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Emissions from traffic with alternative fuels - air pollutants and health risks in 2020

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Summary

In this study the health risks associated with emissions to air from traffic for different possible fuels are studied through air dispersion modelling for the year 2020. The focus is on health risks in the Västra Götaland Region in Sweden but changes in emissions are calculated for the whole Europe. The study includes the following fuels: replacement of petrol with diesel for light duty vehicles (LDV); natural gas for LDVs; natural gas for heavy duty vehicles (HDV); ethanol for HDVs; biodiesel for HDVs; dimethyl ether (DME) for HDVs. The analysis and modelling are done in four steps: 1) Creating an emission model. This is done for Europe and in more detail for Västra Götaland. 2) Dispersion modelling using EMEP (the European Monitoring and Evaluation Programme) for Europe and TAPM (The Air Pollution Model) for the Västra Götaland Region. 3) Calculation of population exposure to different air pollutants in the Västra Götaland Region and 4) health risk assessments.

The emission scenarios for 2020 are constructed for all listed fuels and dispersion modelling is applied to some of them to obtain the human exposure to key air pollutants in the region. The dispersion modelling is performed with the EMEP model for extended Europe and the data obtained are used as boundary conditions for the model for the Västra Götaland region. In the latter, detailed traffic and emissions scenarios are used together with the TAPM model to obtain concentration levels and population exposure. The differences in health impacts are then assessed.

For the scenario where all new passenger cars are fuelled by diesel the emissions of nitrogen oxides (NO_X) and particulate matter (PM) are higher than in the Base scenario while the emissions of non-methane volatile organic compounds (NMVOC) are lower. This gives a higher exposure to PM, black carbon (BC) and NO_X while the ozone (O_3) exposure is lower. The lower emissions of NMVOC could contribute to the decrease in ozone exposure, however our model results show that also an increase in emissions of NOx decreases the ozone exposure due to titration of ozone by the fresh NOx emissions close to the source.

When replacing diesel with compressed natural gas (CNG) in HDV there are significant reductions in NO_X and PM emissions from this vehicle category. The exposure is notably lower for NO_X while the difference for O_3 is small. The O_3 exposure is influenced by both the lower NO_X emissions and the lower NMHC emissions.

For the scenario with ethanol for HDV the emissions are lower compared with the Base scenario for NO_X, PM and NMVOC and so is also the exposure to these substances while the O_3 exposure is somewhat higher. The latter has to do with the reduced emissions of NO_X.

For the scenario with CNG instead of petrol in Otto LDV the differences in emissions for NO_X and PM are small while the NMVOC are lower since the fraction of methane in the hydrocarbon emissions would be higher. With CNG also replacing diesel for LDV the differences in emissions are larger. The emissions of NMVOC in this scenario become larger due to the cold-start emissions.

For the biodiesel in HDV scenario NO_X emissions increases while PM emissions are reduced. For the DME scenario emissions of both PM and NO_X are lower. Changes in NMVOC scenarios are small for these scenarios.

In comparison with the Base scenario, reducing traffic by 10% is estimated to avoid 13.6 preterm deaths per year due to reduced NO_X exposure, while the increased NO_X emissions in the Diesel in LDV scenario is estimated to increase the number of deaths by almost 13 per year. These are the largest impacts on health

that we calculate in the study. However, it should be noted that the assumed exposure-response relation for NO_X is not adjusted for some pollutants in the vehicle exhaust mixture, such as particle mass or soot.

The estimated health impacts from changes in ozone exposure in comparison with the Base scenario are small. The Diesel in LDV scenario is estimated to save 3.3 preterm deaths per year explained by the higher NOx emissions locally reducing ozone levels.

In comparison with the Base scenario, lower PM exposure for the E95 in HDV scenario is estimated to avoid 8.3 preterm deaths per year, while the Diesel in LDV scenario is estimated to increase the number of deaths by 4.3 per year. These are the second largest impacts on health that we calculate in the study.

The estimated health impacts from changes in BC exposure in comparison with the Base scenario are small for all scenarios, and share the same patterns as found for NOx and PM.

Sammanfattning

I denna rapport studeras hälsorisker förknippade med utsläpp till luft från trafik med olika möjliga bränslen genom spridningsmodellering för år 2020. Fokus ligger på hälsorisker inom Västra Götalandsregionen i Sverige men förändringar i utsläpp beräknas för hela Europa. Studien omfattar följande bränslealternativ: byte från bensin till diesel för lätta fordon (LDV); naturgas för LDV; naturgas för tunga fordon (HDV); etanol för HDV; biodiesel för HDV; dimetyleter (DME) för HDV. Analys och modellering görs i fyra steg: 1) Utsläppsmodell. Detta görs för Europa och mer i detalj för Västra Götaland. 2) Spridningsberäkningar med hjälp av EMEP (European Monitoring and Evaluation Programme) för Europa och med TAPM (The Air Pollution Model) för Västra Götalandsregionen. 3) Beräkning av befolkningsexponering för olika luftföroreningar i Västra Götalandsregionen och 4) Hälsoriskbedömning.

Utsläppsscenarier för 2020 konstrueras för de studerade bränslena och spridningsmodellering tillämpas på ett antal av dem för att beräkna exponeringen för viktiga luftföroreningar. Spridningsberäkningarna utförs med EMEP-modellen för utökade Europa och uppgifterna används som randvillkor till modellen för Västra Götaland där detaljerade trafik- och utsläppsscenarier används tillsammans med TAPM modellen för att beräkna haltnivåer och befolkningsexponering. Skillnaderna i hälsoeffekter bedöms sedan.

För scenariot där alla nya personbilar drivs med diesel är utsläppen av kväveoxider (NOx) och partiklar (PM) högre än i basscenariot medan utsläppen av flyktiga, icke-metan organiska föreningar (NMVOC) är lägre. Detta ger en högre exponering för PM, black carbon (BC) och NOx medan ozon (O3) -exponeringen är lägre. Lägre utsläpp av NMVOC kan bidra till minskningen av ozonexponeringen, men modellresultaten visar att även en ökning i utsläppen av NOx minskar ozonexponeringen p g a titrering av ozon.

När diesel ersätts av med komprimerad naturgas (CNG) i HDV fås betydande minskningar i NOx- och PM emissionerna från denna fordonskategori. Exponeringen blir framför allt lägre för NOx medan skillnaden för O3 är liten.

För scenariot med etanol för HDV är utsläppen lägre jämfört med basscenariot för NOx, PM och NMVOC, liksom exponering för dessa ämnen medan O3-exponeringen är något högre. Det senare har att göra med de minskade utsläppen av NOx.

För scenariot med CNG istället för bensin i LDV är skillnader i utsläpp för NOx och PM små medan NMVOC-emissionerna är lägre eftersom andelen metan i kolväteutsläppen är högre. Då CNG också ersätter diesel för LDV är skillnaderna i utsläppen större. Utsläppen av NMVOC blir då större på grund av kallstartutsläppen.

För biodiesel i HDV scenario ökar NOx-utsläppen medan PM-utsläppen minskar. För DME scenariot är utsläppen av både PM och NOx lägre. Förändringarna för NMVOC är liten för dessa scenarier.

I jämförelse med basalternativet ger minskad trafik med 10% uppskattningsvis 13,6 undvikna förtida dödsfall per år på grund av minskad NOx-exponering, medan de ökade NOx-utsläppen i Diesel i LDV scenariot bedöms öka antalet dödsfall med nästan 13 per år. Detta är de största förändringarna i inverkan på människors hälsa som vi funnit i studien. Det bör dock noteras att förmodade dos-respons förhållandena för NOx inte justeras för vissa föroreningar i fordonens avgaser, till exempel partikelmassa och black carbon.

De beräknade hälsoeffekterna av förändringar i ozonexponeringen är små. Diesel i LDV scenariot beräknas spara 3,3 förtida dödsfall per år.

I jämförelse med basalternativet beräknas lägre PM-exponering för etanol i HDV scenario leda till 8,3 färre förtida dödsfall per år, medan Diesel i LDV scenariot bedöms öka antalet dödsfall med 4,3 per år. Detta är de näst största förändringarna i inverkan på människors hälsa som beräknats i studien.

De beräknade hälsoeffekterna av förändringar i BC-exponering jämfört med basalternativet är små för alla scenarier och delar samma mönster som finns för NO_X och PM.

1 Introduction

Facing the problems with global warming and the diminishing supplies of oil, alternative fuels are becoming more and more important for road traffic. Several alternative fuels are being tested such as biogas, alcohols and dimethyl ether (DME).

The main discussion points regarding the environmental performance for these fuels are related to the production. In this study the fuel production is however not in focus but rather the impact from emissions stemming from vehicles running on these fuels. Although the emissions from the use of these fuels are not as well characterised as the emissions from petrol and diesel engines, there are some notable differences in the emissions. This relates to some extent to the emissions of nitrogen oxides (NO_X) and particulate matter (PM) and to the composition of the emitted organic compounds.

These differences in emissions will potentially give different impacts on health and the environment. This can be both through risks linked to the primary emissions and to secondary products formed in the atmosphere. In order to assess the health risks it is necessary to calculate the emissions in space and time, describe the dispersion and chemical reactions taking place in the atmosphere and to calculate the exposure to humans.

In this study the health risks associated with emissions from traffic are studied in four steps: 1) Creating an emission model. This is done for Europe using the EMEP (the European Monitoring and Evaluation Programme) gridded emission database with the scenarios modified with help of GAINS emission database for Europe (GAINS, 2015) and Tremove traffic database (Transport & Mobility Leuven, 2007), for Sweden, and more in detail for the region Västra Götaland, using HBEFA v.3.1 (Keller et al., 2007; Hausberger et al., 2009); 2) Dispersion modelling using EMEP for Europe and TAPM for the Västra Götaland Region; 3) Calculation of population exposure to different pollutants and 4) Health risk assessments. The model year is 2020.

In the present study the change in impact on health risks between the following scenarios are studied.

1. Base scenario 2011. Based on traffic data for 2011. Emission modelling.

2. Base scenario 2020. Based on traffic prognosis for 2020. Emission and dispersion modelling.

3. Scenario 2020 with all road traffic emissions decreased by 10%. Emission and dispersion modelling.

4. Diesel in LDVs scenario 2020. In this scenario all petrol fuelled light duty vehicles are replaced by diesel fuelled vehicles. Emission and dispersion modelling.

5. Natural gas for LDVs 2020. In this scenario all light duty vehicles with Otto engines (petrol cars) are replaced with gas vehicles. Emission modelling.

6. Natural gas for HDVs 2020. In this scenario all heavy duty vehicles are assumed to run on CNG. Emission and dispersion modelling.

7. Ethanol for HDVs 2020. In this scenario all heavy duty vehicles are assumed to run on ED95. Emission and dispersion modelling.

8. Biodiesel for HDVs 2020. In this scenario all heavy duty vehicles are assumed to run on FAME (B-100). Emission modelling.

9. DME for HDVs 2020. In this scenario all heavy duty vehicles are assumed to run on DME. Emission modelling.

The fuel switch in the different scenarios is applied to the EMEP-model domain (covers Europe and surrounding parts of North Africa and Asia) and the health impact is studied for the region of Västra Götaland in Sweden. The emission scenarios for 2020 are constructed and dispersion modelling is applied to some of them to obtain the human exposure to key pollutants in the region. The dispersion modelling is performed with the EMEP model for extended Europe and the data obtained are used as boundary conditions for the model for the Västra Götaland region. In the latter detailed traffic and emissions scenarios are used together with TAPM (The Air Pollution Model) to obtain concentration levels and population exposure. The differences in health impacts are then assessed.

2 Methods

2.1 Overview

The overall objective of the present study is to compare the health impacts in the Västra Götaland region for different emission scenarios for 2020, as described in Chapter 1. The study comprises:

- emission calculations
- dispersion modelling
- population exposure analysis
- health impact assessment.

Emission calculations are carried out for all scenarios described in Chapter 1. Five of these emission scenarios are selected and used as input to the dispersion modelling, exposure calculation and health impact assessment for the Västra Götaland region (see **Error! Reference source not found.**b). The dispersion modelling is conducted using the TAPM model. In order to calculate the pollutants entering this region (the boundary conditions for TAPM) the larger scale EMEP (see **Error! Reference source not found.**a) model is applied to the extended European region.

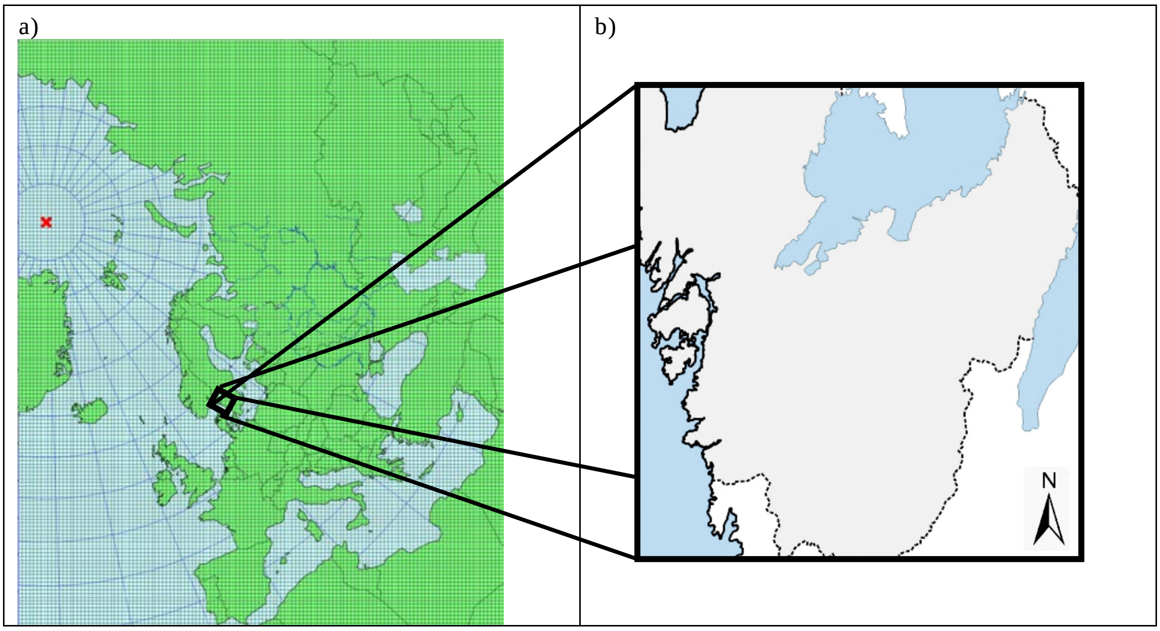

Figure 1 **The model area for a) the EMEP model and b) the TAPM model. For the TAPM modelling the indicated square in b) is the model domain and the defined map is the Västra Götaland region.**

2.2 Description of scenarios

All emission scenarios investigated in the project are based on year 2020 emissions, the 'current legislation' scenario, which means that only the current and already agreed legislation will be in effect. Within the scope of this project we investigate a set of traffic scenarios where vehicles with Euro-5 and Euro-6 technology standard are replaced with vehicles using the alternative fuels. The scenarios consider switch for light- or heavy-duty vehicles separately. For the CNG scenario we assume use of dual-fuel engines in HDVs driving on CNG. However, the differences between emissions from the Otto and dual-fuel CNG engines are unclear and our study of data from the literature and from the industrial partners is inconclusive in this sense. Additionally, one scenario where all light duty vehicles are diesel vehicles is investigated. Impacts of the fuel switch to CNG and ED95 in heavy-duty vehicles and impact of the switch of petrol to diesel vehicles are investigated with the dispersion models while impacts of the other scenarios are investigated only through modelling of the traffic emissions. To obtain impact of the road traffic in total a model calculation with the traffic emissions decreased by 10% is calculated, employing both the traffic emissions and dispersion models. The scenarios are listed in Table 1

.

