uCARe

You Can Always Reduce Emissions

because you care

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Executive summary

The consumer behaviour measures investigated within the uCARe project reduce emissions of passenger cars. The impact of these measures on average annual air pollutant concentrations was investigated for the cities of Zurich, Gothenburg and Amsterdam for the years 2019/2020 and 2030. Pollutants considered are nitrogen dioxide (NO_2) and particulate matter (PM_{10} and $PM_{2.5}$). Two scenarios of implementation are compared to a baseline scenario. The "best-case" scenario assumes the perfect implementation of all interventions considered. The "most-likely" scenario assumes a realistic degree of implementation of the interventions, which is based on comparisons of driving patterns before and after training in the uCARe pilot studies and surveys carried out either within or outside the research program.

For each city a different Gaussian dispersion model is applied to assess the air pollutant concentration. The meteorological input and the chemistry used is roughly the same among the models, but the input for road emissions is more detailed for the models used in Zurich and Amsterdam than in the model used in Gothenburg. The models also differ in terms of accounting for the impact of street canyons and for changes in background concentrations due to the large-scale implementation of uCARe measures.

Reductions in air pollutant concentration due to uCARe measures are generally higher in Zurich than in Gothenburg and Amsterdam. Reasons for the observed differences are that for Zurich, the effect of measures on the background concentration is accounted for, which leads to a greater change in air pollutant concentration.

Another reason for the larger absolute reductions in Zurich as compared to Gothenburg is that the air pollutant concentration levels in Gothenburg are lower than in Zurich. Therefore, an equal relative change in emissions will result in a smaller absolute change in air pollutant concentrations in Gothenburg as compared to Zurich.

In addition, in the modelling for Amsterdam, the effect of street canyons is taken into account (which means that the reduction is large within the canyons but much smaller in the rest of the area that is shielded by the buildings). This leads to smaller changes in average concentrations.

The three models applied show reductions of air pollutant concentrations due to the uCARe measures along the road network in the order of up to 5.6 µg NO_2/m^3 and up to 1.2 µg $PM_{2.5}/m^3$ (95^{th} percentile), depending on the city and the scenario.

Even in the most-likely scenario, a substantial reduction in air pollutant concentration can be achieved along the main roads in all of the investigated study areas. The study area focuses on the city centre, which is densely populated in all three cities. The emission reduction achieved by the measures therefore significantly reduces the population's exposure to high air pollutant concentrations.

For all three cities a substantial reduction of NO_2 and $PM_{2.5}$ concentration is observed already in the baseline scenario between 2020 and 2030. Besides the reduced background emissions from other sources, the main reason for the expected reduction of air pollutant emissions are the changes in the composition of the vehicle fleet, since newer cars have lower emissions. The measures and interventions investigated within the uCARe project will therefore be more effective in the short term than in the long term. This calls for a rapid implementation of the proposed measures and interventions. The idea of the uCARe project indeed was to elaborate measures which can be implemented quickly, since new emission limits for cars, such as the expected EURO 7, take rather long to show full benefits due to the time needed for fleet renewal.

Furthermore, this study shows the importance of applying different types of models. To accurately assess impacts of measures on air pollutant concentrations, the model needs to account for the effect of street canyons, and an accurate assessment of the impact on background concentrations is necessary.

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Definitions & Abbreviations

AC	Air conditioner
ADMS-Urban	The Atmospheric Dispersion Modelling System model for cities
CLRTAP	Convention on Long-range Transboundary Air Pollution
EF	Emission factor
EMEP	European Monitoring and Evaluation Programme
DeltaEF	Delta Emission Factor
DoW	Description of work
HBEFA	The Handbook for Emission Factors
i.e.	Id est
NMVOC	Non-methane volatile organic compounds
NO_x	Nitrogen oxides
NO_2	Nitrogen dioxide
PC	Passenger cars
PHEM	Passenger car and Heavy duty Emission Model
PM_{10}	Particulate matter with a diameter of 10 µm or less
$PM_{2.5}$	Particulate matter with a diameter of 2.5 µm or less
SRM	Standard Calculation Method for air quality calculations in The Netherlands
uCARe	You Can Always Reduce Emissions Because You Care

