a 68 % reduction from Reference 2010 in emissions from wood burning)	1 702 persons [Max build 26924: 145,2 μg/m^3] [Max grid (6,9): 31,7 μg/m^3]
Scenario 4	As Scenario 3 + all roads with speed limit above 60 km/h reduced to 60 km/h	1 022 persons [Max build 25121: 93,2 μg/m^3] [Max grid (6,9): 26,3 μg/m^3]
Scenario 5	As Scenario 4, but requiring a 90 % reduction in the emissions from wood burning (90 % from Reference 2010)	1 002 persons [Max build 25121: 93,0 μg/m^3] [Max grid (6,9): 25,1 μg/m^3]
Scenario 6	As Scenario 4 + 50 % reduction in traffic volume (50 % from Reference 2010)	36 persons [Max build 25121: 50,4 μg/m^3] [Max grid (7,13): 21,8 μg/m^3]
Scenario 7	As Scenario 5 + 50 % reduction in traffic volume (50 % from Reference 2010)	36 persons [Max build 25121: 50,2 μg/m^3] [Max grid (6,9): 18,2 μg/m^3]

5 Maps showing the areas where exceedances are calculated with respect to the “National Target” on PM_{10}

In this section maps are presented which illustrates the locations where the exceedances are calculated. For each city the results from the Reference 2010 and the various scenario simulations are presented. The figure captions give the necessary information to uniquely identify each simulation. The results are discussed further in Section 6 below.

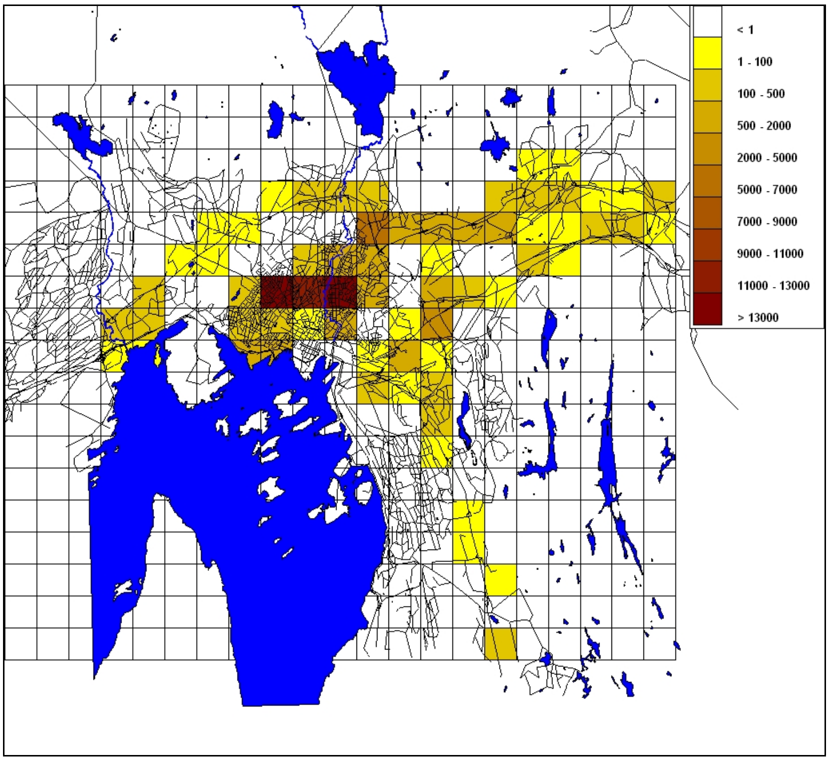

Figure 5.1: Oslo Reference 2010. 85 % non-studded vehicles + emissions from wood burning scaled as described in Appendix A. The colour scale gives the number of people in each grid square that are exposed beyond the National target. Persons exposed in buildings are collected in the grid. 66 071 persons exposed beyond the target value.

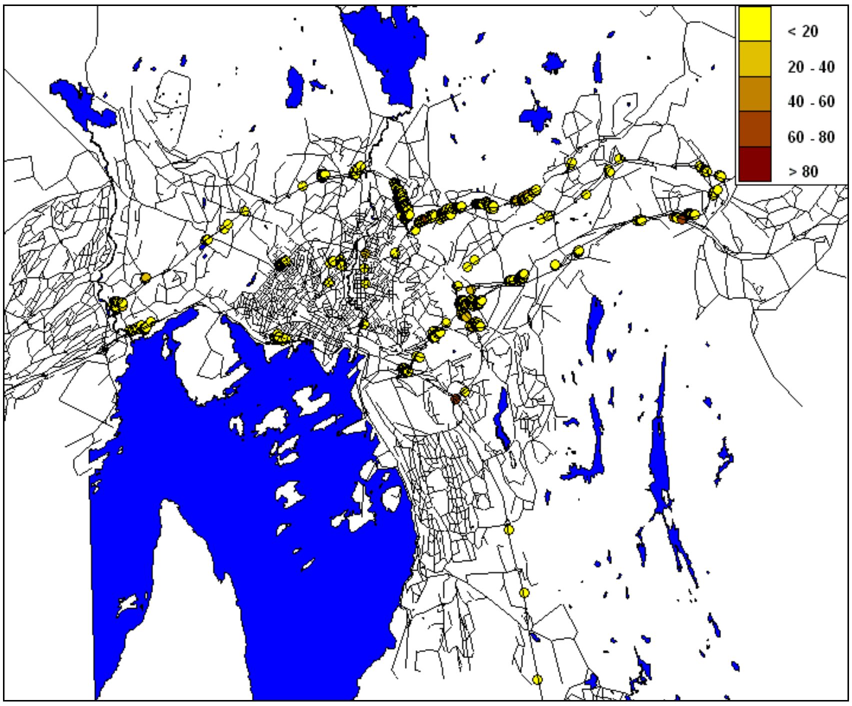

Figure 5.2: Oslo 2010 Scenario 1. As Reference 2010, but with 95 % non-studded vehicles. Buildings with exceedances are plotted. The colour scale gives the number of persons in each building. 5 930 persons exposed beyond the target value.