Table 1 Scenarios investigated within the project (all based on year 2020).

Scenario	Modelling of traffic emissions	Dispersion modelling
Base scenario 2020	+	+
Diesel in LDV*	+	+
CNG in LDV*	+	-
CNG in Otto-engine LDV*	+	-
CNG in HDV*†	+	+
ED-95 in HDV*	+	+
B-100 in HDV*	+	-
DME in HDV*	+	-
Road traffic -10%	+	+

* Euro-5 and Euro-6 technology standard vehicles

† Dual-fuel engine

2.3 Emission factors

2.3.1 Basic EF dataset

The basic set of emission factors (EF) from road vehicles are extracted from HBEFA v.3.1 (Keller et al., 2007; Hausberger et al., 2009). In HBEFA vehicles are divided into categories:

1. Passenger cars (PC)
2. Light commercial vehicles (LCV)
3. Heavy goods vehicles – rigid trucks (HGV-RT)
4. Heavy goods vehicles – articulated trucks, truck + trailer (HGV-AT/TT)
5. Urban buses (UB)
6. Coaches
7. 2-wheel vehicles (MC)

These categories are further divided into sub-segments with different vehicle size categories, fuels, in case of MCs 2-stroke and 4-stroke, and into emission technology classes (from pre-Euro to Euro 6). In our Base scenario calculation fuels considered are petrol and diesel; for PCs, LCVs and buses also CNG and ethanol.

HBEFA contains a number of road categories and driving patterns that affect emission factors within the vehicle sub-segments. For Sweden the HBEFA database is available with traffic activity data that enable calculation of EFs for four different road categories: Rural motorway (R-MW), rural non-motorway (R-NMW), urban motorway (U-MW) and urban non-motorway (U-NMW). For this project we subtract EFs for the above described vehicle type - emission standard – fuel-used sub-segments from HBEFA for the 4 different road categories in Sweden and also for a selection of 16 driving patterns covering type of road, allowed maximum speed and traffic density.

The basic set of EFs for diesel and petrol (together with CNG and E-85 for PCs, LCVs and buses up to Euro 4) specific for the seven vehicle categories, the pre-Euro – Euro 6 emission technologies, the four road categories and the 16 traffic pattern categories are collected in a database for the years 2011 and 2020. The database includes two sets of emission factors, one for specific traffic situations and a second one aggregated for the road categories. These EFs can be applied to the projected traffic volumes.

The database includes also emission factors for cold start emissions for PCs, LCVs and motorcycles and evaporative emissions of VOCs for petrol and E-85 fuelled PCs and LCVs and non-exhaust emissions of PM from tyre and break wear and from the road abrasion (not resuspension). The EFs for excessive cold start emissions (EFc-start) are in HBEFA given per start. The emissions per start are recalculated to factors per vehicle kilometre (EFc-vehkm) using the formula

EFc-vehkm = [EFc-start * vehkm-c/vehkm-tot(TP)]/0.91

where vehcm-c/vehkm-tot(TP) is the ratio of cold-start vehicle-kilometres to total vehicle-kilometres driven in certain traffic pattern and 0.91 is the mean length of one cold start driving. These values come from the study of Ericsson and Larsson (2007) for Malmö.

The evaporative emissions include running losses, hot-soak losses and diurnal losses. The running losses are calculated using emission factors per vehicle km, the hot-soak losses use emission factor per vehicle stop and a methodology similar to the cold-start emission calculation was used to apply these factors on the available traffic data, while the diurnal losses, being very small for the Euro-5 and Euro-6 emission standard vehicles, are neglected.

The database includes also traffic volumes for Sweden for the different road categories, and the above described emission standards and fuels used, allowing calculation and preliminary comparison of the traffic emissions for Sweden for the studied scenarios. These results are shown in Chapter 3.2.

2.3.2 EF for alternative fuels in Copert/Transphorm database

The calculation of EF for alternative fuels is based on the Copert/Transphorm database of EFs (Gkatzoflias et al. (2012), Vouitsis et al., 2013). This database contains EFs for the same vehicle sub-segments and technology standards as HBEFA. The Copert/Transphorm database distinguishes EFs for road categories, in difference from HBEFA the urban category is not divided into U-NMW and U-MW. Since the project goal is to study the effects of a fuel switch in the future vehicle fleet, fuel switch is considered only for vehicles with Euro-5 and Euro-6 technology standards. In 2020 vehicles with Euro 5 and Euro 6 standard makes up 74 – 76% of the traffic activity (=veh.km) for LDVs and 86 – 94% for HDVs. At this point we also compare EFs from HBEFA with Copert in order to make the relative emission factors consistent with HBEFA. A literature review and data made available from the industrial partners in the project are used to verify and in some cases modify the relative EFs for the alternative fuels.

2.4 Traffic data

The European-scale model uses EMEP gridded emissions. The scenarios in the EMEP model are treated through changes in national total emissions from traffic. For each European country (EU 27 + Norway and Switzerland), the relative contributions of Urban, Rural-MW and Rural NMW to the total traffic volumes are calculated using the TREMOVE database (Transport & Mobility Leuven, 2007) in order to calculate the aggregated relative emission factors for the alternative fuels for each country. The relative contributions from the different vehicle categories and fuels to the total traffic emissions are based on the GAINS emission database (GAINS, 2015).

Traffic activity data for Sweden are included in the project's EF database for all available vehicle types, emission technologies, fuels used and road categories, enabling calculation of the total Swedish emissions for these segments in the different scenarios. Figure 2 shows composition of the Swedish vehicle fleet in the years 2011 and 2020.

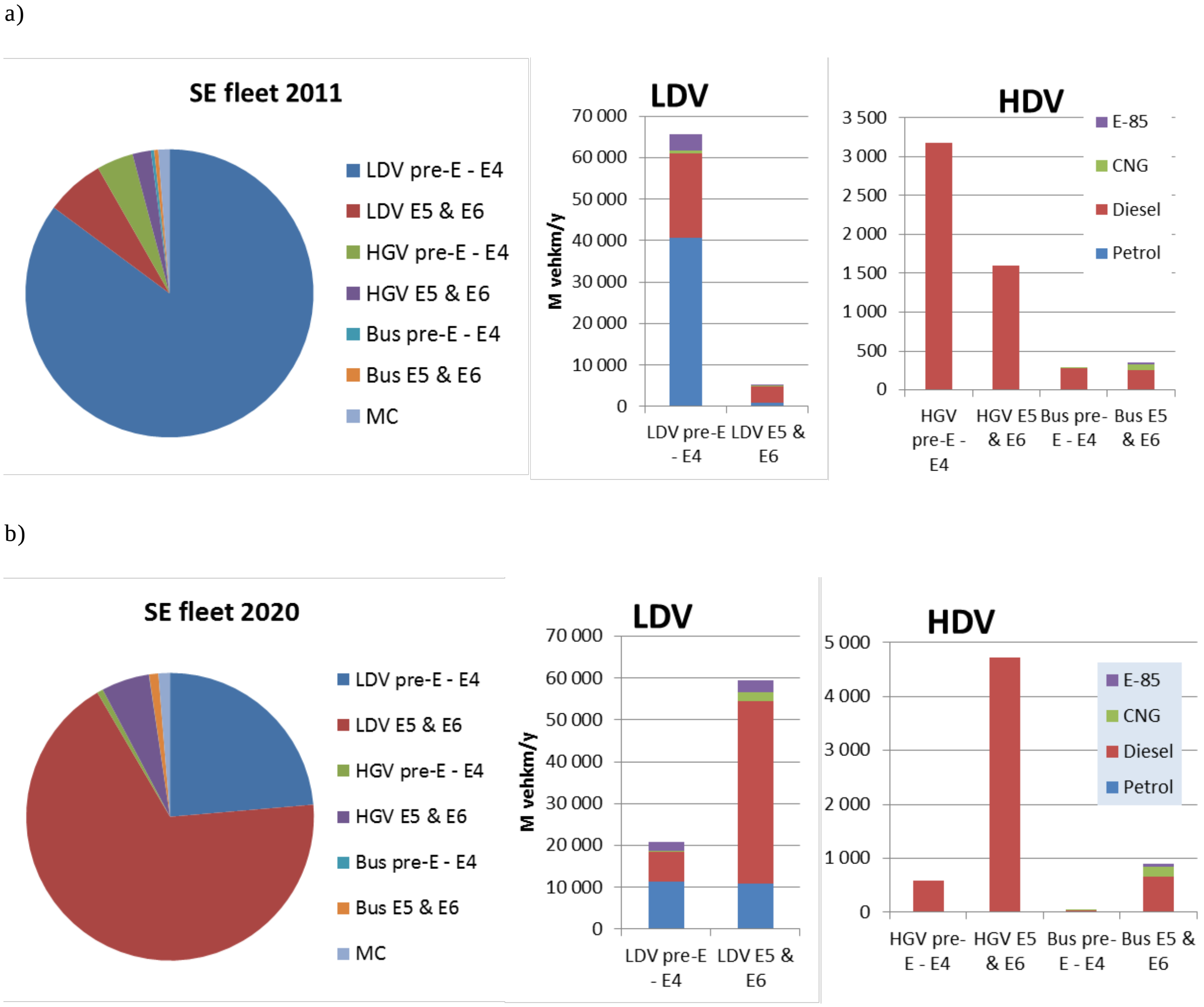

Figure 2 Composition of the Swedish road traffic fleet, with respect to the vehicle kilometres driven, in 2011 and in the Base scenario in 2020 with respect to the vehicle categories and emission standards (pie charts) and with respect to the fuel used by the different vehicle categories (column charts).

The project involves emissions and hence also traffic data on two different levels. On the large scale the above described gridded traffic emissions for Europe with support of the TREMOVE and GAINS databases and the project's EF database are used to calculate the scenarios. The emission model for Västra Götaland is based on a traffic activity database of the Environment Administration, City of Gothenburg (GMFV database). This database includes an excerpt of the Swedish Transport Administration's national road database NVDB for Västra Götaland with the road network, associated coordinates and traffic flows on the national roads, which are completed with traffic flows on the municipal roads based on extensive regional measurements. The roads in the GMFV database are classified according to the driving patterns used in

HBEFA. For this project we simplify the driving patterns to 8 classes, merging road classes with low or no representation with similar ones with high representation. Each road has a time variance associated which distributes the traffic flow over day, week and monthly variations. There is also a critical flow for the road, if the flow is exceeding that value the emission factors for stop and go is used instead of the one for the fluent traffic flow.

The roads are divided into straight line segments that the modelling software can use as line sources. There are a total of 78 706 segments in the database. Table 2 shows statistics for the roads.

Table 2 The traffic data statistics for the TAPM model domain for Västra Götaland.

HBEFA (and similar types)	Number of segments	Million Vehicle km/year
RUR/MW 110	2124	3426
RUR/MW 90	536	620
RUR/Trunk 90	6614	3160
RUR/Trunk 70	35222	3046
RUR/Distr 70	7798	953
URB/Trunk-City 50	1218	246
URB/Distr 50	15496	1398
URB/Access 40	9698	596
Total	78706	13447

2.5 Emissions

2.5.1 Traffic emissions

As already described, the European-scale model uses EMEP gridded emissions. The relative emission changes in the scenario runs are then calculated for each European country. The relative contributions from different vehicle categories and fuels, and from the evaporative and non-exhaust emissions to the total traffic emissions in the individual European countries, are calculated with GAINS. Emissions are calculated for CH4, CO, NOx, NO_2, $PM_{2.5}$, total suspended particles (TSP) and VOC.

To apply the relative emission factors for the alternative fuels on these contributions, the TREMOVE database is used to weight the emission factors for the different road categories. We also consider changes in evaporative emissions due to the fuel switch. Emissions of black carbon (BC) and benzene are calculated from the BC/PM2.5 and benzene/VOC ratios in the Copert database (Vouitsis et al, 2013).

For Västra Götaland the traffic emissions are calculated using a database with the above described EFs and the traffic data from the GMFV database. To apply the EFs for traditional and alternative fuels from the project's EF database based on HBEFA, the emission factors within the vehicle category sub-segments need to be aggregated into the vehicle categories included in the GMFV database, which is LDV (including MC, PC and LCV), HGV and Bus. This is done using the traffic activity data for the HBEFA vehicle types, emission technologies and road categories for Sweden which means that we have assumed an average Swedish composition of the fleet within these three categories. For each road segment the emission is calculated for each hour using the traffic flow time variance and emission factors for LDV, HGV and Bus for that road category. The calculated emissions are then used as input for the TAPM modelling.

2.5.2 Other emissions

The chemical reactions between different pollutants vary depending on the composition of the pollutant species in the atmosphere. Therefore, it is important to include other emission sources, such as emissions from industrial and domestic activities and shipping. To account for such emissions, the Swedish Environmental Emission Data (SMED[1]) are used. This data includes geographically distributed emissions from various industrial sources, machines, aviation and domestic sources divided into point and area sources (Andersson et al., 2014) (see Table 3 for specific details). As this study aims to look at the effects of traffic emissions, the point and area sources are kept constant for all scenarios.

Table 3 Other but road traffic emission sources accounted for in the dispersion modelling.

Point sources	Area sources
• Fugitive emissions from fuel handling • Industrial processes • Refineries • Shipping	• Work machines activites • Waste and Sewage • Fugitive emissions from fuel handling • Domestic heating • Energy via electricity and heating plants • Combustion in industry for energy purposes • Household Work Machines • Industrial processes • Domestic aviation • International aviation LTO • Solvents from the products • Boilers • Stationary combustion in agricultural industries

2.6 Dispersion modelling

Effects of the Europe-wide use of different fuels on air pollution in Sweden are studied with two models on two different geographical scales. To capture the large-scale changes, especially those concerning ozone and other secondary air pollutants, the European-scale chemistry transport model EMEP is used (Simpson et al., 2003). The effects on people's exposure to air pollutants and consequent health effects are studied using air pollutant concentrations calculated with the small scale dispersion model TAPM which is nested into EMEP air pollution fields (see Appendix 1 for details). In this way the large scale effects, such as formation of ozone and secondary PM are accounted for also on the local scale.

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[1] www.smed.se

2.6.1 Local scale modelling

The TAPM model (Hurley, 2008) is used to calculate the local contribution of air pollutants in the Västra Götaland region in five scenarios: Base scenario 2020, 10% traffic decrease, Diesel in LDV, CNG in HDV and ED-95 in HDV. The geographically distributed pollutants, on a 1 x 1 km grid, are then used for the exposure calculations and eventually the health risk assessment.

TAPM is a three dimensional meteorological and chemical model for air pollution studies that includes topography as well as land-use. In order to perform the calculations with TAPM a number of input data are required:

- Emission data for the Västra Götaland region as described above.
- Large scale meteorological data.
- Concentration levels of the relevant pollutants in the model domain boundaries for the five scenarios obtained from the EMEP model.