1 Introduction

1.1 Background uCARe

With four million people dying annually due to outdoor pollution, improvement of air quality has become one of society's main challenges. In Europe, traffic and transport have a large effect on air quality, specifically passenger cars and commercial vehicles and to a lesser extent non-road mobile machinery. While technical improvements and more stringent legislation have had a significant impact, traffic and transport emissions are still too high and air quality is still poor. Although the use of electric and other zero-emission propulsion technologies may drastically reduce the pollutant exhaust emissions from traffic, the slow introduction of such vehicles as well as the trend of increasing vehicle lifetimes means that vehicles with internal combustion engines are expected to dominate the fleet beyond 2030. This project is the first opportunity to improve emissions of vehicles, not by improving vehicle technology, but by actively involving vehicle users and enabling their contribution to clean driving.

So far, expertise on pollutant emissions has mainly been used to advise European policy makers on limited effectiveness of emission legislation (through real-world emission factors such as HBEFA[1] and COPERT[2]) and how to reduce traffic and transport pollutant emissions. The numerous mitigation methods are rarely extended to include the perspectives of users. In this context, uCARe enables a next essential step: providing user targeted emission reduction measures. These measures are implemented and evaluated in real-life pilot projects.

The overall aim of uCARe is *to reduce the overall pollutant emissions of the existing combustion engine vehicle fleet by providing vehicle users with simple and effective tools to decrease their individual emissions and to support stakeholders with an interest in local air quality in selecting feasible intervention strategies that lead to the desired user behaviour*. The overall aim is accompanied by the following objectives:

1. To identify **user-influenced vehicle emission aspects** (such as driving behaviour and vehicle component choice).
2. To determine the **emission reduction potential** of each vehicle emission aspect with help of the uCARe model developed within a toolbox.
3. To develop a **toolbox**, containing models and emission reduction measures, that enables stakeholders to identify the most appropriate intervention strategies that reflect the specific users and their motivation.
4. **Support policy makers** and other **stakeholders with an interest in air quality,** such as municipalities and branch organizations, **in identifying intervention strategies** that translate the measures into desired behaviour of the user.
5. **To test and evaluate** intervention strategies in a set of pilot projects conducted with various target user groups in at least four European countries. The pilot projects illustrate effectiveness and feasibility of the toolbox and intervention strategies developed on its basis.
6. Perform an **impact assessment** of the intervention strategies effectiveness, in terms of cost, penetration, achieved emission reduction and lasting effects.
7. **Actively feed** European cities and international parties with uCARe learning and results, via awareness raising campaigns, communication tools, interactive web application and other dissemination activities. Open access to the broad public to the toolbox, data and developed tools.
8. Summarise the findings **in blueprints for rolling out** different user-oriented emission reduction programmes, based on successful pilots.

[1] The Handbook for Emission Factors for road transport

[2] COPERT | EMISIA SA

1.2 Purpose of the document

The purpose of this document is to provide a summary of the potential for air quality improvement from emission reductions due to different measures.

1.3 Document Structure

The present report is structured in five chapters. Chapter 1 is a general introduction and Chapter 2 shows the general approach of the air pollutant dispersion modelling for the three study areas investigated. It provides a brief description of the study areas and introduces the dispersion models applied in the calculation of the air pollutant concentration under different emission scenarios. The chapter concludes with a description of the general model settings.

Chapter 3 describes the main input data of the dispersion models, i.e. the emission data of the different scenarios, and the implementation in the three study areas.

Resulting maps of air pollutant concentrations as well as the statistical evaluation of the differences in air pollutant concentrations and emissions across the scenarios are provided in chapter 4.

Recommendations and conclusions are summarized in chapter 5.

1.4 Deviations from original DoW

Only minor deviations occurred, which are explained in this chapter.

1.4.1 Description of work related to deliverable as given in DoW

In this task, the potential for air quality improvement from emission reductions will be evaluated using air pollution dispersion models. These models will be set up to represent three to five selected cities, for which in-depth data is already available. Scenarios describing the combined impact of the highest ranked measures and interventions on emissions' reduction identified in Tasks 4.1 and 4.2 will be simulated. The outcome of these simulations will be compared to simulations of a realistic baseline scenario (without measures) for each selected city.