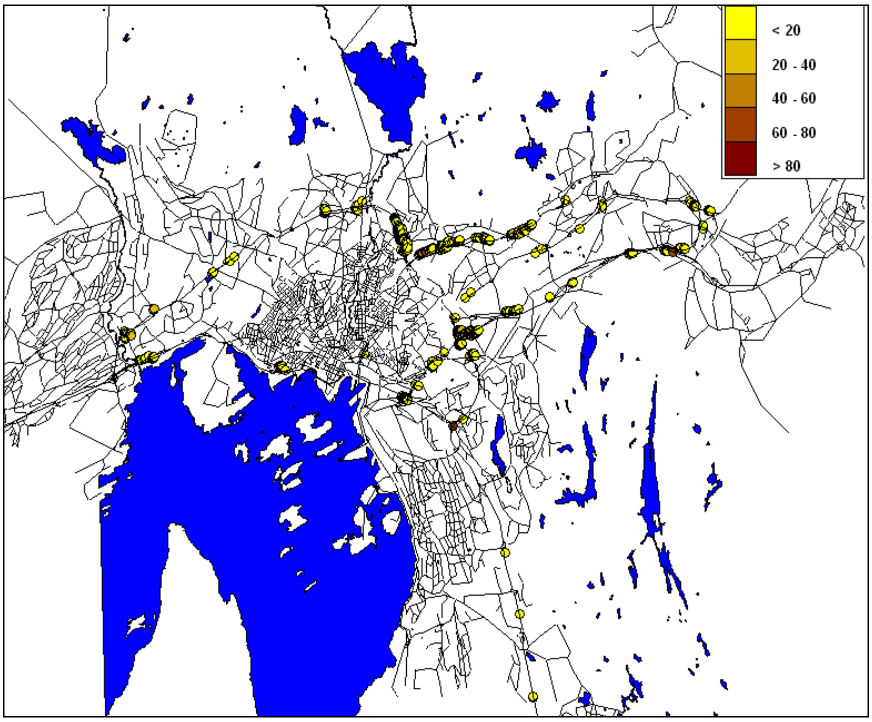

Figure 5.3: Oslo 2010 Scenario 2. As Scenario 1 + exchanging all old ovens with new clean ones; the 22 % of open fireplaces are retained (corresponds to a 47 % reduction from Reference 2010 in emissions from wood burning). The buildings with exceedances are plotted. The colour scale gives the number of persons in each building. 4 467 persons exposed beyond the target value.

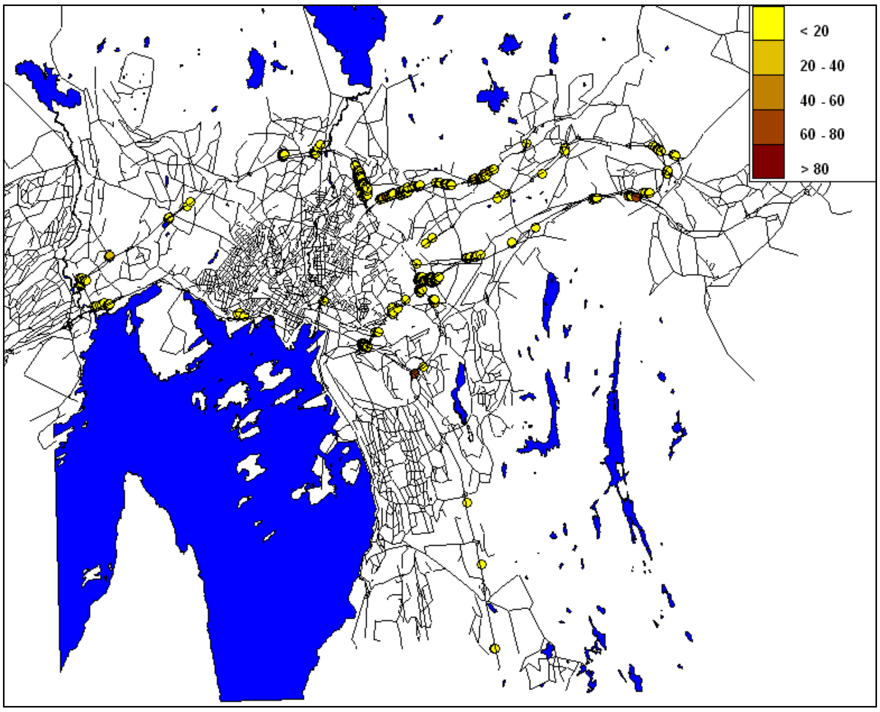

Figure 5.4: Oslo 2010 Scenario 3. As Scenario1 + only new clean-burning ovens allowed (corresponds to a 62 % reduction from Reference 2010 in emissions from wood burning). Buildings with exceedances are plotted. The colour scale gives the number of persons in each building. 4 023 persons exposed beyond the target value.

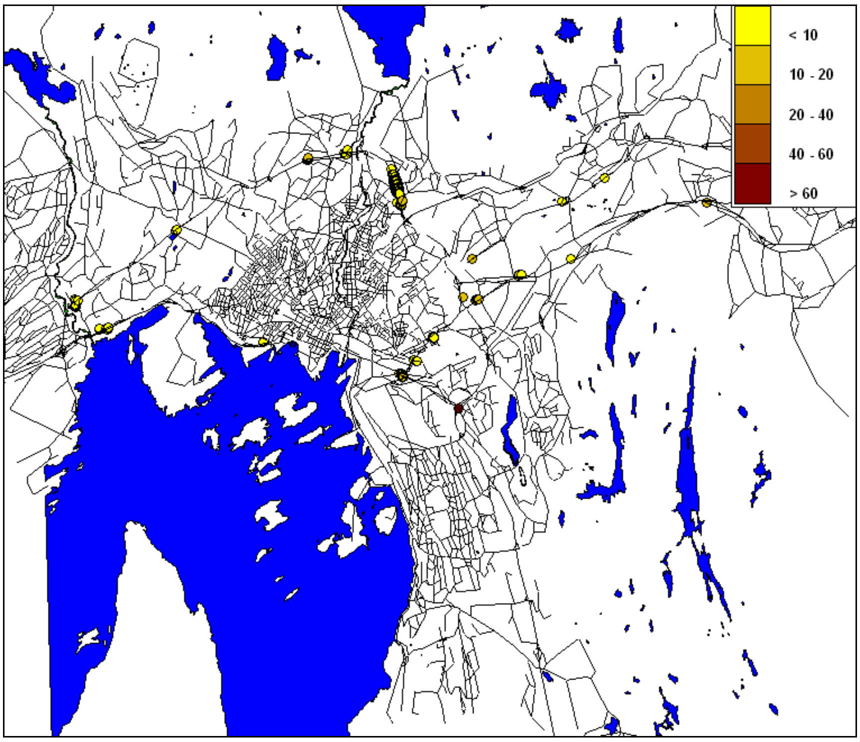

Figure 5.5: Oslo 2010 Scenario 4. As Scenario 3 + all roads with speed limit above 60 km/h reduced to 60 km/h. Buildings with exceedances are plotted. The colour scale gives the number of persons in each building. 872 persons exposed beyond the target value.