On the basis of this, the model generates the meteorological parameters required for the dispersion modelling, such as temperature layering (inversions) and three dimensional wind field, all based on daily synoptic input data (large scale meteorological re-analysed data –called GASP (Global AnalysiS and Prediction) from the Australian Government Bureau of Meteorology (www.bom.gov.au). TAPM also includes chemistry such as NO/NO_2, ozone, SO_2 and particle transformation, see further Appendix 2.

2.6.2 EMEP modelling

Several EMEP models are developed and used for air quality policy work in Europe, mainly for the Convention on Long-range Transboundary Air Pollution. The Unified EMEP model used in this study is designed to calculate concentrations in air and deposition patterns for major acidifying and eutrophying pollutants, photo-oxidants and particulate matter. In its standard version it has a 50 km x 50 km resolution in the horizontal direction and 20 layers distributed from the ground up to the pressure level of 100 hPa (c.a. 16 km) in the vertical direction. A detailed description is given in Simpson et al. (2003). The model version used for calculations in this study is OpenSource rv4.5 (www.emep.int). The meteorological data used for the simulations, obtained from www.emep.int, are for the year 2011 and are of the same spatial resolution with time resolution of three hours.

The concentration fields generated by the EMEP model are used as boundary conditions for the TAPM model. The boundary concentration fields for TAPM are calculated from hourly concentrations in the EMEP grid cells surrounding the Västra Götaland model domain that are weighted with wind vectors calculated by EMEP for the same grid cells. Since the chemistry of the organic compounds differs between the two models all organic compounds in EMEP are used and recalculated to the reactivity of organic compounds as used by TAPM.

The effect of NO_X, NMVOC and PM emissions can be investigated directly by implementing the scenario emissions and consecutively subtracting the concentration fields in the scenario results from the Base scenario concentration fields. The effects of the emissions of BC are calculated with help of additional sensitivity runs where the $PM_{2.5}$ emissions from traffic were reduced with the BC emissions. The differences in particle concentration between the original and the sensitivity runs are used to asses the concentrations of BC from road traffic.

2.7 Exposure

The population exposure to annual mean concentrations of $PM_{2.5}$, NO_X, O_3, and BC are calculated based on the dispersion calculation results for the Västra Götaland area in combination with the population density for the same 1 x 1 km grid. The population density distribution 2011 for the Västra Götaland region is obtained from Eurostat and shown in Figure 3. The total population in the investigated area is 1 533 599.

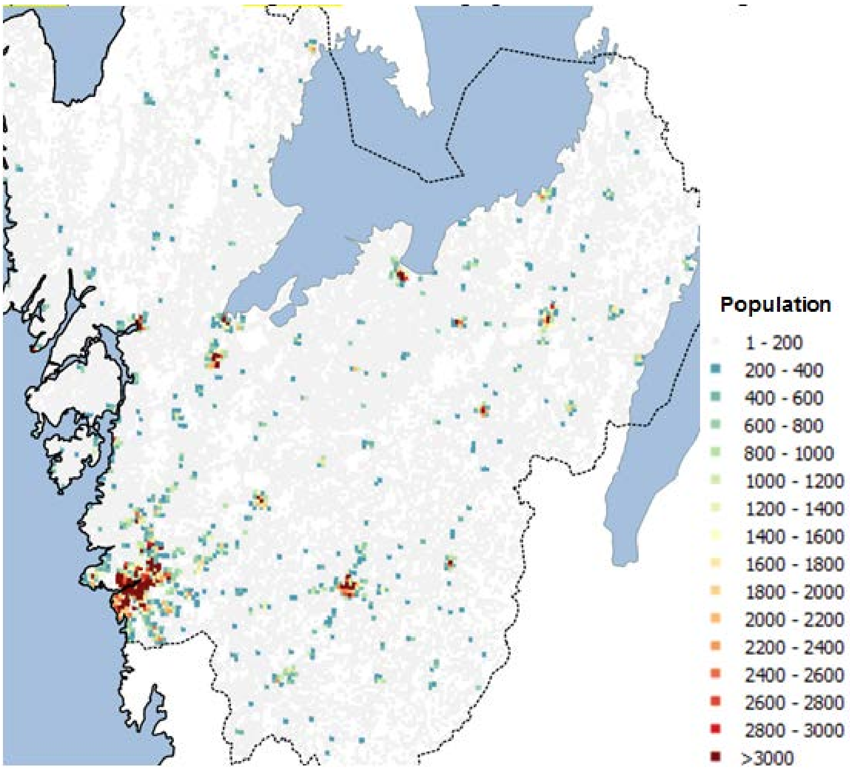


Figure 3 Population density distribution (number of people in a 1 km x 1 km grid for 2011) for the investigated area (according to Error! Reference source not found.).

2.8 Health effects and risk assumptions

2.8.1 NO_X and NO_2

It has long been recognized that traffic related air pollutants correlate with mortality, both temporally (short-term fluctuations) and spatially based on mortality and survival, and the particle exposure has been assumed to be important as a causal component (WHO, 2013a). Since the most commonly cited associations between particle mass (PM2.5) and mortality built on inter-city comparisons, the contrasts in estimated particle exposure were much driven by the regional background concentrations of secondary particles. For this reason other exposure indicators have been used, e.g. NO2 and NOx (Faustini et al., 2014).

One of the studies used to reflect exhaust exposure in several previous health impact assessments (HIA) (Fridell et al, 2014; Orru et al, 2015) built on modelled levels of NOx in the residential area in a Norwegian study of 16 000 men from Oslo and found a strong association (Nafstad et al., 2004). This cohort, with people of between 40-49 years of age at the start of the study, was followed from 1972/73 through 1998 where 25% died during the follow up. NOx was estimated in a model with 1000 m grids, and a street contribution added for the largest streets. When the median concentration of NOx for 1974-78 was used (mean 10.7 µg/m^3), the relative risk for total non-violent mortality was 8% per 10 µg/m^3. If no other exhaust component is included in the health impact calculation, we see this relative-risk function possible to apply. The major problem using these results is that NOx or even NO2 probably not is most important as causal component behind the association with mortality.

2.8.2 Ozone

Regarding ozone there is still a discussion if the effects on mortality of long-term exposure are well enough documented to be assumed in a HIA. Multi-pollutant models in the largest European study of short-term exposure suggest that short-term exposure increases total mortality by approx. 0.3% per 10 µg/m^3 using the daily 8-hr or 1-hr maximum (Gryparis et al, 2004). A WHO meta-analysis for the AQ guidelines (WHO 2003) reported a relative risk of 0.3% per 10 µg/m^3 increase with the 95% CI 0.1–0.4% which we see as a robust exposure–response assumption to apply.

2.8.3 PM

For the recent WHO HRAPIE impact assessment (WHO, 2013b) it was for long-term exposure to PM2.5 and all cause (natural) mortality in ages 30+ recommended to use the exposure-response function from a meta-analysis of 13 cohort studies (Hoek et al., 2013). The RR for PM2.5 from this meta-analysis was 1.062 (95% CI 1.040-1.083) per 10 µg/m^3. This is a coefficient very close to the long-term effect on mortality of PM2.5 from the American Cancer Society (ACS) Cohort Study (Pope et al., 1995) reported to be 1.06 per 10 µg/m^3 increment of the annual average PM2.5. This assumption, 6% per 10 µg/m^3, has been the “golden standard” and used in a large number of health impact assessments of PM2.5 as the regional background but also regardless of particle source. For secondary particles we find 6% per 10 µg/m^3 as an acceptable assumption, but for exhaust particles this RR is less relevant.

The ExternE Project (www.externe.info, ExternE 2005) includes assumptions about the toxicity of different types of PM, which reflect results that indicate a higher toxicity of combustion particles and especially of particles from internal combustion engines. ExternE treats nitrates as equivalent to half the toxicity of PM10; sulfates as equivalent to PM10; primary particles from power stations as equivalent to PM10; primary particles from vehicles as equivalent to 1.5 times the toxicity of PM2.5.

Support for different toxicity comes from the larger effect on mortality per unit found for a subset of American Cancer Society subjects all from Los Angeles County (Jerrett et al, 2005). The authors extracted health data from the ACS survey for metropolitan LA on a zip code-area scale. Using kriging and multiquadric models and data from 23 state and local district monitoring stations in the LA basin they then assigned exposure estimates to 267 zip code areas with a total of 22 905 subjects. For all-cause mortality with adjustments for 44 individual confounders the RR was 1.17 (95% CI = 1.05–1.30) per 10 µg/m^3. These results suggest that the chronic health effects associated with PM2.5 from local sources, mainly traffic and heating, are much larger than reported for metropolitan areas. The direct comparison with the ACS main results shows effects that are nearly 3 times larger than in models relying on inter-community exposure contrasts. For exhaust particles expressed as PM2.5 we find it reasonable to apply the RR 1.17 (95% CI = 1.05–1.30) per 10 µg/m^3 from the intraurban Los Angeles analysis of ACS data.

2.8.4 Black Carbon

A recent review collected information on studies of mortality and long-term exposure to the combustion-related particle indicators (Hoek et al., 2013). The included studies used different methods, and their relation and conversion factors have been described before (Janssen et al., 2011) All-cause mortality was significantly associated with elemental carbon, the meta-analysis resulted in a RR of 1.061 per 1 μg/m^3 EC (95% CI 1.049-1.073), with highly non-significant heterogeneity of effect estimates. Most of the included studies assessed EC exposure without accounting for small-scale variation related to proximity to major roads. We find this RR most relevant to use if exposure to exhaust particles are expressed as EC or BC.

The conversion from PMexhaust to EC is complicated. The vehicle emission model HBEFA gives the emissions of NOx and PMexhaust from the vehicle fleet and measurements performed 2013 by Stockholm City Environment Administration in the tunnel Söderledstunneln suggest that EC represents 30% of PMexhaust. With the RR for EC (1.061 per 1 μg/m^3) and the assumption that 30% of PMexhaust is EC, the RR for PMexhaust would become 1.183 per 10 μg/m^3. This calculated RR for PMexhaust comes very close to the RR found for the subset of ACS subjects all from Los Angeles County.

2.8.5 Health Impact Assessment

Health impact assessments (HIA) are built on epidemiological findings; exposure-response functions and population relevant rates. A typical health impact function has four components: an effect estimate from a particular epidemiological study, a baseline rate for the health effect, the affected number of persons and the estimated “exposure” (here pollutant concentration).

The excess number of cases per year may be calculated as:

$$\boxed{\Delta y = (y_0 \bullet pop)\ \ (e^{ß \bullet \Delta x} - 1)}$$

where y_0 is the baseline rate, pop is the affected number of persons; ß is the exposure-response function (relative risk (RR) per change in concentration), and x is the estimated excess exposure.

If there is a low threshold this means that the effect occurs only above that level. However, there is not enough evidence to assume a specific level to be safe, why we consider effects to follow all changes in exposure. If we would subtract a part of the annual mean exposure for a pollutant this would not change the comparison of health impacts (effects on mortality) between the fuel scenarios included in this study.

For a cost-benefit analysis it is important to cover all or most of the effects. In this study the aim is more of an indicative comparison of exposure from fuels, why we restrict the calculations to impacts on mortality.

In order to estimate how many deaths that depend on elevated air pollution exposure we need to use a base-line rate. We collect the base-line rates 2010 for Sweden from the Swedish National Board of Health and Welfare.

For mortality we calculate the following rates: total mortality (all causes) all ages: 965.2 per 100 000 persons minus external causes all ages: 49.7 per 100 000 persons; total mortality in age group 30+: 1489.8 minus external causes in age group 30+: 69.4.

3 Results and Discussion

3.1 Emission factors

The fuel switch in the different scenarios is applied to Euro 5 and 6 vehicles (Euro V and VI for HDV). The tables in Appendix 3 show the emission factors for regulated emissions for these vehicles for 4 selected road types, each for 2 different traffic densities for the different scenarios. These EFs are weighted for the Swedish fleet of LDVs, HGVs and buses.

Some observations are worth mentioning regarding the EFs:

Comparison of the EFs for the petrol and diesel fuel in LDVs gives indications for the 'Diesel in LDV' scenario. In Table A3.1 we can see that the Petrol fuelled LDVs with Euro 5 and 6 emission standards have lower emissions of NOx (factor EFpetrol/EFdiesel 0.1 – 0.5 for Euro 5, 0.3-1.3 for Euro 6). However, including the cold-start emissions increases significantly the NOx emissions from the petrol fuelled LDVs while for the diesel ones the excessive cold-start emissions are slightly negative (lower emissions during the cold driving than during the normal driving) which leads to much smaller differences between the petrol and diesel LDV emissions on urban roads with high contribution of cold-start emissions; in the case of Euro 6 LDVs even to somewhat higher NOx emissions from petrol fuelled cars comparing to diesel fuelled ones. The diesel fuelled LDVs have significantly higher contribution of NO2 to NOx in their exhaust comparing to the petrol fuelled LDVs (Table A3.6). The petrol fuelled LDVs also have lower emissions of PM and its component BC (for PM factor EFpetrol/EFdiesel 0.70-0.10 for Euro 5 and 0.85-0.12 for Euro 6, for BC 0.23-0.03 for Euro 5 and 0.27 – 0.04 for Euro 6). In this case the cold-start emissions significantly increase emissions from diesel LDVs, meaning that the diesel scenario leads to a significant increase of PM and BC on smaller urban roads (Tables Ax.3 and Ax.5). Emissions of CO and VOCs are much higher for petrol fuelled LDVs with no significant differences between the E5 and E6 emission standards and for both fuels cold-start emissions dominate (for CO factor EFpetrol/EFdiesel 6-14, for NMVOC 3-14) (Tables A3.2 and A3.4). To summarize the Diesel in LDV scenario will lead to higher NOx emissions, however a smaller increase on smaller urban roads, to an increase of PM and BC, this especially on the smaller urban roads and to a decrease of emissions of NMVOC and CO.

The CNG fuelled LDVs have somewhat lower EFs for NOx and NO2 (0-20%) (Tables A3.1 and A3.6) and CO (70-90%) (Table A3.2) compared to the petrol fuelled ones. Further, the PM emissions are lower, by ca. 10% for rural and about 60% for urban driving (Table A3.3). The BC fraction of the PM emissions is the same for the CNG- and petrol fuelled cars (Table A3.5). The NMVOC emissions are much lower for CNG (about 20% of the petrol value) (Table A3.4) with emissions of benzene decreasing accordingly, while the emissions of CH4 are about 20 times higher compared to the petrol drive.

The CNG fuelled HDVs have lower emissions of NOx compared to the diesel fuelled (by 20 - 60%) while the CO emissions are higher (by 60-90%). The NMVOC are lowered by ~90% while the CH4 much higher than for diesel. The PM emissions are lower for the CNG fuelled HDVs only for Euro V vehicles (by 40-80%), while for the Euro VI vehicles the PM emissions are expected to be the same.