The focus will be to simulate effects on annually averaged concentrations and relevant percentiles of nitrogen dioxide and particulate matter in the urban air. The calculations will cover different spatial scales, starting on a 100 m grid to evaluate the effects on the city as a whole. In order to assess the environment where traffic emissions commonly play the most important role, calculations will also cover urban street canyons and other hot-spots on grids with higher spatial resolutions. Although primary attention will be on traffic emissions, we will take into account the emissions by other sources, such as industrial activity, residential/commercial combustion and long-range transported pollutants as background.

The different models used in this task are already available at the participating institutions and have been used in many studies. They have all been extensively verified and shown good agreement with observational data. In these advanced dispersion models, meteorological data is used to calculate dispersion including effects from the urban landscape and buildings, topography, deposition and photochemistry.

Results will be presented in a milestone report including maps showing pollution concentrations, as well as contributions to scientific papers prepared in Task 4.3 and to the information material which will be prepared in Task 4.5.

1.4.2 Time deviations from original DoW

As agreed with the Project Officer, an extension of 6 months was granted to finalize this document.

1.4.3 Content deviations from original DoW

The calculations will not cover different spatial scales for all cities, as initially described in the DoW. Instead, there will be one spatial scale for each city, namely the highest resolution.

The effect of single measures was not estimated, as this would require extensive additional model runs, which were not feasible within the framework of this project.

2 Approach

2.1 General approach

The uCARe consumer behaviour measures lead to changes in vehicle emissions, which were quantified in Task 4.1 and 4.2. Potentially the reduced emissions lead to improvements in air quality. These are quantified in the present task, using air pollution dispersion models, for selected cities in different countries by different partners:

- Zurich, Switzerland: INFRAS
- Gothenburg, Sweden: IVL
- Amsterdam, the Netherlands: TNO

The emission reductions from Task 4.1 and 4.2 are reflected in a change in HBEFA emission factors for a number of vehicle categories. The emission factors serve as an input to the traffic flow models that underpin the air pollution dispersion models.

The models, as introduced in paragraph 2.4, were developed by different institutes for different purposes. However, they all output city maps with changes in average emission concentrations and effects of measures in terms of changes in mass emissions on a city level.

The model parameters, such as resolution are harmonised as much as possible, as described in paragraph 2.3. Differences among the models are described in this paragraph, as far as these have an influence on the comparability of the results.

2.2 Introduction of the study areas

Zurich is located in the northeast of Switzerland, on the river Limmat at the outflow of Lake Zurich. The road network of Zurich is shown in Figure 1. Besides road transport, other important sources of emissions are the airport, located in the north of Zurich, heating furnaces in buildings, as well as industrial processes (e.g. waste incineration).