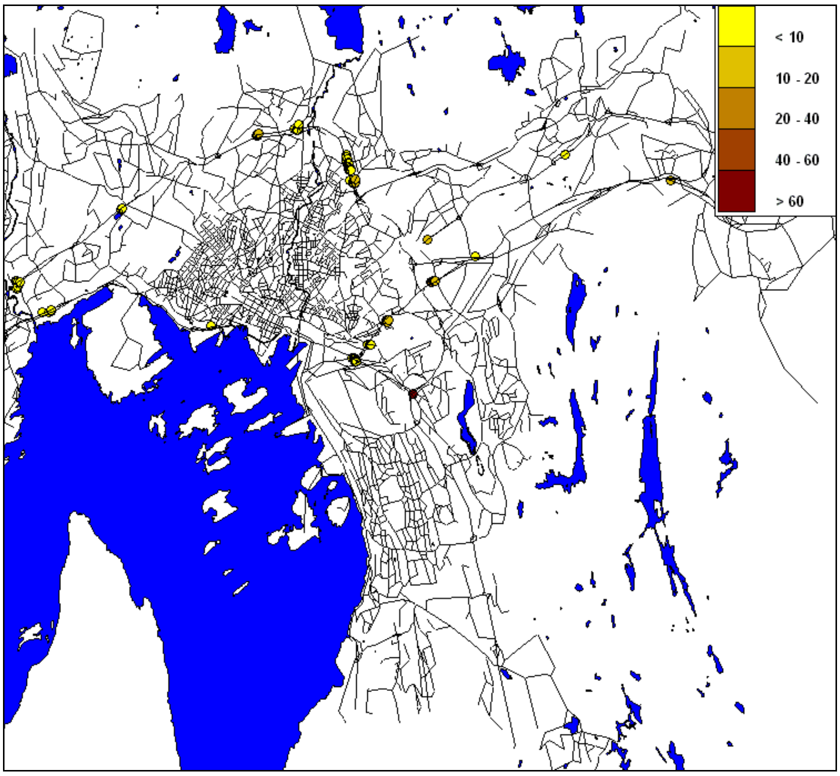

Figure 5.6: Oslo 2010 Scenario 5. As Scenario 4, but requiring a 90 % reduction in the emissions from wood burning (90 % from Reference 2010). The buildings with exceedances are plotted. The colour scale gives the number of persons in each building. 689 persons exposed beyond the target value.

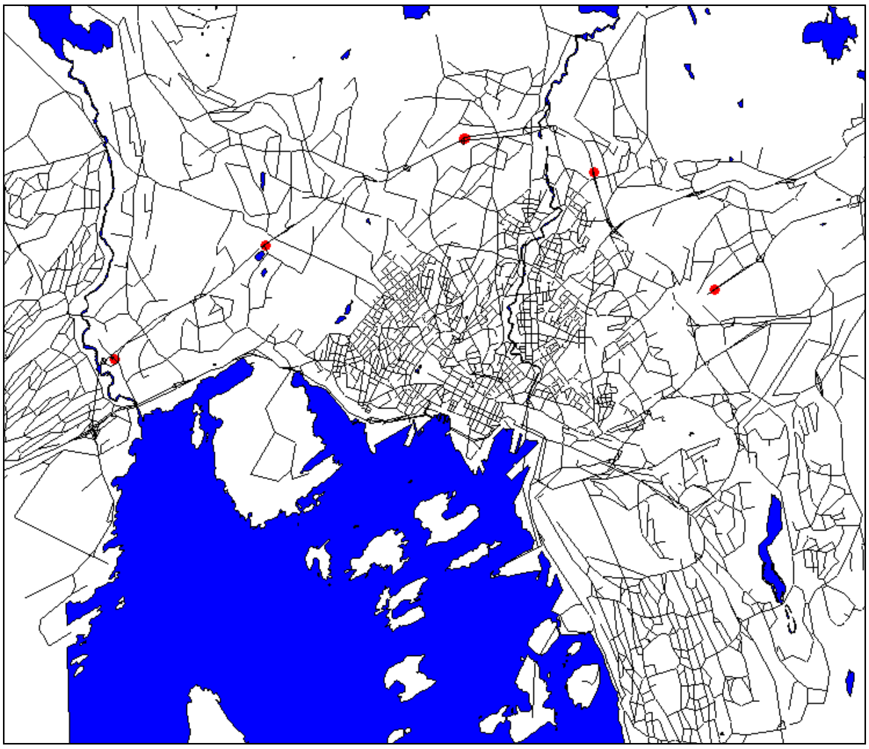

Figure 5.7: Oslo 2010 Scenario 6. As Scenario 4 + 50 % reduction in traffic volume (50 % from Reference 2010). The buildings with exceedances are plotted. 56 persons (5 buildings) exposed beyond the target value.

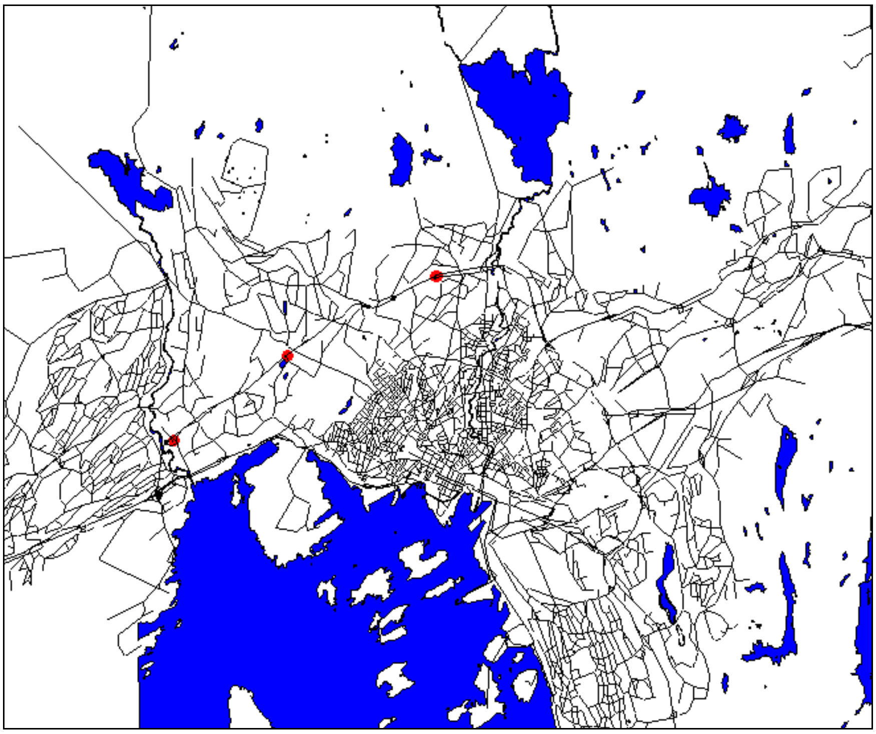

Figure 5.8: Oslo 2010 Scenario 7. As Scenario 5 + 50 % reduction in traffic volume (50 % from Reference 2010). The buildings with exceedances are plotted. 30 persons (3 buildings) exposed beyond the target value.