The use of ED95 in HDVs leads to lower emissions of NOx (by 20-60%) and to higher emissions of CO (by 0-80%) when compared to diesel drive. When it concerns the organic species, the ED-95 fuel causes, compared to the diesel, somewhat higher emissions of CH4, while the emissions of NMVOCs are lower. For the ED-95 fuel additional evaporative emissions need to be considered, these are zero for the diesel. As these evaporative emissions are largely unknown, they were approximated from those for LDVs, assuming that they are proportional to the fuel consumption. Even with these additional evaporative emissions the

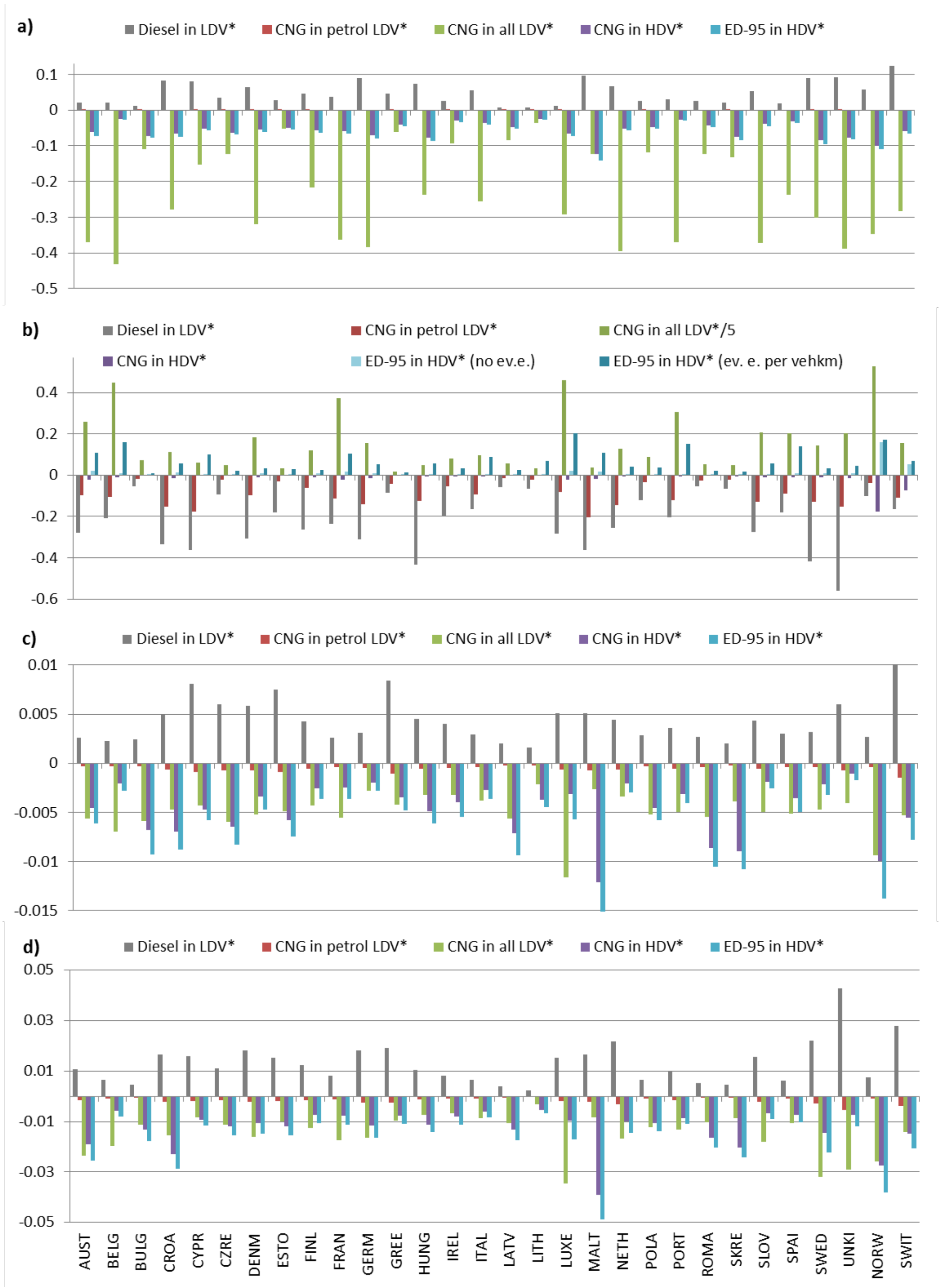
NMVOC emissions from the ED-95 drive remain below the diesel. Emissions of PM are significantly lower than for the diesel (by more than 90%) for Euro V technology HDVs while they are almost unchanged for Euro VI.

Biodiesel fuelled HDVs have, compared to the diesel, slightly higher emissions of NO_X (by ~10%) and lower emissions of CO and NMVOC (by ~20% and ~30%, respectively). A study of Rounce et al. (2012) shows that the benzene content in the emitted NMVOCs is 80% lower compared to what is the case for diesel. The PM emissions are similar; the EFs in COPERT are somewhat lower in urban (by ~10%) and higher in rural driving (by ~10%).

The DME fuel gives lower emissions of NO_X compared to the diesel (by ~10-40%) and much lower emissions of PM in Euro V technology HDVs (by 90-97% lower). The Euro VI HDVs have similar PM EFs for both fuels. For DME only 2% of the PM is BC which means that the BC emissions are extremely low for this fuel. Emissions of CO and NMVOC are similar for both fuels. The NMVOC emitted from the DME fuelled HDVs are dominated by DME and formaldehyde, while the benzene content is zero (Zhu et al., 2012).

3.2 Emissions

The emissions from road traffic vary between the scenarios due to the differences in the emission factors. On the European scale gridded emissions for the Base scenario run are modified by a factor specific for each country and emission source, in our case road traffic. The methodology for calculation of the scenario factors are described in Chapter 2. Figure 4 shows the difference in emissions of NOx, VOC and PM2.5 from road traffic between the scenario- and the Base scenario for the different European countries. For the VOC emissions Figure 4b shows also how the emissions change when evaporative emissions from the ethanol fuelled HDVs are taken into consideration (two nuances of blue columns).



* Euro-4 and Euro-5 emission standard

Figure 4 **Relative change in emissions from the road traffic in the different scenarios for European countries. a – NOx, b – NMVOC, c - $PM_{2.5}$ (exhaust + wear) and d – exhaust PM2.5. In b – no ev.e. is a scenario when no evaporative emissions from the ED-95 fuelled HDVs are considered, ev.e. per vehkm is a scenario when evaporative emissions from the ED-95 fuelled HDVs are considered the same as for ethanol (E-85) fuelled LDVs, calculated per vehkm.**

It can be seen in Figure 4 that the NOX-emissions are higher in the Diesel in LDV scenario; the change depends on the use of diesel/petrol in the Base scenario. Also in the scenario where the petrol fuelled LDVs are replaced by CNG the emissions of NOx are slightly increased. For the other scenarios the NOX-emissions are lower, most significantly for the case when both Petrol and Diesel fuelled LDVs are replaced by CNG. The most significant changes for NMVOC are for the scenarios affecting LDVs, due to the fact that the NMVOC emissions are largely dominated by the cold-start emissions and for HDVs the cold-start emissions are neglected in all emission databases. In earlier inventories the NMVOC emissions for trucks were largely dominated by the hot emissions. However, for vehicles of the Euro-V and Euro-VI standards this is probably not true any longer and the cold-start emissions could be significant. Data for the cold-start emissions of HDVs are, however, not available at this moment. Since the cold-start emissions from diesel fuelled LDVs are significantly lower than for petrol and CNG fuelled LDVs, the Diesel in LDV scenario has decreased NMVOC emissions and CNG in all LDV (= including the Diesel LDVs) has increased NMVOC emissions. The PM emissions are larger in the Diesel in LDV scenario and lower than the Base scenario for all other studied scenarios. The difference is small since a large part of the emitted particles are the non-exhaust wear particles which are not affected in our scenarios. Figure 4 d) shows impact in of the scenarios on emissions of exhaust particles.

Figure 5 shows exhaust emissions of NOx, NO2, VOC, Benzene, PM and BC calculated for the different scenarios for Sweden. The cold-start emissions are not included. Contribution of emissions from HDV and LDV with new (Euro 5 and 6) and older (pre-Euro – Euro 4) emission standards can be seen in the figure. One can see that the largest contributor to the NOx and NO2 emissions are the modern light-duty vehicles, while the PM emissions are dominated by older LDVs and the NMVOC emissions are dominated by motorcycles (responsible for 1% of the traffic activity) and by older LDVs. NMVOC emissions are, however, largely dominated by the cold-start emissions as can be seen in Figure 6.

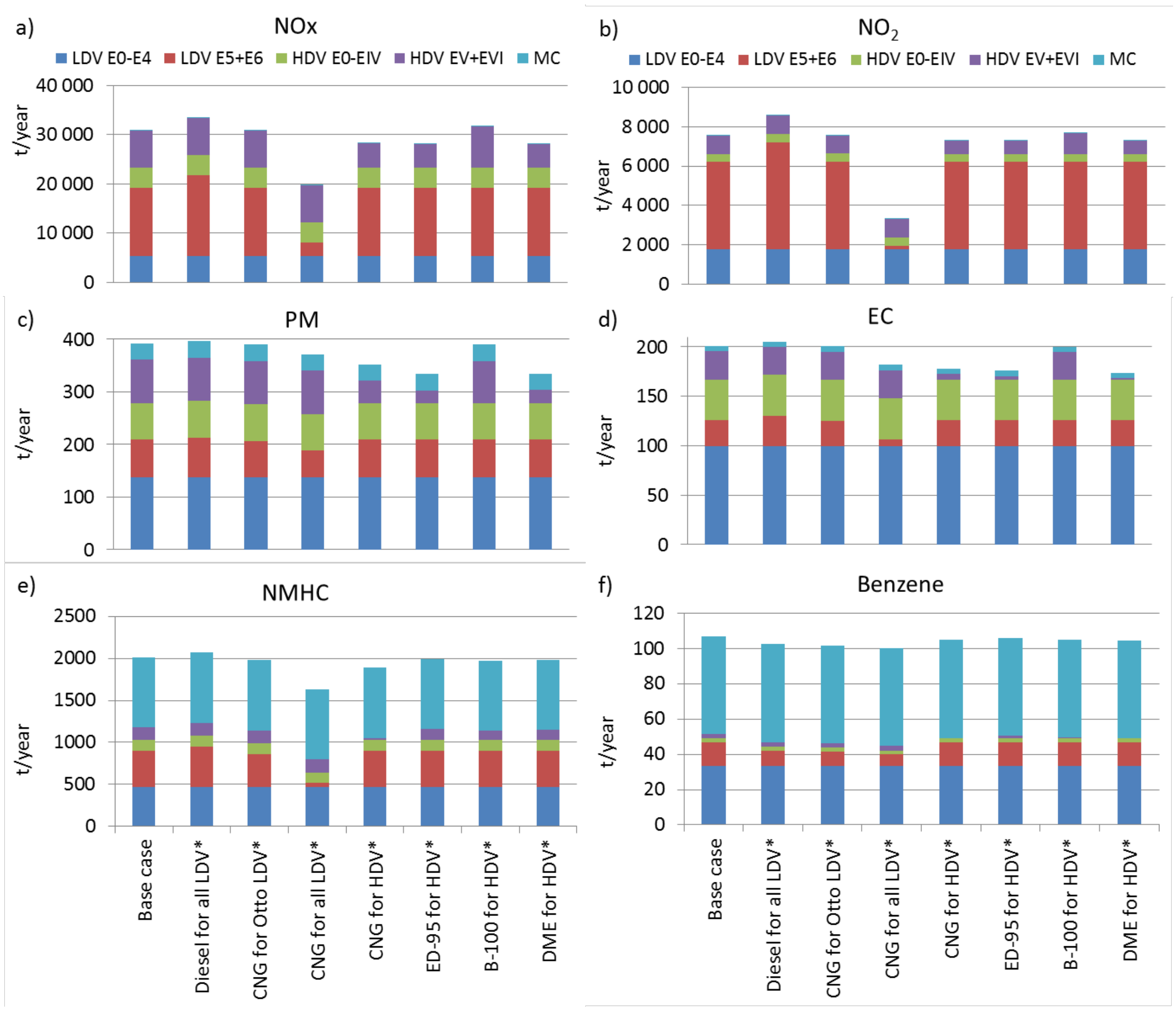


Figure 5 **Hot exhaust emissions of a – NOx, b – NO2, c – particulate matter (PM), d – EC, e – NMVOC, f – benzene from Swedish road traffic in the different emission scenarios divided into emissions from older (Euro 1-4) and modern (Euro 5-6) light- and heavy-duty vehicles and from motorcycles.**

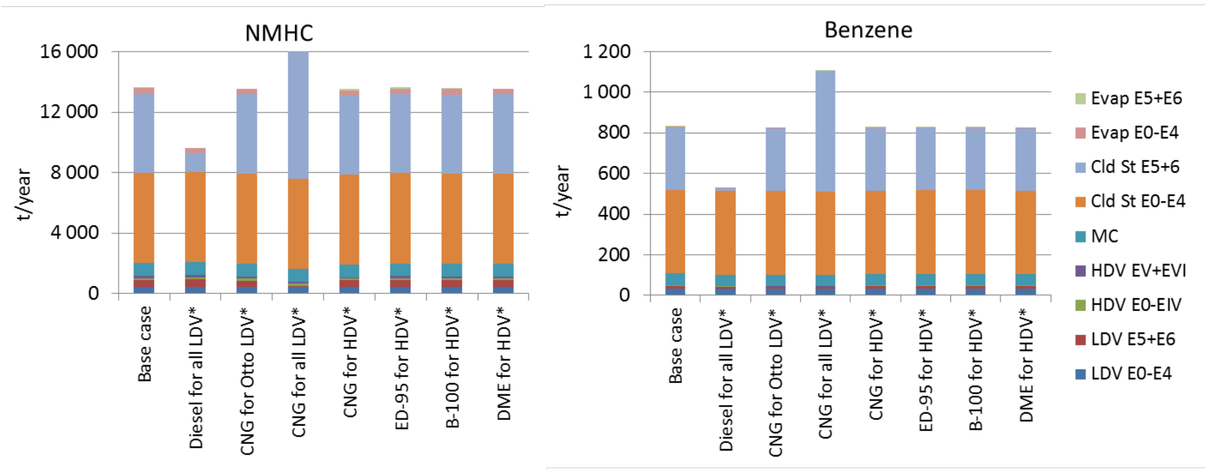


Figure 6 **Exhaust emissions, including the cold-start excessive emissions (marked as ‘Cld St’) and evaporative emissions (‘Evap’), of NMVOC (left) and benzene (right) from Swedish road traffic in the different emission scenarios.**

Table 4 shows the scenario emission totals for the Västra Götaland model domain and Table 5 shows the emission totals for Sweden.

Table 4 **Emissions from traffic for the Västra Götaland region in four different emission scenarios (in tonnes/year). LDV* and HDV* mark fuel switch in LDVs of Euro 5 and Euro 6 emission standard and HDVs with Euro V and Euro VI emission standard, respectively. PM_{10} includes both exhaust and wear particles.**

Substance	Base 2011	Base 2020	Diesel in all LDV*	CNG in HDV*	ED95 in HDV*
NO_X	10 731	5 160	5 576	4 699	4 684
PM_{10} total	804	640	640	629	626
EC		31	32		
NMVOC	616	278	288	244	273

Table 5 Emissions from traffic in Sweden (in tonnes/year) for the different 2020 scenarios. Both emissions specific for hot exhaust emissions from LDV + MC ('LDV+MC') and HDV ('HDV'), cold-start emissions ('Cold start', assumed 0.0 from HDV) and evaporative emissions ('Evaporative', assumed 0.0 from HDV with exception for ED-95 scenario where evaporative emissions from ED-95 fuelled HDVs has the same emission factor of evaporative NMVOC per fuel consumed as LDVs and emission factor for benzene is 0.0). LDV* and HDV* mark fuel switch in LDVs of Euro 5 and Euro 6 emission standard and HDVs with Euro V and Euro VI emission standard, respectively. PM_{10} includes exhaust particles only.