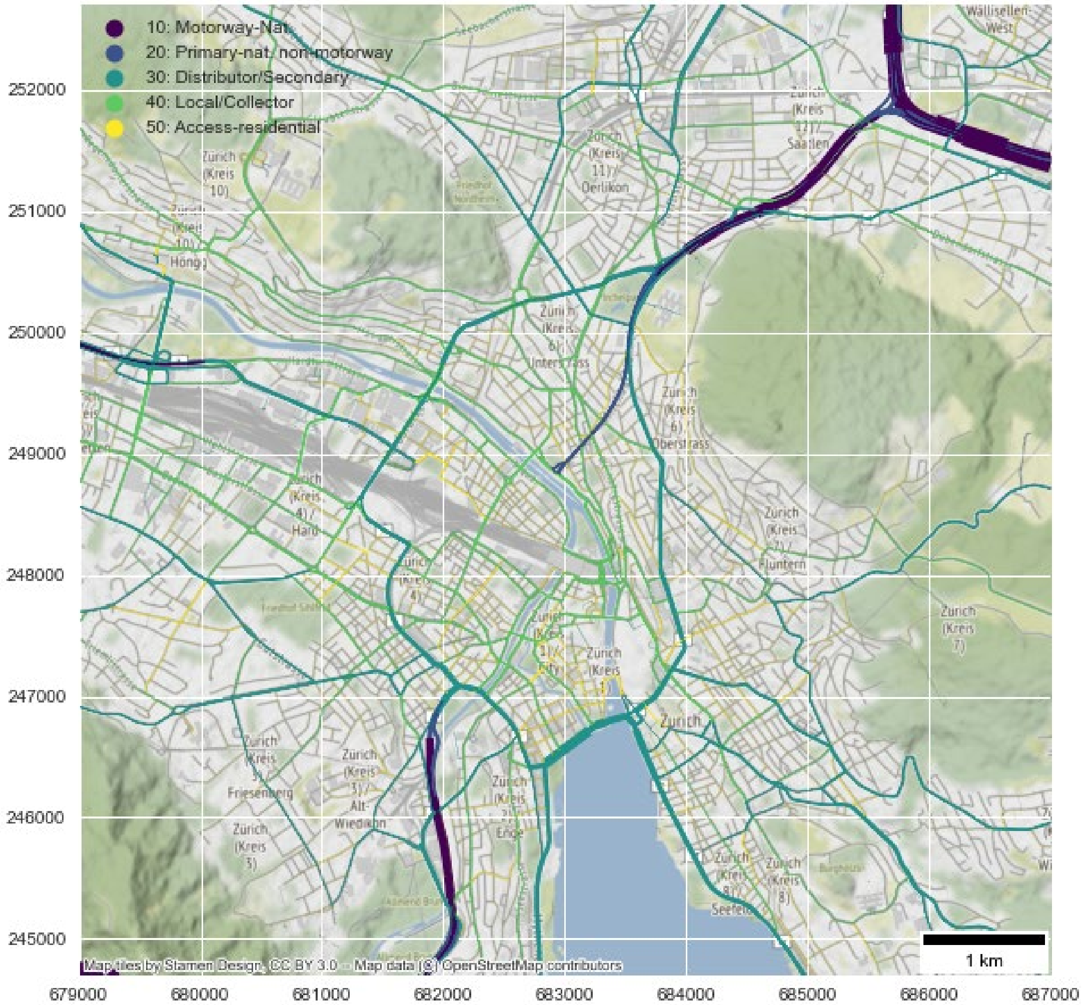


Figure 1. Road network of the city of Zurich

Gothenburg is located on the west coast of Sweden, at the mouth of Göta river. It has a large harbour and several industries. It has several major traffic routes close to the city centre, as shown in Figure 2.

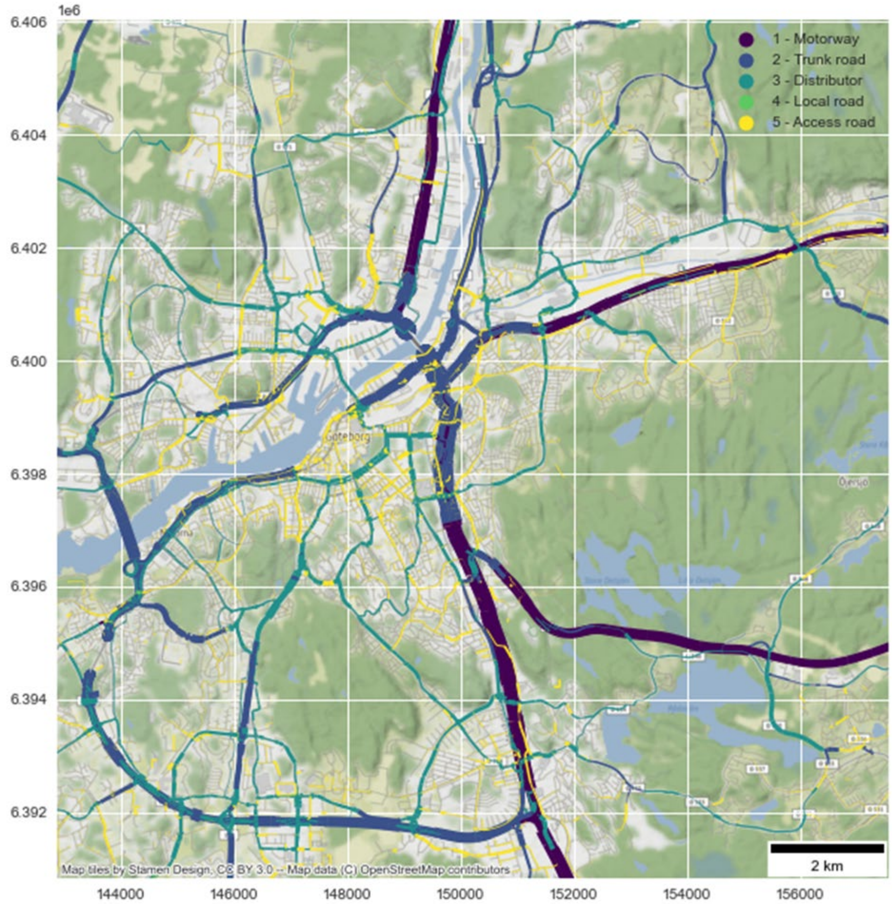


Figure 2. Road network of the city of Gothenburg

Amsterdam is situated in the west of the Netherlands. The harbour to the northwest hosts many industrial activities such as fuels storage and transhipment. To the southwest, Schiphol airport is located, just outside the actual municipality of Amsterdam.