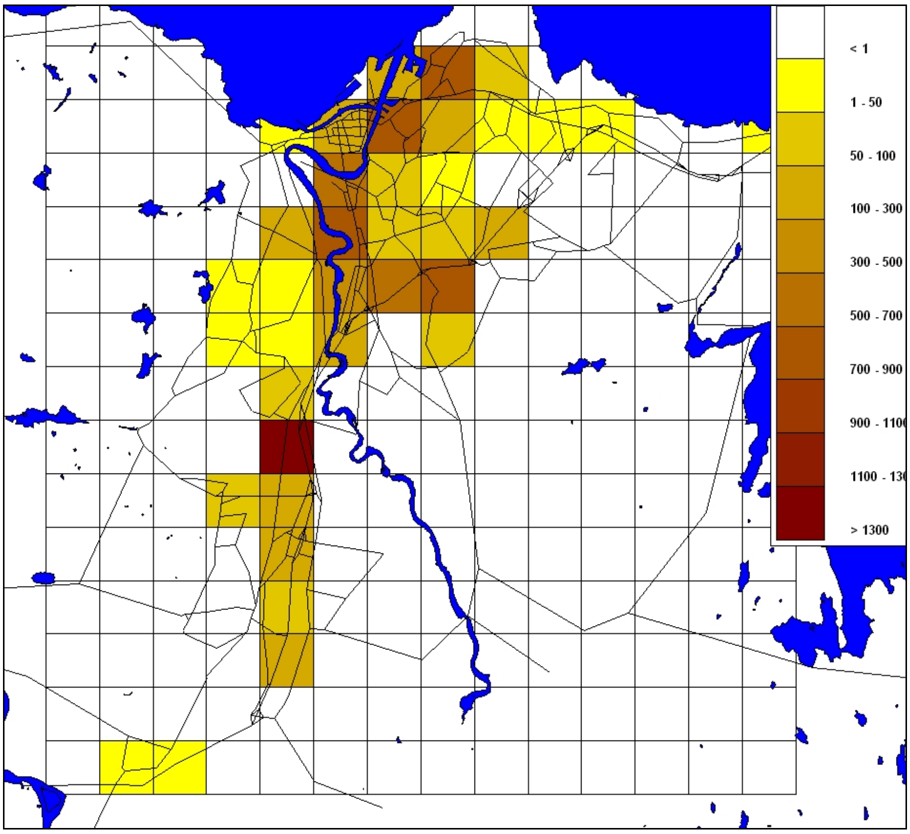

Figure 5.9: Trondheim Reference 2010. 75 % non-studded vehicles + emissions from wood burning scaled as shown in Appendix A. 8 555 persons exposed beyond the target value.

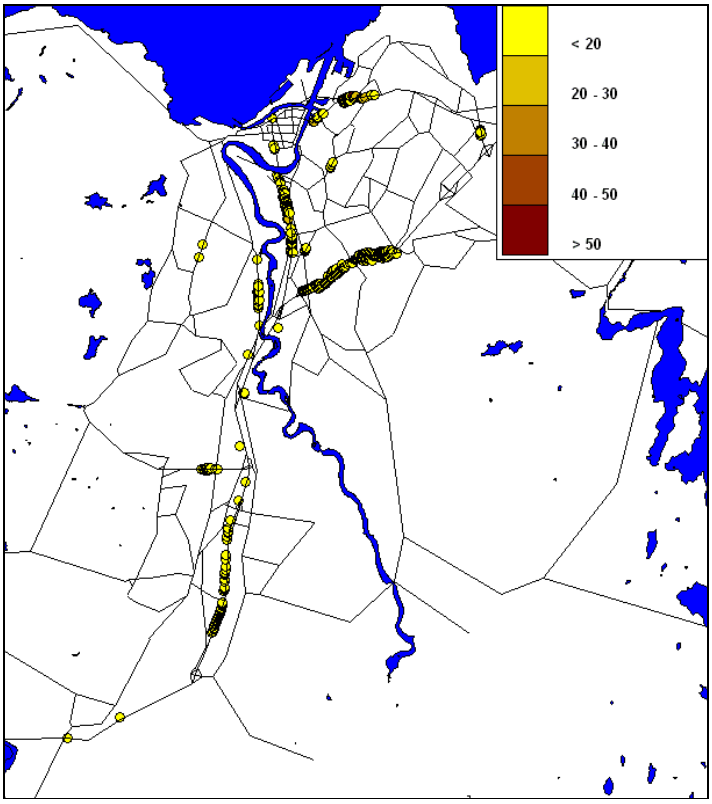

Figure 5.10: Trondheim 2010 Scenario 1. As Reference 2010, but with 95 % non-studded vehicles. 2 378 persons exposed beyond the target value.