	Base 2020	Diesel in all LDV*	CNG in Otto LDV*	CNG in all LDV*	CNG in HDV*	ED-95 in HDV*	B-100 in HDV*	DME in HDV*
NO_X								
LDV+MC	19 332	21 919	19 344	8 232	19 332	19 332	19 332	19 332
HDV	11 663	11 663	11 663	11 663	9 100	9 011	12 474	8 991
Cold start	715	-274	715	2 429	715	715	715	715
Total	31 710	33 308	31 722	22 323	29 147	29 058	32 521	29 038
PM_{10} exhaust								
LDV	240	244	238	219	240	240	240	240
HDV	152	152	152	152	113	94	150	95
Cold start	92	100	57	92	92	92	92	92
Total	484	496	446	463	444	426	481	426
NMVOC								
LDV	1 739	1 792	1 702	1 355	1 739	1 739	1 739	1 739
HDV	278	278	278	278	152	255	235	248
Cold start	11 203	7 226	11 203	14 429	11 203	11 203	11 203	11 203
Evaporative	445	363	363	445	445	445	445	363
Total	13 664	9 658	13 546	16 507	13 539	13 642	13 622	13 553
Benzene								
LDV	102	98	97	96	102	102	102	102
HDV	5	5	5	5	3	4	3	2
Cold start	719	426	719	1 003	719	719	719	719
Evaporative	3	3	3	3	3	3	3	3
Total	829	531	823	1 106	827	828	827	826

3.3 Dispersion modelling

The dispersion of pollutants for the five scenarios (described in Chapter 1); Base scenario 2020, 10% traffic decrease, Diesel in LDV, CNG in HDV and ED-95 in HDV, are calculated for 2020 using meteorology for 2011. A comparison between the Base scenario 2020 and each of the other scenarios are conducted. The results are described and discussed in the following chapter. Results for $PM_{2.5}$, NO_X, ozone and BC are presented below as these pollutant species are later used for the health calculations.

3.3.1 **Base scenario 2020**

The mean annual concentrations of $PM_{2.5}$, NO_X, ozone and BC for the Base case 2020 are shown in Figure 7. The mean annual concentrations are relatively low for most parts of the investigation area with values well below the environmental standards. The highest concentrations of $PM_{2.5}$, NO_X and BC are found in the larger towns and in the city of Gothenburg. For ozone the opposite trend is seen due to that there were no primary emissions of ozone, and due to the well-known process of ozone titration by freshly emitted nitrogen monoxide (Seinfeld and Pandis, 1998) which generally results in a reduction of ozone in urban areas.

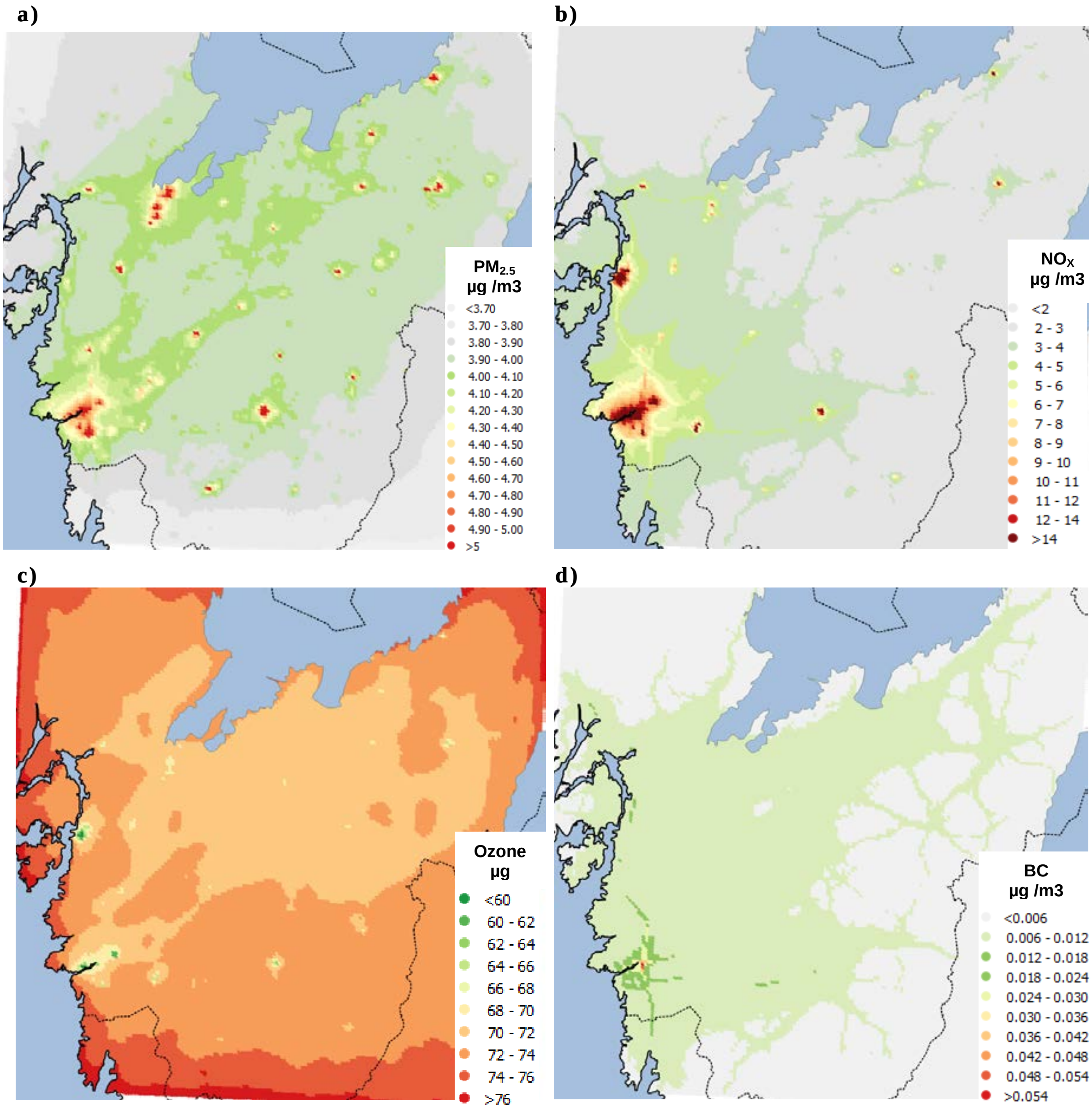


Figure 7 Annual mean concentration of a) $PM_{2.5}$, b) NO_X, c) Ozone and d) BC for the Base scenario 2020

3.3.2 10% reduction of traffic

To illustrate the results of the scenario where the traffic 2020 is reduced by 10%, the geographically distributed concentration of NO_X is presented as the difference in yearly average NO_X concentration between the 10% traffic decrease and the Base scenario 2020, both as µg /m3 and as percentage of the difference (Figure 8). The model results show that reducing the traffic by 10% 2020 will lead to a reduction in the NO_X concentration of more than 0.4 µg /m3 in the central parts of Gothenburg and between 0.1 and 0.15 µg /m3 in rural areas of Västra Götaland (Figure 8a). The percentage reduction of the NO_X concentration between 10% traffic decrease scenario and the Base scenario 2020 is highest along the main roads and in urban areas. The differences in $PM_{2.5}$, ozone and BC between the 10% traffic decrease and the Base scenario 2020 are smaller than the calculation error and are therefore not shown here.

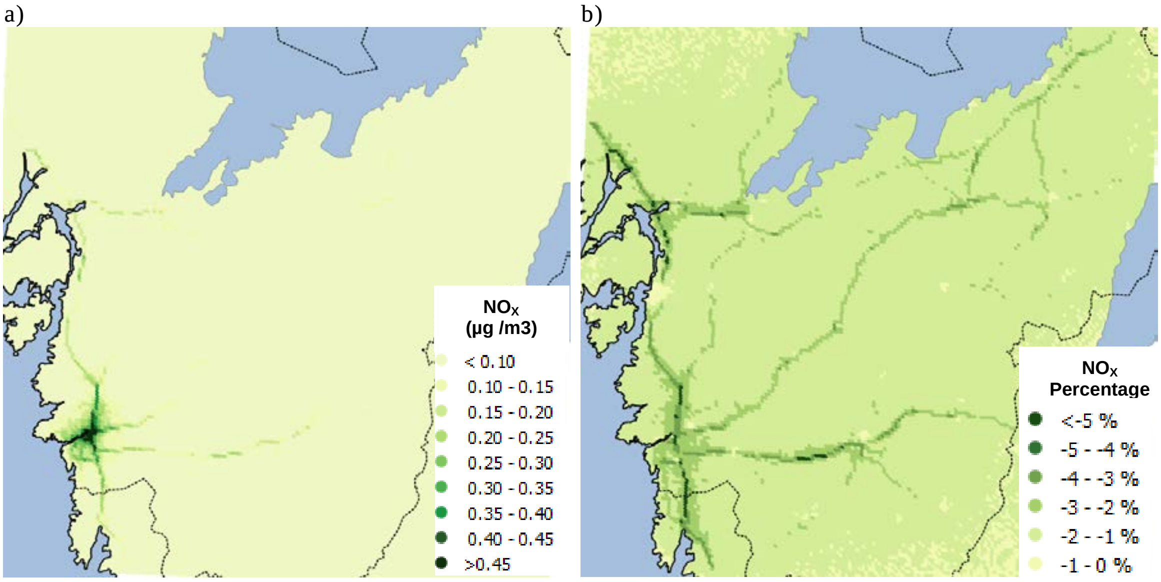


Figure 8 **The difference (a) and the percentage difference (b) in yearly average concentrations of NO_X for 2020 between the 10 % decrease in traffic and the Base scenario 2020.**

3.3.3 Light duty vehicles with Euro 5 and 6 emission standard running on diesel

To illustrate the results of the scenario where all LDVs with Euro 5 and 6 emission standard run on diesel (Diesel in LDV), the geographically distributed concentrations are presented as the difference in yearly average concentrations between Diesel in LDV and the Base scenario 2020, both as µg /m^3 and as percentage of the difference to the Base scenario (Figure 9).

The increase in NO_X and $PM_{2.5}$ concentrations, resulting from a switch to diesel, is up to about 0.5 µg/m^3 or 8 % for $PM_{2.5}$ and 0.5 g/m^3 or 4 % for NO_X in the larger urban areas and along the major roads. This is a result of the higher emission of NO_X and $PM_{2.5}$ from the increased use of diesel. For ozone the situation is opposite. In the Diesel in LDV scenario for 2020 the concentration of ozone decreases by up 4 % in urban areas as a result of the increase in NO_X emissions. For BC there is a small increase in concentration, although too small to plot sensibly.

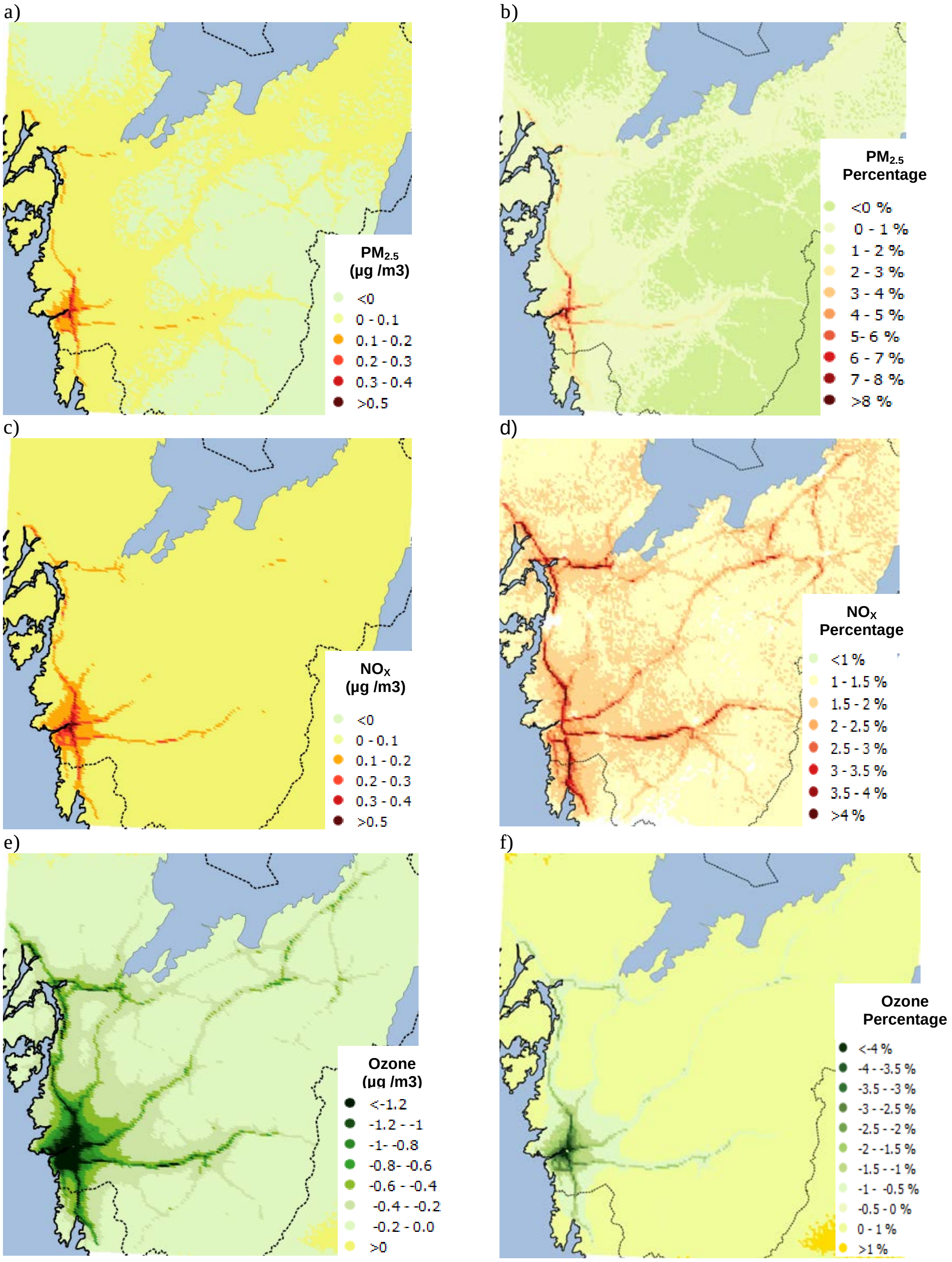


Figure 9 **The difference (left column) and the percentage difference (right column) in yearly average concentrations of a-b) PM$_{2.5}$, c-d) NO$_X$ and e-f) ozone for 2020 between the Diesel in LDV scenario and the Base scenario (µg /m3).**

3.3.4 All heavy duty vehicles run in CNG

The geographically distributed concentrations of NO_X are presented as the difference in yearly average NO_X concentration between the CNG in HDV scenario and the Base scenario 2020, both as µg/m³ and as percentage of the difference to the Base scenario (Figure 10). The CNG in HDV scenario result in an overall reduction of NO_X with the greatest reduction along the main roads and in the urban areas surrounding Gothenburg. The differences in $PM_{2.5}$, ozone and BC between the CNG in HDV scenario and the Base scenario 2020 are smaller than the calculation error and are therefore not shown here.