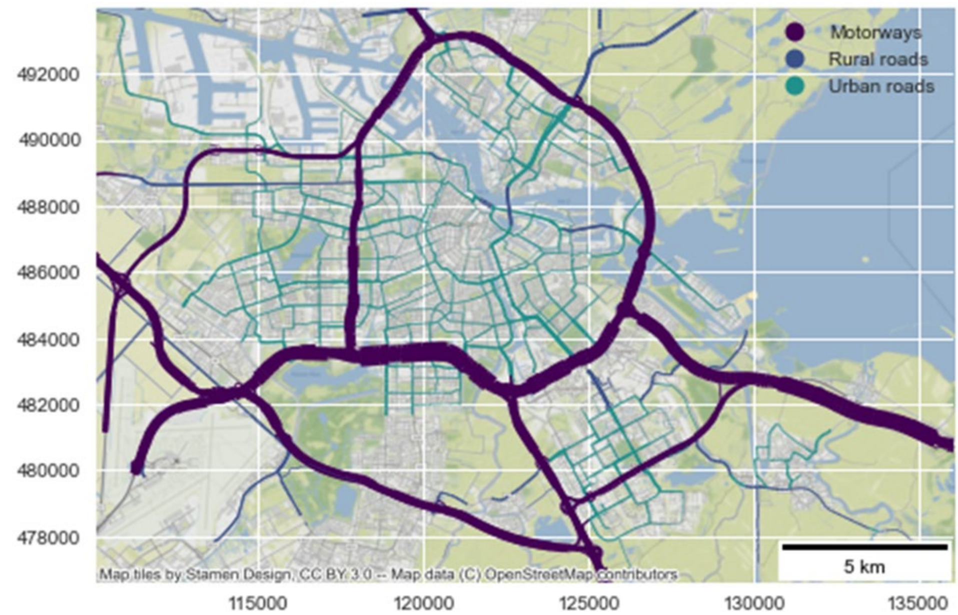


Figure 3. Road network of the city of Amsterdam

Details about the three study areas, Zurich, Gothenburg and Amsterdam are described in Table 1.

Table 1. Characteristics of the study area

Parameter	Unit	Zurich	Gothenburg	Amsterdam
Area	km^2	64	231	219* (of which 54 water)
Inhabitants	-	338,640	607,882	905,000
Major emission sources	-	Road transport Airport Buildings Industry	Industrial sources Large harbour Major traffic routes in city centre	Airport Harbour Industry
Total vehicle kilometres	million vkm	1,173.6	2,725.9	3,135.7
Meteorological conditions	-	Temperate climate	Marine climate	Marine climate

*) excluding Weesp. Inhabitants and vehicle kilometres are including Weesp.

2.3 General model settings

Three scenarios are investigated for the years 2019 (Gothenburg), 2020 (Zurich, Amsterdam)[3] and 2030 (all cities). Pollutants considered are nitrogen dioxide (NO_2) and particulate matter (PM_{10} and $PM_{2.5}$). For PM_{10} and $PM_{2.5}$ both exhaust and non-exhaust emissions are accounted for. For Gothenburg, PM_{10} is not included, due to the lack of data (no emission factors for PM_{10}).

The scenarios include a **baseline scenario**, which shows the expected evolution until 2030 without any interventions, a **best-case scenario**, which assumes ideal implementation of the behavioural measures to reduce emissions from road transport and a **most-likely scenario,** which accounts for the most-likely implementation of measures. The difference between the best-case scenario and the baseline scenario corresponds to the maximum reduction the measures can achieve.