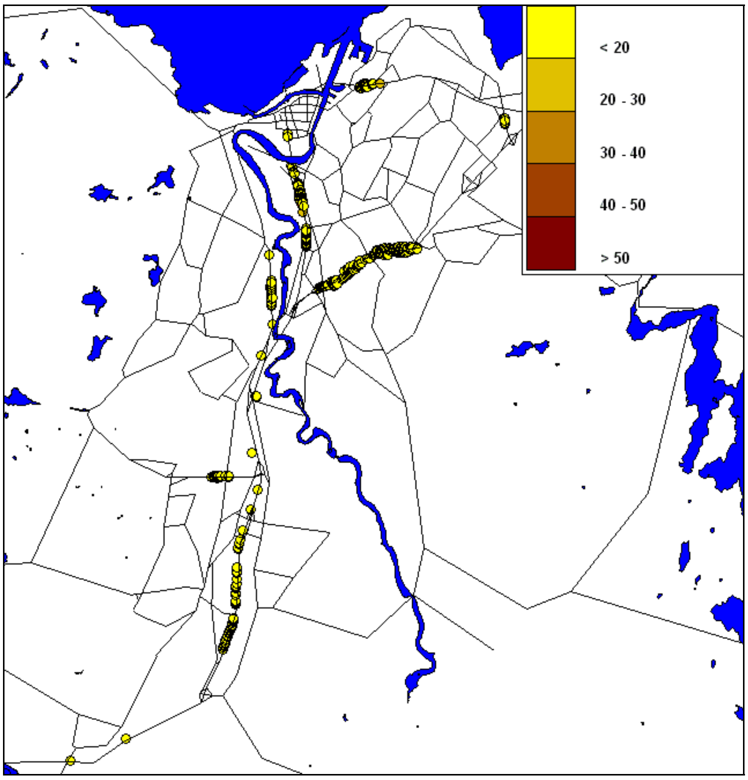

Figure 5.11: Trondheim 2010 Scenario 3. As Scenario 1 + only new clean-burning ovens allowed (corresponds to 68 % reduction from Reference 2010 in emissions from wood burning) + 95 % non-studded vehicles 1 702 persons exposed beyond the target value.

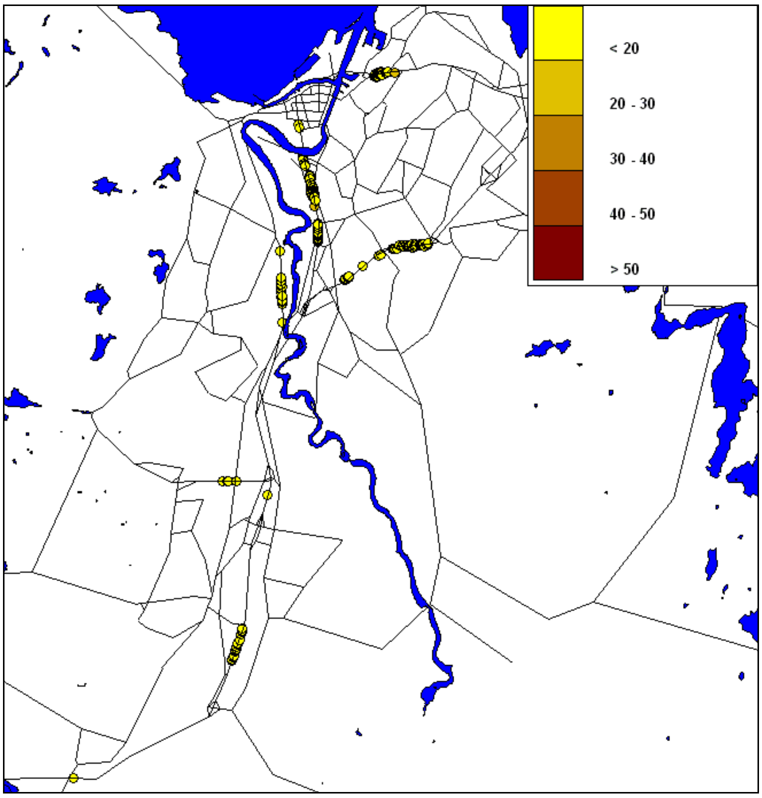

Figure 5.12: Trondheim 2010 Scenario 4. As Scenario 3 + all roads with speed limit above 60 km/h reduced to 60 km/h. 1 022 persons exposed beyond the target value.

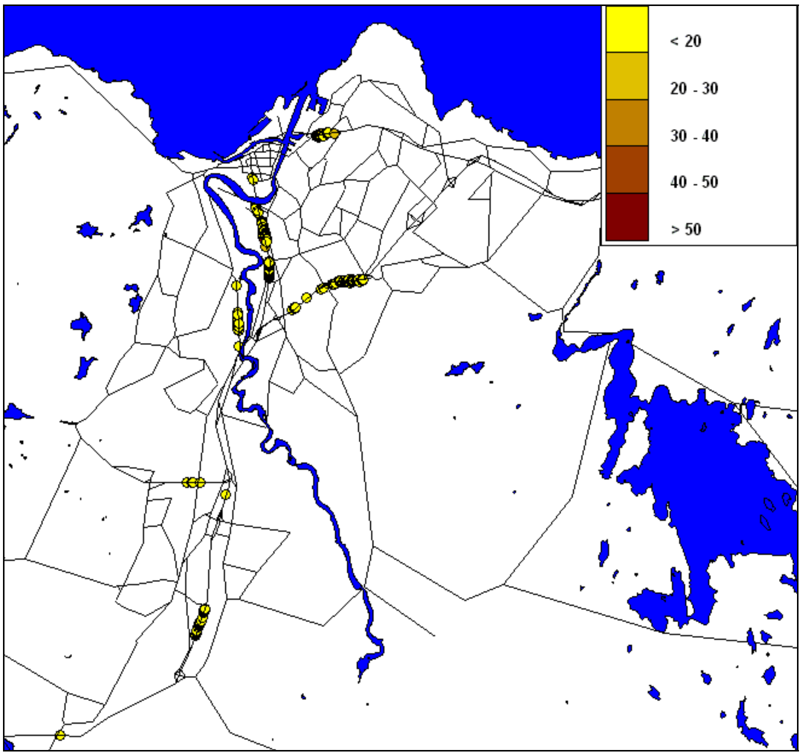

Figure 5.13: Trondheim 2010 Scenario 5. As Scenario 4, but requiring a 90 % reduction in the emissions from wood burning (90 % from Reference 2010). 1 002 persons exposed beyond the target value.