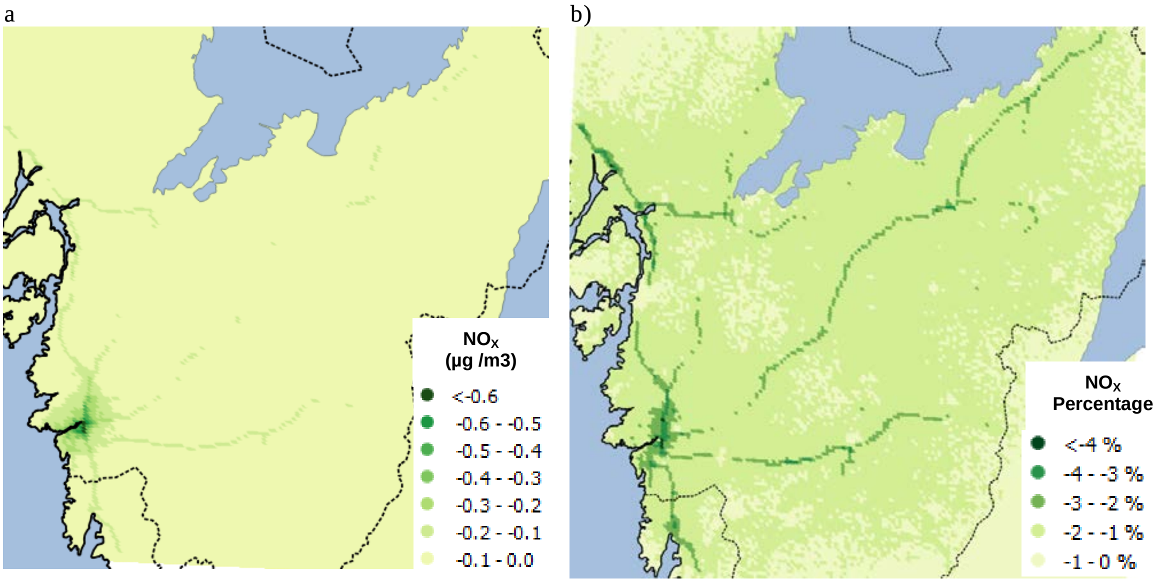


Figure 10 The difference (a) and the percentage difference (b) in yearly average concentrations of NO_X for 2020 between the CNG in HDV and the base case 2020 scenarios.

3.3.5 All heavy duty vehicles run in ED95

The geographically distributed concentrations are presented as the difference in yearly average concentrations between the ED-95 in HDV scenario and the Base scenario 2020, both as µg/m³ and as percentage of the difference to the Base scenario (Figure 11). Similar to the CNG in HDV scenario, the ED-95 in HDV scenario result in an overall reduction of NO_X with the greatest reduction along the main roads and in the urban areas surrounding Gothenburg. The differences in $PM_{2.5}$, ozone and BC between the ED-95 in HDV scenario and the Base scenario 2020 are smaller than the calculation error and are therefore not shown here.

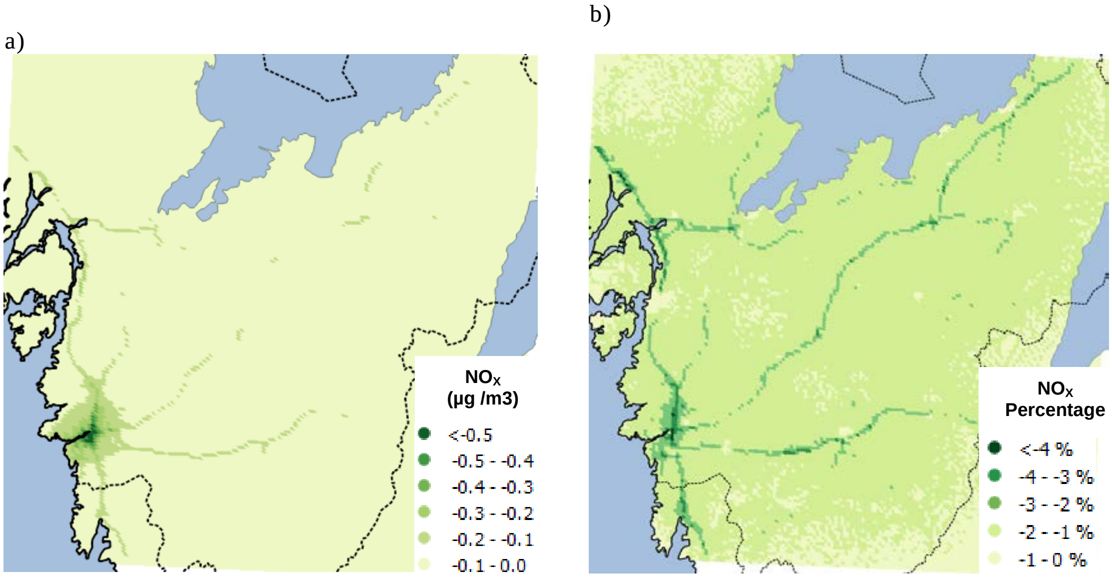


Figure 11 The difference (a) and the percentage difference (b) in yearly average concentrations of NO_X for 2020 between the ED-95 in HDV and the base case 2020 scenarios.

3.4 Exposure

The resulting concentrations from the dispersion modelling together with the population density distribution are used to assess the population exposure to $PM_{2.5}$, NO_X, ozone and BC for the five scenarios. Table 6 shows the population weighted mean exposure both as total concentrations and as the difference between each scenario and the Base scenario. The exposure to $PM_{2.5}$ is very similar for all five scenarios; the largest difference in concentration is between the Diesel in LDV scenario and the Base scenario 2020 with a 0.05 $\mu g/m^3$ increase. It can be seen in Table 6 that the exposure to all pollutants, are somewhat lower for the all scenarios, except for the Diesel in LDV scenario, than for the Base scenario 2020. However the effect on health also depends on the value of the dose-response functions. For example, if the level of concentration is low in a populated area but the dose-response function is high, the effect of even a low concentration increase can become important. In Figure 12 the percentages of the population, in the investigated area, exposed to different concentration levels of $PM_{2.5}$ and NO_X are shown, as well as the difference in the number of people exposed in the different concentration levels compared to the Base scenario.

Table 6 **Populated weighted mean exposure (µg/m³).**

	Base 2020	10% traffic decease		Diesel in LDV		CNG in HDV		ED-95 in HDV	
	mean	mean	Difference	mean	Difference	mean	Difference	mean	Difference
$PM_{2.5}$	4.111	4.109	-0.003	4.163	0.051	4.110	-0.002	4.011	-0.100
NO_X	6.220	6.097	-0.123	6.337	0.117	6.112	-0.109	6.108	-0.113
BC	0.011	0.010	-0.001	0.0112	0.0002	0.010	-0.001	0.010	-0.002
O_3	71.803	71.762	-0.041	71.012	-0.791	71.773	-0.031	71.878	0.075

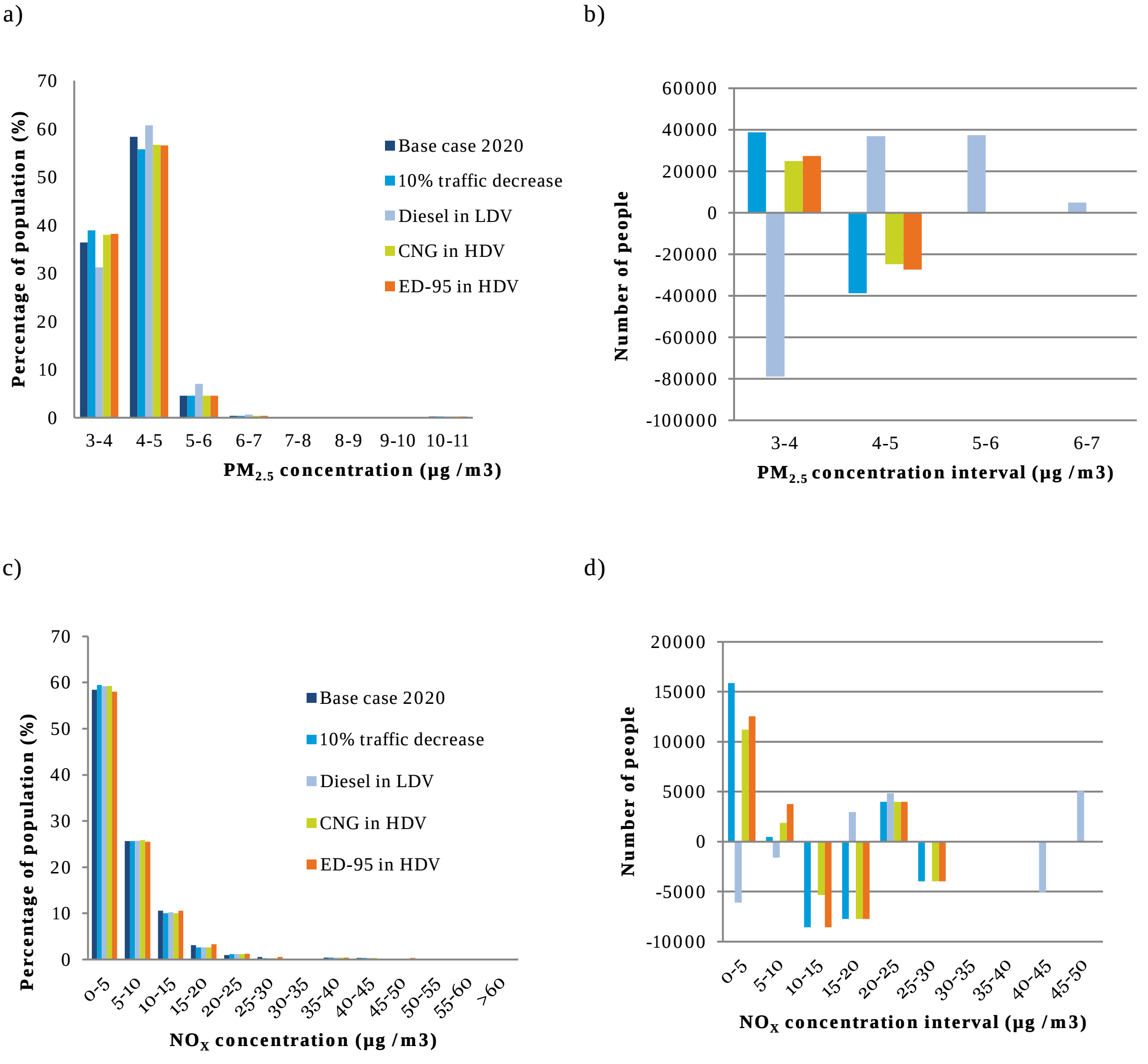


Figure 12 **The percentages of the population, in the investigated area, exposed to different concentration levels of $PM_{2.5}$ and NO_X are shown (a) $PM_{2.5}$, c) NO_X), as well as the difference in the number of people exposed in the different concentration levels compared to the Base scenario (b) $PM_{2.5}$ and d) NO_X).**

3.5 Impact on health in Västra Götaland

We use effects on preterm mortality as an indicator of the health impact since all the studied pollutants are associated with both mortality and morbidity. The total burden on health is larger than indicated from preterm mortality, but in calculation of disability adjusted life years (DALYs) and health economic costs, the impact on mortality is always the biggest number. The results are presented in Table 7. Here the populated weighted mean exposures from Table 6 are shown together with the exposed population for the different substances. The population varies between the substances depending on the relevant age group. Further, the number of mortality cases for each scenario and substance is shown as well as the respective change relative the Base scenario.

Table 7 Health risk assessments

Scenario	**Exposure (µg /m3)**	**Population (N)**	**Mortality Cases**	**Difference in mortality from the Base scenario**
$PM_{2.5}$ (RR=0.006, Baseline=0.014204)				
BASE	4.111	973835	341.2	
-10% traffic	4.109	973835	341.0	-0.22
Diesel in LDV	4.163	973835	345.5	4.27
CNG in HDV	4.110	973835	341.1	-0.15
E95 in HDV	4.011	973835	332.9	-8.33
NO_X (RR=0.008, Baseline=0.014204)				
BASE	6.220	973835	688.3	
-10% traffic	6.097	973835	674.7	-13.61
Diesel in LDV	6.337	973835	701.3	12.95
CNG in HDV	6.112	973835	676.3	-12.03
E95 in HDV	6.108	973835	675.9	-12.48
BC (RR=0.061, Baseline=0.014204)				
BASE	0.011	973835	9.4	
-10% traffic	0.009	973835	7.9	-1.43
Diesel in LDV	0.011	973835	9.6	0.08
CNG in HDV	0.010	973835	8.3	-1.10
E95 in HDV	0.010	973835	8.1	-1.27
O_3 (RR=0.0003, Baseline=0.0009155)				
BASE	71.80	1533599	302.4	
-10% traffic	71.76	1533599	302.3	-0.17
Diesel in LDV	71.01	1533599	299.1	-3.33
CNG in HDV	71.772	1533599	302.3	-0.13
E95 in HDV	71.88	1533599	302.8	0.32

The impacts that are calculated for Västra Götaland could be used to estimate the total impact of vehicle exhaust exposure in Västra Götaland (approx. ten times the impact of 10% reduction in traffic), and crude impacts for all Sweden. However, since the epidemiological studies providing exposure-response functions were unable to separate the effect of many correlated components, NOx and PM2.5 likely represent partly the same exposure mix and effects. Adding the estimated health impacts probably results in at least some double counting.

3.5.1 NO_2 and NO_X

In comparison with the Base scenario, reducing traffic by 10% is estimated to avoid 13.6 preterm deaths per year, while the Diesel in LDV scenario is estimated to increase the number of deaths by almost 13 per year. These are the largest impacts on health that we calculate in the study. However, it should be noted that the assumed exposure-response relation is not adjusted for other pollutants in the vehicle exhaust mixture, such as particle mass or soot.

3.5.2 Ozone

The estimated health impacts from changes in ozone exposure in comparison with the Base scenario are small. The Diesel in LDV scenario is estimated to save 3.3 preterm deaths per year explained by the higher NOx emissions reducing ozone levels.

3.5.3 $PM_{2.5}$

In comparison with the Base scenario, lower PM exposure for the E95 in HDV scenario is estimated to avoid 8.3 preterm deaths per year, while Diesel in LDV scenario is estimated to increase the number of deaths by 4.3 per year. These are the second largest impacts on health that we calculate in the study.

3.5.4 Black carbon

The estimated health impacts from changes in BC exposure in comparison with the base scenario are small, and share the same patterns as found for NOx and PM2.5.

4 Conclusions

For the scenario where all new passenger cars are fuelled by diesel the NO_X and the PM emissions are higher than in the Base scenario while the emissions of NMVOC are lower. This gives a higher exposure to $PM_{2.5}$, BC and NO_X while the O_3 exposure is lower.

When replacing diesel with CNG in HDV there are significant reductions in NO_X and PM emissions from this vehicle category. The exposure is notably lower for NO_X while the difference for O_3 is small.

For the scenario with ethanol for HDV the emissions are lower compared with the Base scenario for NO_X, PM and NMVOC and also the exposure to these substances while the O_3 exposure is somewhat higher. The latter has to do with the reduced emissions of NO_X.

For the scenario with CNG instead of petrol in Otto LDV the differences in emissions for NO_X and PM are small while the NMVOC is lower since the fraction of methane in the hydrocarbon emissions would be higher. Dispersion modelling was not made for this scenario but it can be expected that the exposure to ozone would be somewhat lower. With CNG also replacing diesel for LDV the differences in emissions are larger. The emissions of NMVOC are here larger due to the cold-start emissions.