In the present report results are shown for the following scenarios and time steps:

1. Baseline scenario 2019/2020
2. Most-likely scenario 2019/2020
3. Best-case scenario 2019/2020
4. Baseline scenario 2030
5. Most-likely scenario 2030
6. Best-case scenario 2030

The best-case scenario is the scenario with the lowest emissions from road transport, due to implementations of measures described in section 3. The most-likely scenario has higher emissions than the best-case scenario since the measures are assumed to be implemented in a more likely way. The difference between the pollutant emissions for the most-likely and baseline scenario give the "real-world" emission savings that we expect for the measures.

[3] The impact of the Corona pandemic on emissions from road transport due to a drop in traffic volumes is not accounted for in the scenarios for 2020. The results are based on a business as usual scenario based on historical data.

For each city, two areas are studied: a total area which is the whole city, and a focus area which is the city centre. The total area of the cities is shown in Figure 1, Figure 2 and Figure 3 and the focus area is for Zurich the black rectangle in the pollution maps, (Figure 14-Figure 20), for Gothenburg the focus area is the pollution maps (Figure 24-Figure 31), and for Amsterdam (Figure 34-Figure 39) it is the area with colours.

For each scenario, emissions are first calculated in the total area for each city, total emissions for Amsterdam and Zurich and road emissions for all three cities.

Then modelling is performed in the focus area. The following statistics are studied:

1. Annual mean concentration in the study area (µg/m^3)
2. Mean of difference in total air pollutant concentrations between scenarios (µg/m^3)
3. Median of difference in total air pollutant concentrations between scenarios (µg/m^3)
4. 5th and 95th percentiles of difference in total air pollutant concentrations between scenarios (µg/m^3)
5. Impact of measures on annual mean concentration in the study area (µg/m^3)

For all models, the traffic network is assumed to remain unchanged in 2030 compared to 2020.

2.4 Introduction of dispersion models

2.4.1 Introduction

In the cities, three different models were applied. In the next paragraphs these will be discussed separately. Table 2 gives a brief overview of the main features.

Table 2. Features of the three models

	Gothenburg/ADMS Urban	Zurich/PolluMap	Amsterdam/Urban Strategy – Air Model
Model description	Quasi-Gaussian plume air dispersion model	Gaussian dispersion model. Depending on the location, emission height and emission pattern, a different annual average dispersion pattern is applied. Contribution of background contributions and secondary PM is accounted for.	Gaussian. The air quality model is a real-time implementation of the URBIS model. It calculates the dispersion of NO_2 and PM_{10} on a street level for urban areas (SRM1) and around highways (SRM2). It uses the Dutch SRM1 and SRM2 (standardized calculation methods).
Emission input	Transport	Transport (road, rail, ship, air) Heating Industry Agriculture	Detailed traffic model of Amsterdam Other sources: Industry and energy sector, households, SME and services, agriculture & nature; taken from Generic Concentrations Netherlands (GCN)
Meteorological input	Hourly data for: Wind speed and direction	Wind speed and direction Stability classes	Urban: Average annual wind speed Highway: Frequency of wind direction, average wind speed and

	Gothenburg/ADMS Urban	Zurich/PolluMap	Amsterdam/Urban Strategy – Air Model
	Air temperature Relative humidity Precipitation Downwelling shortwave radiation	Height of mixed classes	average ozone concentration per direction
Chemistry	Reactions between NO_x and O_3 Conversion of SO_2 into particles	NO_x-NO_2-transformation	Secondary effect NO to NO_2
Grid	50 m	20 m for road transport, 100 m all other sources. 100 m for output grid.	Flexible, 10 m next to urban roads, larger in other areas

All three models are Gaussian or quasi-Gaussian, this means that the emission dispersion is modelled in the same way.

In the model used for Gothenburg, only road transport emissions are included (and the background concentration), while other emission types are included in the models for Zurich and Amsterdam. This could lead to an underestimation of the pollutant concentration in Gothenburg.

The meteorological input and the chemistry used is roughly the same among the models, but the input grid for road emissions is finer for the models used in Zurich and Amsterdam than in the model used in Gothenburg (since different grid resolutions are suitable for the different models). This means that the level of detail is lower for Gothenburg.

2.4.2 PolluMap (INFRAS)

For the city of Zurich, the dispersion model "PolluMap" (developed by INFRAS and Meteotest) is applied. The latest version stems from July 2020 [1].