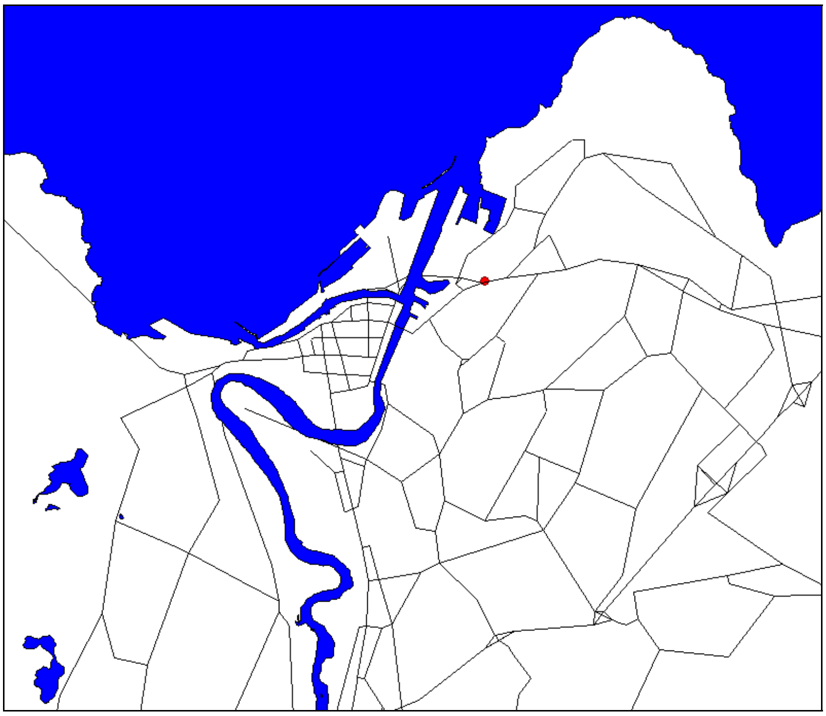

Figure 5.14: Trondheim 2010 Scenario 6. As Scenario 4 + 50 % reduction in traffic volume (50 % from Reference 2010). 36 persons (one building) exposed beyond the target value.

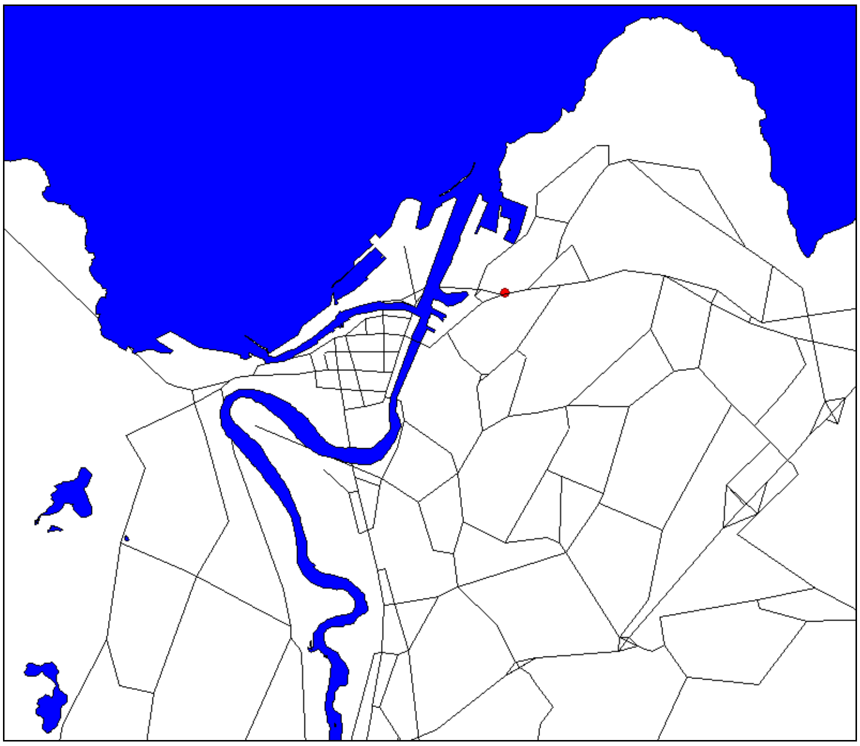

Figure 5.15: Trondheim 2010 Scenario 7. As Scenario 5 + 50 % reduction in traffic volume (50 % from Reference 2010). 36 persons (one building) exposed beyond the target value.

6 Discussion of the modelling results

The reason for the relatively large change in number of exceedances between the reference 2010 and the various scenario simulations, is that only the reference calculation estimate exceedances in the grid squares. As seen in the tables presented in Section 4, the maximum 8th highest daily grid value in the Reference 2010 simulation for Oslo reached 58,5 µg/m^3. This means that all of the persons living inside grid cells with (the 8th highest) values above 50 µg/m^3 are considered as exposed beyond the “National Target”. In the Reference 2010 simulation for Trondheim the corresponding maximum grid value was 53,2 µg/m^3. For all of the scenario simulations the 8th highest daily grid values were below 50 µg/m^3 (46,7 µg/m^3 in Oslo and 39,4 µg/m^3 in Trondheim for Scenario 2), and therefore the number of exceedances is reduced significantly.

From the Reference 2010 results presented in the tables in Section 4, it is seen that a moderate decrease in the grid values are needed to get below the 50 µg/m^3 target value (a 8,5 µg/m^3 decrease in Oslo and a 3,2 µg/m^3 decrease in Trondheim). However, a substantial reduction is needed for building points close to the major road network (a 224 µg/m^3 decrease in Oslo and a 214 µg/m^3 decrease in Trondheim). This clearly indicates that strong traffic-oriented measures are needed in order to reach the goal. Furthermore, the Scenario 0 simulation (see start of Section 3) clearly demonstrates that all local sources apart from road traffic and domestic wood burning are of marginal importance, and the emphasize should therefore be put on measures reducing the contribution from these two major sources.

Based on this reasoning Scenario 1 was defined by requiring 95 % of the vehicles to be equipped with un-studded tyres. This measure effectively reduced the maximum 8^{th} daily concentrations in the building points, and even brought the grid values below the 50 μg/m^3 target value in both cities. For the rest of the scenarios, in which Scenario 2, 3 and 5 are measures on domestic wood burning and Scenario 4, 6 and 7 are further traffic measures, the 95 % un-studded tyres portion was retained. Since, after the inclusion of the Scenario 1 measure, the 8^{th} highest daily grid value is below 50 μg/m^3, the rather large restrictions on domestic wood burning emissions (Scenario 2, 3 and 5) are of moderate importance when considering the exceedance numbers. The reason for this is that the influence from these measures on the 8^{th} highest grid and building point concentrations are of minor consequence, as seen from the values presented in the tables of Section 4. The additional traffic measures (Scenario 4, 6 and 7), on the other hand, have a much more profound effect on the 8 highest building point concentrations, and seems therefore more appropriate. Of these measures, the one where the traffic speed on roads with speed limits higher than 60 km/h is reduced to 60 km/h (Scenario 4) seems promising. The reason why this measure is effective is that the strength of the traffic induced suspension of PM_{10} increases approximately proportional to the square of the traffic speed. The 50 % reduction in traffic volume (i.e., number of vehicles) in Scenario 6 and 7, has of course an even stronger impact than the speed reduction, but is also a more drastic measure to implement. In summary, the traffic measures introduced in Scenario 1 (95 % un-studded vehicles) and Scenario 4 (speed limits above 60 km/h reduced to 60 km/h) are strongly recommended, and in order to further reduce the number of inhabitants exposed beyond the target value, a combination of the other measures should be applied as found necessary. It should be noted, however, that the conclusions above are tightly linked with the goal at hand. If, instead, the aim had been to design effective abatement measures to reduce the huge number of exceedances in the Reference 2005 situation, reductions in emissions from domestic wood burning would probably have been of greater significance. This assertion is based on the fact that emissions from domestic wood burning are distributed rather homogenously over most of the city areas, and a rather modest reduction in the grid square concentrations could bring a large number of the inhabitants below the exceedance level.