For the B-100 in HDV scenario NO_X emissions increases while PM emissions are reduced. For the DME scenario emissions of both PM and NO_X are lower. Changes in NMVOC scenarios are small for these scenarios.

In comparison with the Base scenario, reducing traffic by 10% is estimated to avoid 13.6 preterm deaths per year through decreased exposure to NO_X, while the Diesel in LDV scenario is estimated to increase the number of deaths by almost 13 per year. However, it should be noted that the assumed exposure-response relation for NO_X is not adjusted for some pollutants in the vehicle exhaust mixture, such as particle mass or soot.

The estimated health impacts from changes in ozone exposure in comparison with the Base scenario are small. The Diesel in LDV scenario is estimated to save 3.3 preterm deaths per year explained by the higher NOx emissions reducing ozone levels.

In comparison with the Base scenario, lower PM exposure for the E95 in HDV scenario is estimated to avoid 8.3 preterm deaths per year, while Diesel in LDV scenario is estimated to increase the number of deaths by 4.3 per year.

The estimated health impacts from changes in BC exposure in comparison with the Base scenario are small, and share the same patterns as found for NOx and PM2.5.

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Appendix 1

Defining of boundary concentrations for TAPM from EMEP fields

Calculation of initial concentration field for TAPM from EMEP concentration field of NO_2 (as example) and EMEP mean wind vector components u_mid and v_mid. Two EMEP model gridcells (i=56, j=60 and i=56, j=61) represent the TAPM model domain and concentrations from the surrounding EMEP gridcells SE-S, SE-N, NW-S, NW-N, NE, NW (Figure A1) are used for calculation of boundary concentration NO_2(bc) according to the following code:

```
if
  u_mid <= 0 then ( isite = SE-S and jsite = SE-N)
else
  isite = NW-S and jsite = NW-N)
endif

if
  v_mid <= 0 then ( ksite = NE)
else
  ksite = SW
endif
```

NO_2(bc) = [(NO_2(isite)*u_mid(isite) + NO_2(jsite)*u_mid(jsite))/2. +
NO_2(ksite)*v_mid(ksite)] / [(u_mid(isite) + u_mid(jsite))/2 + v_mid(ksite)]

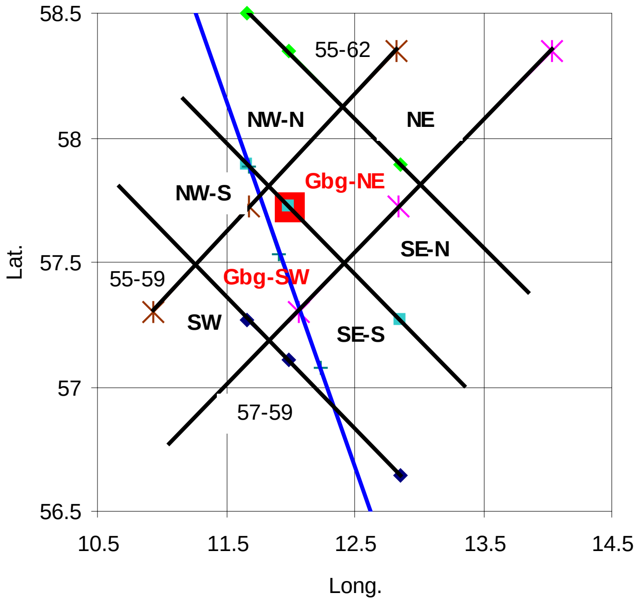

Figure A1 Gridcells covering Gothenburg domain and its boundary in EMEP model plotted on latitude-longitude coordinates. The red square represents centre of Gothenburg and the blue line the coastline. EMEP i and j coordinates for the boundary gridcells are: SE-S = 57-60, SE-N = 57-61, NW-S = 55-60, NW-N = 55-61, NE = 56-62, NW = 56-59 and for Gothenburg grid cells are: Gbg-NE = 56-61, Gbg-SW = 56-60.

Appendix 2

Model description

The Air Pollution Model - TAPM

The TAPM consists of two models, one meteorological and one dispersion model.

Meteorology model

The meteorological component of TAPM is an incompressible, non-hydrostatic, primitive equation model with a terrain-following vertical coordinate for three-dimensional simulations. The model solves the momentum equations for horizontal wind components, the incompressible continuity equation for vertical velocity, and scalar equations for potential virtual temperature and specific humidity of water vapour, cloud water and rainwater. Explicit cloud microphysical processes are included. Turbulence kinetic energy and eddy dissipation rates are calculated for determining the turbulence terms and the vertical fluxes. Further, surface energy budget is considered to compute the surface temperature. A vegetative canopy and soil scheme is used at the surface. Radiative fluxes at the surface and at upper levels are also calculated.

Air pollution model

The air pollution component of TAPM, which uses predicted meteorology and turbulence from the meteorological component, includes three modules. The Eulerian Grid Module (EGM) solves prognostic equations for concentration and for cross-correlation of concentration and virtual potential temperature. The Lagrangean Particle Module (LPM) can be used to represent near-source dispersion more accurately, while the Plume Rise Module is used to account for plume momentum and buoyancy effects for point sources. The model also has gas-phase photochemical reactions based on the Generic Reaction Set, and gas- and aqueous-phase chemical reactions for sulfur dioxide and particles. In addition, wet and dry deposition effects are also included.

Appendix 3

Emission factors

Table A3.1 Emission factors for NOx (g/veh.km) used in the scenarios developed in the project.

Vehicle type			LDV				HDV		Buses	
Emission Type			Hot Exhaust		Cold start		Hot Exhaust		Hot Exhaust	
Emission standard			E-5	E-6	E-5	E-6	E-V	E-VI	E-V	E-VI
Fuel	Road/Driving pattern									
Petrol	MW-90	Freeflow	0.04	0.03	0.01	0.01				
	MW-90	St+Go	0.09	0.08	0.01	0.01				
	RUR-NMW-70	Freeflow	0.04	0.04	0.06	0.06				
	RUR-NMW-70	St+Go	0.08	0.08	0.06	0.06				
	URB-Access-40	Freeflow	0.05	0.05	0.14	0.13				
	URB-Access-40	St+Go	0.09	0.08	0.14	0.13				
Diesel	MW-90	Freeflow	0.47	0.15	-0.01	0.00	2.72	0.24	1.95	0.19
	MW-90	St+Go	0.74	0.26	-0.01	0.00	6.52	1.66	13.07	1.99
	RUR-NMW-70	Freeflow	0.37	0.13	-0.03	-0.01	3.32	0.33	2.14	0.22
	RUR-NMW-70	St+Go	0.90	0.32	-0.03	-0.01	7.07	2.39	10.96	2.26
	URB-Access-40	Freeflow	0.47	0.16	-0.07	-0.03	5.34	0.74	8.07	0.87
	URB-Access-40	St+Go	0.97	0.35	-0.07	-0.03	7.63	3.00	17.49	3.23
CNG	MW-90	Freeflow	0.03	0.03	0.01	0.01	1.83	0.21	1.45	0.14
	MW-90	St+Go	0.09	0.09	0.01	0.01	3.75	1.23	4.66	0.71
	RUR-NMW-70	Freeflow	0.04	0.04	0.06	0.06	2.41	0.27	0.96	0.10
	RUR-NMW-70	St+Go	0.09	0.09	0.06	0.06	4.07	1.79	3.99	0.81
	URB-Access-40	Freeflow	0.06	0.05	0.14	0.13	3.07	0.56	2.86	0.31
	URB-Access-40	St+Go	0.10	0.09	0.14	0.13	4.39	2.25	6.24	1.15
E-85	MW-90	Freeflow	0.03	0.03	0.00	0.00	1.79	0.21	1.45	0.14
	MW-90	St+Go	0.08	0.07	0.00	0.00	3.67	1.21	4.66	0.71
	RUR-NMW-70	Freeflow	0.03	0.03	0.02	0.02	2.37	0.26	0.96	0.10
	RUR-NMW-70	St+Go	0.08	0.07	0.02	0.02	3.98	1.76	3.99	0.81
	URB-Access-40	Freeflow	0.05	0.04	0.05	0.04	3.00	0.55	2.86	0.31
	URB-Access-40	St+Go	0.08	0.08	0.05	0.04	4.30	2.21	6.24	1.15
B-100	MW-90	Freeflow					2.91	0.26	2.10	0.20
	MW-90	St+Go					7.32	1.85	14.79	2.26
	RUR-NMW-70	Freeflow					3.74	0.37	2.42	0.25
	RUR-NMW-70	St+Go					7.93	2.68	12.40	2.56
	URB-Access-40	Freeflow					5.99	0.83	9.13	0.98
	URB-Access-40	St+Go					8.56	3.36	19.80	3.65
DME	MW-90	Freeflow					1.78	0.21	1.45	0.14
	MW-90	St+Go					3.66	1.20	4.66	0.71
	RUR-NMW-70	Freeflow					2.36	0.26	0.96	0.10
	RUR-NMW-70	St+Go					3.97	1.75	3.99	0.81
	URB-Access-40	Freeflow					3.00	0.54	2.86	0.31
	URB-Access-40	St+Go					4.28	2.20	6.24	1.15

Table A3.2. Emission factors for CO (g/veh.km) used in the scenarios developed in the project.

Vehicle type			LDV				HDV		Buses	
Emission Type			Hot Exhaust		Cold start		Hot Exhaust		Hot Exhaust	
Emission standard			E-5	E-6	E-5	E-6	E-V	E-VI	E-V	E-VI
Fuel	Road/Driving pattern									
Petrol	MW-90	Freeflow	0.21	0.28	0.30	0.30				
	MW-90	St+Go	0.40	0.37	0.30	0.30				
	RUR-NMW-70	Freeflow	0.18	0.16	1.69	1.67				
	RUR-NMW-70	St+Go	0.35	0.39	1.69	1.67				
	URB-Access-40	Freeflow	0.20	0.21	3.83	3.80				
	URB-Access-40	St+Go	0.44	0.43	3.83	3.80				
Diesel	MW-90	Freeflow	0.01	0.01	0.03	0.03	0.77	0.77	1.21	0.66
	MW-90	St+Go	0.06	0.09	0.03	0.03	2.21	2.21	4.35	2.43
	RUR-NMW-70	Freeflow	0.01	0.02	0.16	0.15	0.95	0.94	0.89	0.55
	RUR-NMW-70	St+Go	0.06	0.09	0.16	0.15	2.62	2.64	3.34	2.18
	URB-Access-40	Freeflow	0.03	0.04	0.36	0.35	1.56	1.53	2.86	1.50
	URB-Access-40	St+Go	0.06	0.09	0.36	0.35	2.98	3.01	5.88	3.34
CNG	MW-90	Freeflow	0.14	0.19	0.30	0.30	1.28	1.27	2.00	1.09
	MW-90	St+Go	0.34	0.32	0.30	0.30	4.20	4.21	8.27	4.63
	RUR-NMW-70	Freeflow	0.15	0.13	1.69	1.67	0.96	0.95	0.90	0.56
	RUR-NMW-70	St+Go	0.30	0.34	1.69	1.67	4.98	5.02	6.35	4.15
	URB-Access-40	Freeflow	0.18	0.18	3.83	3.80	2.96	2.92	5.45	2.85
	URB-Access-40	St+Go	0.38	0.37	3.83	3.80	5.68	5.73	11.18	6.36
E-85	MW-90	Freeflow	0.20	0.27	2.64	2.63	0.86	0.85	1.21	0.66
	MW-90	St+Go	0.38	0.35	2.64	2.63	2.56	2.54	4.35	2.43
	RUR-NMW-70	Freeflow	0.18	0.16	14.76	14.66	0.94	0.93	0.89	0.55
	RUR-NMW-70	St+Go	0.33	0.37	14.76	14.66	3.04	3.03	3.34	2.18
	URB-Access-40	Freeflow	0.19	0.20	33.52	33.29	1.79	1.75	2.86	1.50
	URB-Access-40	St+Go	0.42	0.41	33.52	33.29	3.47	3.46	5.88	3.34
B-100	MW-90	Freeflow					0.62	0.61	0.96	0.53
	MW-90	St+Go					1.77	1.77	3.48	1.95
	RUR-NMW-70	Freeflow					0.76	0.75	0.71	0.44
	RUR-NMW-70	St+Go					2.10	2.11	2.67	1.74
	URB-Access-40	Freeflow					1.25	1.23	2.29	1.20
	URB-Access-40	St+Go					2.39	2.41	4.70	2.67
DME	MW-90	Freeflow					0.77	0.77	1.21	0.66
	MW-90	St+Go					2.21	2.21	4.35	2.43
	RUR-NMW-70	Freeflow					0.95	0.94	0.89	0.55
	RUR-NMW-70	St+Go					2.62	2.64	3.34	2.18
	URB-Access-40	Freeflow					1.56	1.53	2.86	1.50
	URB-Access-40	St+Go					2.98	3.01	5.88	3.34

Table A3.3 Emission factors for PM (g/veh.km) used in the scenarios developed in the project.

Vehicle type			LDV				HDV		Buses	
Emission Type			Hot Exhaust		Cold start		Hot Exhaust		Hot Exhaust	
Emission standard			E-5	E-6	E-5	E-6	E-V	E-VI	E-V	E-VI
Fuel	Road/Driving pattern									
Petrol	MW-90	Freeflow	0.0010	0.0011	0.0000	0.0000				
	MW-90	St+Go	0.0013	0.0012	0.0000	0.0000				
	RUR-NMW-70	Freeflow	0.0006	0.0005	0.0000	0.0000				
	RUR-NMW-70	St+Go	0.0006	0.0008	0.0000	0.0000				
	URB-Access-40	Freeflow	0.0003	0.0004	0.0000	0.0000				
	URB-Access-40	St+Go	0.0009	0.0009	0.0000	0.0000				
Diesel	MW-90	Freeflow	0.0012	0.0011	0.0001	0.0001	0.0327	0.0033	0.0164	0.0030
	MW-90	St+Go	0.0027	0.0026	0.0001	0.0001	0.0877	0.0089	0.1003	0.0086
	RUR-NMW-70	Freeflow	0.0013	0.0012	0.0007	0.0007	0.0387	0.0040	0.0132	0.0022
	RUR-NMW-70	St+Go	0.0035	0.0034	0.0007	0.0007	0.0986	0.0100	0.0824	0.0070
	URB-Access-40	Freeflow	0.0017	0.0017	0.0017	0.0015	0.0645	0.0066	0.0674	0.0062
	URB-Access-40	St+Go	0.0045	0.0043	0.0017	0.0015	0.1058	0.0107	0.1294	0.0105
CNG	MW-90	Freeflow	0.0008	0.0009	0.0000	0.0000	0.0060	0.0033	0.0030	0.0029
	MW-90	St+Go	0.0005	0.0005	0.0000	0.0000	0.0532	0.0089	0.0525	0.0086
	RUR-NMW-70	Freeflow	0.0005	0.0004	0.0000	0.0000	0.0077	0.0040	0.0026	0.0022
	RUR-NMW-70	St+Go	0.0003	0.0003	0.0000	0.0000	0.0598	0.0100	0.0421	0.0070
	URB-Access-40	Freeflow	0.0001	0.0002	0.0000	0.0000	0.0391	0.0066	0.0354	0.0062
	URB-Access-40	St+Go	0.0004	0.0004	0.0000	0.0000	0.0642	0.0107	0.0675	0.0105
E-85	MW-90	Freeflow	0.0005	0.0006	0.0000	0.0000	0.0024	0.0028	0.0018	0.0028
	MW-90	St+Go	0.0007	0.0006	0.0000	0.0000	0.0072	0.0086	0.0078	0.0076
	RUR-NMW-70	Freeflow	0.0003	0.0002	0.0000	0.0000	0.0027	0.0038	0.0008	0.0020
	RUR-NMW-70	St+Go	0.0003	0.0004	0.0000	0.0000	0.0080	0.0097	0.0063	0.0061
	URB-Access-40	Freeflow	0.0002	0.0002	0.0000	0.0000	0.0053	0.0064	0.0052	0.0055
	URB-Access-40	St+Go	0.0005	0.0005	0.0000	0.0000	0.0086	0.0103	0.0100	0.0093
B-100	MW-90	Freeflow					0.0355	0.0004	0.0170	0.0008
	MW-90	St+Go					0.0797	0.0089	0.0882	0.0086
	RUR-NMW-70	Freeflow					0.0422	0.0040	0.0135	0.0022
	RUR-NMW-70	St+Go					0.0896	0.0100	0.0720	0.0070
	URB-Access-40	Freeflow					0.0586	0.0066	0.0593	0.0062
	URB-Access-40	St+Go					0.0962	0.0107	0.1137	0.0105
DME	MW-90	Freeflow					0.0027	0.0033	0.0018	0.0028
	MW-90	St+Go					0.0071	0.0088	0.0078	0.0076
	RUR-NMW-70	Freeflow					0.0026	0.0040	0.0008	0.0020
	RUR-NMW-70	St+Go					0.0080	0.0099	0.0063	0.0061
	URB-Access-40	Freeflow					0.0052	0.0065	0.0052	0.0055
	URB-Access-40	St+Go					0.0085	0.0105	0.0100	0.0093

Table A3.4 Emission factors for NMVOC (g/veh.km) used in the scenarios developed in the project. Evaporative emissions (Evap.) includes hot soak emissions and running losses, both are recalculated to emissions per vehicle kilometre.