Emission data

The main input of the dispersion model PolluMap consist of emissions of different emission sources. These data are based on the national inventory on air pollutant emissions, which Switzerland reports annually under the Convention on Long-range Transboundary Air Pollution (CLRTAP). The PolluMap model accounts for emission sources from transport, households and the industrial sector as well as agriculture and forestry (see Table 3). Total emissions are regionally disaggregated by means of suitable indicator, such as number of inhabitants, agricultural area, living area per hectare etc. (see [2] for further information on the spatial disaggregation of emissions). The emission grids exhibit a spatial resolution of 100 m. For road transport a resolution of 20 m is applied up to a distance of 150 m from the road network[4], since these emissions show a considerable spatial variation. Large

[4] Because the dispersion of emissions close to roads strongly depends on the building density, three categories are distinguished in the dispersion modelling: low, medium, high building density.

industrial emission sources are accounted for as point sources and all other emission sources are accounted for as “area sources”.

Table 3. Emission sources PolluMap model

Category	Emission sources
Traffic	Road transport
	Rail transport
	Shipping
	Air transport
	Other (Vehicle fire)
Households	Furnaces oil/gas
	Furnaces wood
	Gardening machinery
	Other (Fireworks, fires, tobacco use, illegal burning of waste)
Industry/Services	Furnaces oil/gas/wood
	Large industrial plants
	Construction industry
	Industrial vehicles and machinery
Agriculture/Forestry	Livestock
	Agricultural machinery
	Forestry machinery
	Open burning of waste
	Agricultural furnaces
	Fermentation

Apart from road transport, emissions from all other sources are kept constant in the scenarios analysed in the present report. The model simulations are based on the same data source as described in [1]. Emission data are available for the years 2020 and 2030.

The dispersion model PolluMap provides annual mean air pollutant concentrations based on hourly inputs. The hourly emission inputs are calculated by applying temporal patterns that account for the daily variations in emissions from road transport and from furnaces used for the heating of buildings. For the latter also seasonal variability is accounted for.

Meteorological data

The dispersion model takes into account the following meteorological variables:

- Wind speed and direction
- Stability classes
- Height of mixed classes

The model applies these meteorological data at an hourly resolution to account for daily and seasonal variability in the meteorological conditions. Furthermore, three climatic regions are distinguished (Alpine area, Swiss midland, Southern Switzerland). The model calculations apply average meteorological conditions for each climatic region.

Model approach

Using the emission grids and the meteorological data described above, the PolluMap model calculates air pollutant concentrations in 3 steps (Figure 4). In a first step, dispersion patterns are calculated. In the second step, these are applied to the emission grids and in the last step total air pollutant concentration is calculated by summing up the different emission sources, including background concentrations and secondary sources of particulate matter.