Even with the strongest measures invoked (Scenario 6 and 7) the exposure calculations still predict exceedances in some few buildings. When interpreting these results, however, the model uncertainties should be kept in mind. These buildings are typically located close to tunnel mouths or near major road junctions with appurtenant bridges, tunnels or steep road cuttings. When estimating 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. In the scenarios where only a limited number of buildings are indicated as exceedance locations, these areas should instead be regarded as potential ”hot-spots”, and subsequently be subjected to a more detailed investigation.

Another aspect of the results that need more consideration is the influence of the regional background levels. Both in the Reference 2010 and in the scenario calculations, we have applied the observed regional background values of PM_{10} (measured at the nearest regional EMEP station, Birkenes) from the simulation period in 2005. These values have not been adjusted, even though it is to be expected that the background concentration of PM_{10} will decrease towards 2010 as a result of reduced European emissions. The applied values should therefore be regarded more as an upper bound of the regional contribution, and any reduction in these levels will lower the estimated number of persons exposed above the "National Target" accordingly.

Moreover, there is a considerable distance between the background stations and the city areas under consideration. The application of these data at the model boundaries therefore depend heavily on the assumption that the regional background vary slowly both in time and space. The fulfilment of this assumption is particularly important when performing real time simulations, since in this case the success of the calculations are judged by the actual fit with observations. For projections of the type considered here, however, the exact timing of the boundary values are not so important. For this type of application the most important aspect is that the boundary values are varying in a realistic manner; i.e., with a correct statistical behaviour.

The 16th highest daily PM_{10} values observed in Oslo at a street station (RV4) and at a nearby urban background station (Aker Hospital), and at the EMEP background station Birkenes during the 2005 simulation period are presented in Figure 6.1 below.

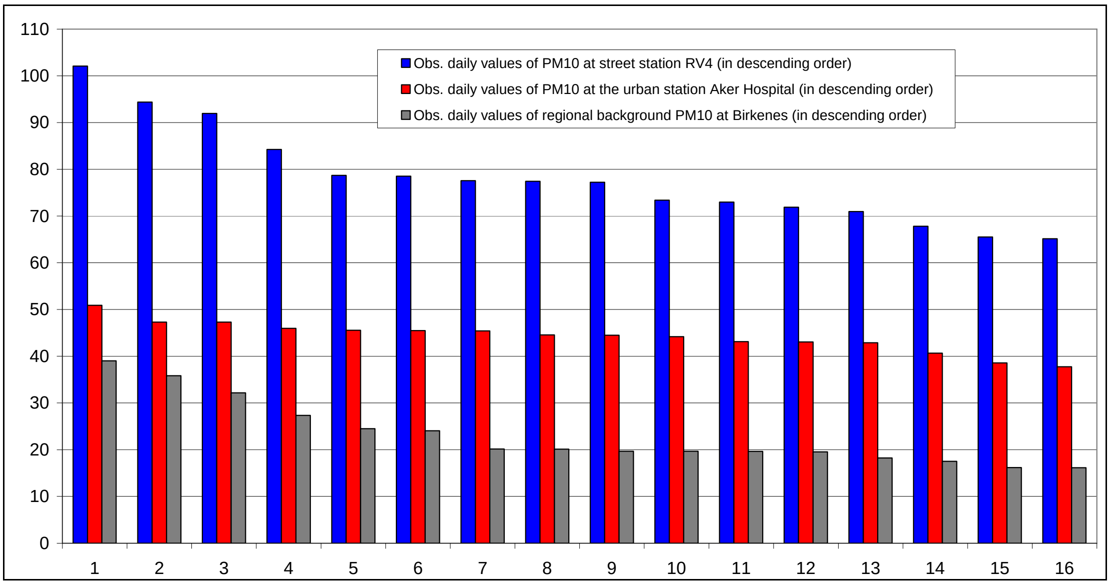

Figure 6.1: The 16 highest daily PM_{10} values observed in Oslo at RV4 (street station), Aker Hospital (urban background station), and at the regional background station at Birkenes (background station in the regional EMEP network). These values are selected from the simulation periods: 1. January – 31. March, and 1. October – 31. December 2005.

The four highest values at the regional background station are all from an episode that occurred in the middle of October 2005, when extraordinary high values were measured at this station. The dates of these four values are the 8th, 12th, 13th, and 11th of October, respectively. It is interesting to note that the 2nd, the 12th, and the 15th highest value observed at Aker hospital also are from this period, i.e., from the 13th , 12th and 11th of October, respectively, and a substantial portion of these concentrations are probably of regional origin. As seen from Figure 6.1, the highest daily values observed at the street station (RV4) are significantly higher than those at the nearby station at Aker Hospital, reflecting the strong impact from the passing traffic at RV4. Furthermore, for the street station none of the 16 highest values are measured during the October period. The highest value during this regional episode occurred at the street station on the 12th of October, with a value of 50.2 $\mu g/m^3$. This was the 34th highest value recorded at this station during the 212 days simulation period, and illustrates that the regional contribution is of less influence close to the main road network where the highest ambient particle concentrations are found.

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Appendix A

Description of the applied method for scaling the emissions from domestic wood burning in Oslo and Trondheim

The basic parameters used in the estimation of the PM_{10} emissions from domestic wood burning are listed below. These parameters are also used when constructing scaling factors for these emissions for the year 2005 and for the “Reference” and “Scenario” simulations for 2010.