Vehicle type			LDV					HDV		Buses	
Emission Type			Hot Exhaust		Cold start		Evap.	Hot Exhaust		Hot Exhaust	
Emission standard			E-5	E-6	E-5	E-6	E-5, E-6	E-V	E-VI	E-V	E-VI
Fuel	Road/Driving pattern										
Petrol	MW-90	Freeflow	0.0037	0.0039	0.0620	0.0586	0.0015				
	MW-90	St+Go	0.0072	0.0073	0.0620	0.0586	0.0015				
	RUR-NMW-70	Freeflow	0.0034	0.0031	0.3462	0.3273	0.0062				
	RUR-NMW-70	St+Go	0.0073	0.0077	0.3462	0.3273	0.0062				
	URB-Access-40	Freeflow	0.0040	0.0040	0.7862	0.7432	0.0143				
	URB-Access-40	St+Go	0.0083	0.0081	0.7862	0.7432	0.0143				
Diesel	MW-90	Freeflow	0.0077	0.0070	0.0035	0.0036	0.0000	0.0379	0.0206	0.0215	0.0194
	MW-90	St+Go	0.0177	0.0163	0.0035	0.0036	0.0000	0.1350	0.0668	0.0680	0.0624
	RUR-NMW-70	Freeflow	0.0088	0.0081	0.0198	0.0202	0.0000	0.0512	0.0257	0.0151	0.0152
	RUR-NMW-70	St+Go	0.0217	0.0200	0.0198	0.0202	0.0000	0.1585	0.0769	0.0564	0.0557
	URB-Access-40	Freeflow	0.0120	0.0111	0.0449	0.0460	0.0000	0.0913	0.0472	0.0455	0.0412
	URB-Access-40	St+Go	0.0244	0.0225	0.0449	0.0460	0.0000	0.1741	0.0856	0.0872	0.0808
CNG	MW-90	Freeflow	0.0007	0.0007	0.0147	0.0015	0.0000	0.0042	0.0023	0.0024	0.0021
	MW-90	St+Go	0.0013	0.0013	0.0359	0.0015	0.0000	0.0148	0.0073	0.0075	0.0067
	RUR-NMW-70	Freeflow	0.0006	0.0005	0.0205	0.0050	0.0000	0.0056	0.0028	0.0017	0.0016
	RUR-NMW-70	St+Go	0.0013	0.0013	0.0450	0.0050	0.0000	0.0174	0.0084	0.0062	0.0060
	URB-Access-40	Freeflow	0.0007	0.0007	0.0276	0.0117	0.0000	0.0100	0.0052	0.0050	0.0045
	URB-Access-40	St+Go	0.0014	0.0014	0.0488	0.0117	0.0000	0.0191	0.0094	0.0096	0.0087
E-85	MW-90	Freeflow	0.0075	0.0080	0.0287	0.0029	0.0008	0.0322	0.0175	0.0183	0.0165
	MW-90	St+Go	0.0145	0.0148	0.0698	0.0029	0.0008	0.1148	0.0568	0.0578	0.0530
	RUR-NMW-70	Freeflow	0.0068	0.0062	0.0400	0.0097	0.0034	0.0435	0.0219	0.0128	0.0130
	RUR-NMW-70	St+Go	0.0148	0.0157	0.0876	0.0097	0.0034	0.1347	0.0654	0.0479	0.0473
	URB-Access-40	Freeflow	0.0081	0.0081	0.0537	0.0228	0.0079	0.0776	0.0401	0.0387	0.0351
	URB-Access-40	St+Go	0.0168	0.0164	0.0949	0.0228	0.0079	0.1480	0.0728	0.0742	0.0687
B-100	MW-90	Freeflow						0.0271	0.0206	0.0154	0.0194
	MW-90	St+Go						0.0965	0.0668	0.0486	0.0624
	RUR-NMW-70	Freeflow						0.0366	0.0257	0.0108	0.0152
	RUR-NMW-70	St+Go						0.1132	0.0769	0.0403	0.0557
	URB-Access-40	Freeflow						0.0652	0.0472	0.0325	0.0412
	URB-Access-40	St+Go						0.1244	0.0856	0.0623	0.0808
DME	MW-90	Freeflow						0.0303	0.0033	0.0018	0.0028
	MW-90	St+Go						0.0071	0.0088	0.0078	0.0076
	RUR-NMW-70	Freeflow						0.0026	0.0040	0.0008	0.0020
	RUR-NMW-70	St+Go						0.0080	0.0099	0.0063	0.0061
	URB-Access-40	Freeflow						0.0052	0.0065	0.0052	0.0055
	URB-Access-40	St+Go						0.0085	0.0105	0.0100	0.0093

Table A3.5. Emission factors for BC (g/veh.km) used in the scenarios developed in the project.

Vehicle type			LDV				HDV		Buses	
Emission Type			Hot Exhaust		Cold start		Hot Exhaust		Hot Exhaust	
Emission standard			E-5	E-6	E-5	E-6	E-V	E-VI	E-V	E-VI
Fuel	Road/Driving pattern									
Petrol	MW-90	Freeflow	1.29E-04	1.41E-04	0.0	0.0				
	MW-90	St+Go	1.67E-04	1.54E-04	0.0	0.0				
	RUR-NMW	Freeflow	7.37E-05	6.03E-05	0.0	0.0				
	RUR-NMW	St+Go	8.57E-05	1.03E-04	0.0	0.0				
	URB-Acce	Freeflow	4.57E-05	5.28E-05	0.0	0.0				
	URB-Acce	St+Go	1.17E-04	1.19E-04	0.0	0.0				
Diesel	MW-90	Freeflow	5.17E-04	4.67E-04	5.48E-05	5.07E-05	1.18E-02	1.20E-03	5.89E-03	1.08E-03
	MW-90	St+Go	1.12E-03	1.08E-03	5.48E-05	5.07E-05	3.16E-02	3.21E-03	3.61E-02	3.09E-03
	RUR-NMW	Freeflow	5.29E-04	5.06E-04	3.06E-04	2.83E-04	1.39E-02	1.44E-03	4.74E-03	7.98E-04
	RUR-NMW	St+Go	1.46E-03	1.42E-03	3.06E-04	2.83E-04	3.55E-02	3.60E-03	2.96E-02	2.52E-03
	URB-Acce	Freeflow	7.16E-04	6.94E-04	6.95E-04	6.43E-04	2.32E-02	2.37E-03	2.43E-02	2.23E-03
	URB-Acce	St+Go	1.86E-03	1.81E-03	6.95E-04	6.43E-04	3.81E-02	3.84E-03	4.66E-02	3.78E-03
CNG	MW-90	Freeflow	1.12E-04	1.22E-04	0.0	0.0	8.00E-04	4.41E-04	3.95E-04	3.86E-04
	MW-90	St+Go	7.08E-05	6.61E-05	0.0	0.0	7.11E-03	1.19E-03	7.01E-03	1.14E-03
	RUR-NMW	Freeflow	6.63E-05	5.42E-05	0.0	0.0	1.03E-03	5.35E-04	3.43E-04	2.96E-04
	RUR-NMW	St+Go	3.63E-05	4.39E-05	0.0	0.0	7.98E-03	1.33E-03	5.62E-03	9.33E-04
	URB-Acce	Freeflow	1.93E-05	2.26E-05	0.0	0.0	5.22E-03	8.79E-04	4.72E-03	8.26E-04
	URB-Acce	St+Go	4.98E-05	5.11E-05	0.0	0.0	8.57E-03	1.43E-03	9.01E-03	1.40E-03
E-85	MW-90	Freeflow	6.92E-05	7.64E-05	0.0	0.0	3.26E-04	3.69E-04	2.39E-04	3.69E-04
	MW-90	St+Go	8.95E-05	8.37E-05	0.0	0.0	9.56E-04	1.15E-03	1.04E-03	1.02E-03
	RUR-NMW	Freeflow	3.95E-05	3.27E-05	0.0	0.0	3.59E-04	5.08E-04	1.13E-04	2.69E-04
	RUR-NMW	St+Go	4.60E-05	5.56E-05	0.0	0.0	1.07E-03	1.29E-03	8.45E-04	8.18E-04
	URB-Acce	Freeflow	2.45E-05	2.86E-05	0.0	0.0	7.03E-04	8.49E-04	6.97E-04	7.34E-04
	URB-Acce	St+Go	6.29E-05	6.47E-05	0.0	0.0	1.15E-03	1.38E-03	1.34E-03	1.24E-03
B-100	MW-90	Freeflow					1.28E-02	1.39E-04	6.12E-03	3.00E-04
	MW-90	St+Go					2.87E-02	3.21E-03	3.17E-02	3.09E-03
	RUR-NMW	Freeflow					1.52E-02	1.44E-03	4.88E-03	7.98E-04
	RUR-NMW	St+Go					3.22E-02	3.60E-03	2.59E-02	2.52E-03
	URB-Acce	Freeflow					2.11E-02	2.37E-03	2.13E-02	2.23E-03
	URB-Acce	St+Go					3.46E-02	3.84E-03	4.09E-02	3.78E-03
DME	MW-90	Freeflow					5.99E-05	7.36E-05	4.02E-05	6.22E-05
	MW-90	St+Go					1.59E-04	1.98E-04	1.75E-04	1.71E-04
	RUR-NMW	Freeflow					5.95E-05	8.90E-05	1.91E-05	4.53E-05
	RUR-NMW	St+Go					1.79E-04	2.22E-04	1.42E-04	1.38E-04
	URB-Acce	Freeflow					1.17E-04	1.46E-04	1.17E-04	1.24E-04
	URB-Acce	St+Go					1.92E-04	2.37E-04	2.25E-04	2.10E-04

Table A3.6. Ratios of NO2/NOx for aggregated emission factors used in the scenarios developed in the project.

Vehicle type			LDV		HDV		Buses	
Emission standard			E-5	E-6	E-V	E-VI	E-V	E-VI
Fuel	Road/Driving pattern							
Petrol	MW-90	Freeflow	5.0%	5.0%				
	MW-90	St+Go	5.0%	5.0%				
	RUR-NMW	Freeflow	5.0%	5.0%				
	RUR-NMW	St+Go	5.0%	5.0%				
	URB-Acce	Freeflow	5.0%	5.0%				
	URB-Acce	St+Go	5.0%	5.0%				
Diesel	MW-90	Freeflow	35.0%	30.0%	7.3%	28.0%	9.7%	28.0%
	MW-90	St+Go	35.0%	30.0%	7.9%	28.0%	8.1%	28.0%
	RUR-NMW	Freeflow	35.0%	30.0%	7.4%	28.0%	8.8%	28.0%
	RUR-NMW	St+Go	35.0%	30.0%	8.0%	28.0%	8.1%	28.0%
	URB-Acce	Freeflow	35.0%	30.0%	7.6%	28.0%	8.1%	28.0%
	URB-Acce	St+Go	35.0%	30.0%	8.1%	28.0%	8.1%	28.0%
CNG	MW-90	Freeflow	5.2%	5.3%	7.3%	28.0%	9.7%	28.0%
	MW-90	St+Go	5.0%	5.1%	7.9%	28.0%	8.1%	28.0%
	RUR-NMW	Freeflow	5.2%	5.4%	7.4%	28.0%	8.8%	28.0%
	RUR-NMW	St+Go	5.0%	5.1%	8.0%	28.0%	8.1%	28.0%
	URB-Acce	Freeflow	5.0%	5.1%	7.6%	28.0%	8.1%	28.0%
	URB-Acce	St+Go	5.0%	5.1%	8.1%	28.0%	8.1%	28.0%
E-85	MW-90	Freeflow	3.3%	3.3%	7.3%	28.0%	9.7%	28.0%
	MW-90	St+Go	3.3%	3.3%	7.7%	27.3%	8.1%	28.0%
	RUR-NMW	Freeflow	3.3%	3.3%	7.2%	27.5%	8.8%	28.0%
	RUR-NMW	St+Go	3.3%	3.3%	7.8%	27.3%	8.1%	28.0%
	URB-Acce	Freeflow	3.3%	3.3%	7.4%	27.3%	8.1%	28.0%
	URB-Acce	St+Go	3.3%	3.3%	7.9%	27.4%	8.1%	28.0%
B-100	MW-90	Freeflow	35.0%	29.8%	7.3%	28.0%	9.7%	28.0%
	MW-90	St+Go	35.0%	29.8%	7.9%	28.0%	8.1%	28.0%
	RUR-NMW	Freeflow	35.0%	29.8%	7.4%	28.0%	8.8%	28.0%
	RUR-NMW	St+Go	35.0%	29.8%	8.0%	28.0%	8.1%	28.0%
	URB-Acce	Freeflow	35.0%	29.8%	7.5%	28.0%	8.1%	28.0%
	URB-Acce	St+Go	35.0%	29.8%	8.1%	28.0%	8.1%	28.0%
DME	MW-90	Freeflow	35.0%	30.0%	7.3%	28.0%	9.7%	28.0%
	MW-90	St+Go	35.0%	30.0%	7.9%	28.0%	8.1%	28.0%
	RUR-NMW	Freeflow	35.0%	30.0%	7.4%	28.0%	8.8%	28.0%
	RUR-NMW	St+Go	35.0%	30.0%	8.0%	28.0%	8.1%	28.0%
	URB-Acce	Freeflow	35.0%	30.0%	7.6%	28.0%	8.1%	28.0%
	URB-Acce	St+Go	35.0%	30.0%	8.1%	28.0%	8.1%	28.0%

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