F^{02} [ton wood/year]	: Consumption of wood per unit time, valid for the year 2002.
Q^{02} [kg PM_{10}/year]	: Emissions of PM_{10} per unit time, valid for the year 2002.
a^{new} = 6.2 kg/ton	: Emission factor for new clean-burning ovens.
a^{old} = 33.0 kg/ton	: Emission factor for old ovens.
a^{fp} = 17.3 kg/ton	: Emission factor for open fireplaces.
$\Delta F^{02\text{-}05}$; $\Delta F^{05\text{-}10}$	: Change (in percentage) of the wood consumption between the given years indicated by the superscript.

The above parameters are the one used for Oslo. For Trondheim the superscript ^{02} is replaced with ^{03}, since the wood consumption data for this city are valid for 2003. Knowing the values of the above parameters we now seek a scaling factor, $k^{02\text{-}05}$, such that the emission for the selected year can be expressed simply as:

.

<u>Oslo:</u>

In ***2002*** 18 % of the consumed wood was burnt in new clean-burning ovens, 60 % in old ovens and 22 % in open fireplaces. In ***2005*** this was changed to 30 % clean-burning, 48 % old and 22 % open, and in ***2010*** it is anticipated that it would change to 50 % clean-burning, 28 % old and 22 % open.

Estimations for Oslo indicate an increase in yearly wood consumption from 15700 tons in 2002 to 16500 tons in 2005. This means an increase of 5.1 %, which further imply that . Moreover, a yearly increase of 1 % has been estimated for the years after 2005, which gives .

The total PM_{10}-emissions from domestic wood consumption for 2005 and 2010 can therefore be computed from the following scaling expressions

,

and the scaling factors for the two years are therefore 0.914 (emission reduction of 8.6 % from 2002 to 2005) and 0.721 (emission reduction of 27.9 % from 2002 to 2010), respectively.

For Scenario 3, 4 and 7: For these scenarios a complete transition to new clean-burning ovens was required. Here we take the Reference 2010 emission inventory as starting point (which is already downscaled by the factor of 0.721 from the

2002 emissions), assume no change in the wood consumption, and construct the following scaling factor

This amounts to an emission reduction of 62 % from domestic wood burning from Reference 2010 emissions.

For Scenario 5 and 6: For the scaling factor to become as low as 0.1 (90 % emission reduction from Reference 2010) a further reduction in the wood consumption is required in addition to the complete transition to new clean-burning ovens. Thus, the consumption must change by a factor 0.1/0.384 = 0.26; i.e., a reduction in the wood consumption of 74 % with respect to the consumption assumed in Reference 2010.

For Scenario 8: When keeping the percentage of open fireplaces, and only exchange old ovens with new, the scaling factor becomes

which represents a reduction in emissions from domestic wood burning of 47 % as compared to Reference 2010.

<u>Trondheim:</u>

In ***2003*** 25 % of the consumed wood was burnt in new clean-burning ovens, 72 % in old ovens and 3 % in open fireplaces. In ***2005*** this was changed to 30 % r clean-burning, 67 % old and 3 % open, and in ***2010*** it is anticipated that it would change to 50 % clean-burning, 47 % old and 3 % open. No change in wood consumption was found in Trondheim between 2003 and 2005, which imply that . However, the same yearly increase in wood combustion from 2005 to 2010 as applied in Oslo (1 %) has been anticipated for Trondheim, that is .

The total PM_{10}-emissions from domestic wood consumption for 2005 and 2010 for Trondheim can therefore be computed from the following scaling expressions

and the scaling factors for the two years are therefore 0.948 (emission reduction of 5.2 % from 2003 to 2005) and 0.778 (emission reduction of 22.2 % from 2003 to 2010), respectively.

As shown above for Oslo further downscaling can then be applied for the different abatement scenarios for 2010. The scaling factor, for instance, for the complete transition to clean-burning ovens (without changing the consumption estimate)

To reach a downscaling of 0.1 (90 % reduction of the 2010-emissions) a further downscaling of the wood consumption of 0.1/0.324 = 0.31 is required, i.e., a reduction in consumption of 69 %.

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REPORT SERIES SCIENTIFIC REPORT	REPORT NO. OR 82/2006	ISBN 82-425-1811-4 (p) 978-82-425-1876-7 (e) ISSN 0807-7207	
DATE	SIGN.	NO. OF PAGES 26	PRICE NOK 150,-
TITLE Evaluation of abatement measures for PM_{10} in Oslo and Trondheim for the year 2010		PROJECT LEADER Leiv Haavard Slørdal	
		NILU PROJECT NO. O-106107	
AUTHOR(S) Leiv Håvard Slørdal, Harold McInnes and Herdis Laupsa		CLASSIFICATION * A	
		CONTRACT REF. Roar Gammelsæter	

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ABSTRACT
Commissioned by SFT, NILU has performed dispersion and exposure calculations to investigate the extent of abatement measures needed in order to fulfil the goals defined in the "National Air Quality Target for PM_{10}". This target specifies that at most 7 days during a year the inhabitants are allowed exposure levels of PM_{10} above an average value of 50 µg/m^3. This target is to be met within the year 2010. The simulation results show that traffic specific measures are clearly needed. Especially, it is recommended that as much as 95 % of the vehicles need to be equipped with un-studded tyres. Furthermore, a reduction in vehicle speed to a maximum allowed speed of 60 km/h gives promising results. In order to further reduce the number of inhabitants exposed beyond the target value, a combination of additional traffic measures and specific measures to reduce emissions from domestic wood burning should be considered.

NORWEGIAN TITLE
Tiltaksberegninger for PM_{10} i Oslo og Trondheim for 2010.

KEYWORDS		
Abatement measures	PM_{10} calculations	Norwegian cities

ABSTRACT (in Norwegian)
På oppdrag fra SFT har NILU gjennomført sprednings- og eksponeringsberegninger for å undersøke hvilke utslippsreduserende tiltak som er nødvendige for å oppfylle "Nasjonale mål for luftkvalitet for PM_{10}". I henhold til dette målet skal befolkningen ikke utsettes for mer enn 7 døgn med døgnkonsentrasjoner av PM_{10} over 50 µg/m^3 i løpet av ett år. Dette målet skal nås innen 2010. Beregningsresultatene viser klart at spesifikke trafikktiltak er nødvendige for å innfri nasjonale mål for luftkvalitet. Spesielt anbefales en overgang til 95 % piggfrie biler. Videre viser resultatene at tiltak der trafikkhastigheten reduseres til 60 km/t på alle veier med høyere tillatt hastighet er lovende. For å oppnå ytterligere reduksjon av antall innbyggere utsatt for overskridelser, må deretter øvrige trafikktiltak og spesifikke tiltak mot vedfyring vurderes.

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