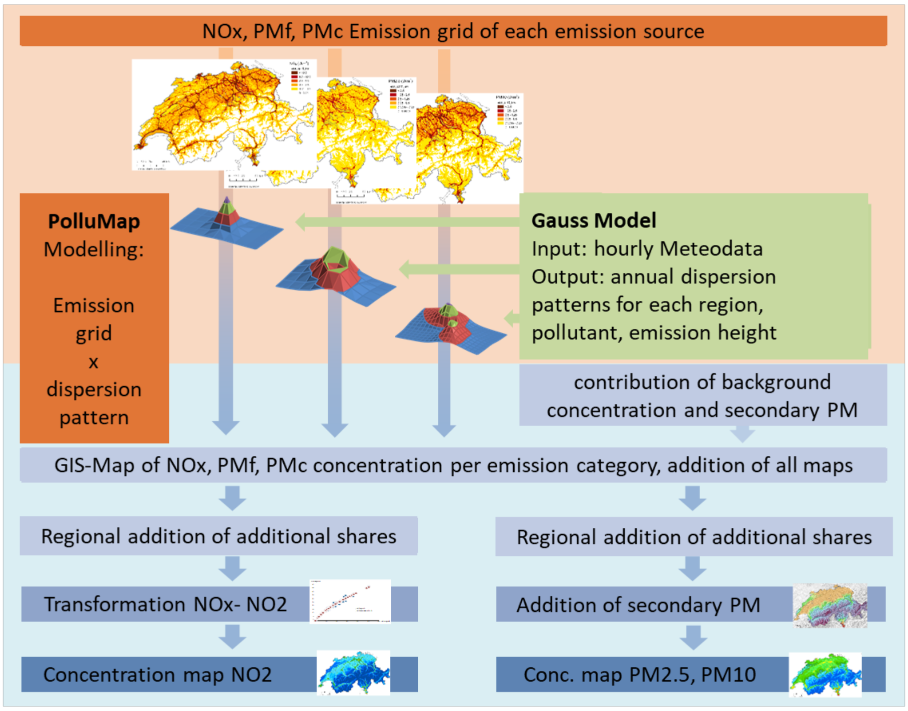


Figure 4. Overview PolluMap simulation procedure

1. Dispersion patterns

The dispersion patterns are calculated by a Gaussian dispersion model for a unit emission of 1 t per year (based on hourly meteorological data).

$$C(x,y,z) = \frac{E}{2\pi u \sigma_y \sigma_y} exp\left(\frac{y^2}{2\sigma_y^2}\right)\left[exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right]$$

x, y, z: Cartesian coordinates

E: Emission in tons

u: wind velocity in m/s

H: Emission height in m (Ejection height plus plume rise)

σ_y , σ_z : horizontal and vertical dispersion parameters, dependent on meteorological conditions.

2. Multiplication of emission grids with dispersion patterns

Each raster cell of an emission grid is multiplied by its corresponding dispersion pattern resulting in a corresponding concentration grid for each emission source. These concentration grids cover an area of 20 km x 20 km.

$$c_\alpha(x, y; x_0, y_0) = E_\alpha(x_0, y_0) \cdot M_\alpha(x, y);$$

$M_\alpha(x,y)$ Dispersion pattern

$E_\alpha(x_0,y_0)$ Emission at location x_0,y_0

x ranges from x_0 – 10 km to x_0 + 10 km

y ranges from y_0 – 10 km to y_0 + 10 km

For point sources with high emission heights a distance of 20 km is applied.

3. Calculation of total air pollutant concentration maps

The total air pollutant concentration at a given location $C(x, y)$ is calculated by summing up the contribution of concentration grids from all emission sources $c_\alpha(x, y; x_i, y_j)$ covering that location.

$$C(x, y) = \sum_{\alpha,i,j} c_\alpha(x, y; x_i, y_j),,$$

where α indicates the emission sources.

In addition, in this step also the transformation of NO_x to NO_2 is accounted for. Furthermore, additional contributions to air pollutant concentration besides direct emission sources are accounted for (Table 4).

Table 4: Additional contributions to air pollutant concentration

Emission source	Description
Background concentration	Some of the air pollutant concentration is imported from neighbouring countries. This contribution is based on calibration to measured air pollutant concentrations in different regions of Switzerland and a height dependent contribution is assumed. $HG_{Region}(h, t) = c_{0,Region}(t) \cdot e^{-h/h_{0,Region}}$ For the area of Zurich c_0 is 28 µg/m^3 for NO_x and 7.5 µg/m^3 for PM_{10} (with $PM_{2.5}$ contributing a share of 47% of PM_{10} concentration in 2020) and h0 =714 m. For the temporal evolution it is assumed that the background concentrations of NO_x, PM_{10} and $PM_{2.5}$ will exhibit the same relative changes as the corresponding emissions of these gases.
Biogenic and geogenic sources of PM	The emission grids used as inputs in the PolluMap model only account for anthropogenic sources of emissions. For particulate matter, also geogenic sources (e.g. erosion, Sahara dust) and biogenic sources (e.g. non-methane volatile organic compounds (NMVOC) from forests) need to be accounted for. The contribution of geogenic sources is also estimated based on calibration to measurements and is assumed constant across Switzerland (1 µg $PM_{2.5}$/m^3).

Emission source	Description
	Biogenic sources (NMVOC) are estimated based on EMEP data[5], in the area of Zurich the concentration is 1 µg NMVOC/m³.
Compensation for limited dispersion distance	As the dispersion patterns are limited to a distance of 10-20 km, the air pollutant concentration is underestimated by the model. To compensate for the limited dispersion a constant concentration is added at elevations below 700 m (e.g. 2 µg NO_x /m³).
Secondary sources of air pollutants	Secondary particulate matter is formed from gaseous air pollutants in the atmosphere. The important precursor gases are NO_x, SO_2, NH_3 and NMVOC. The concentration of the resulting particulate matter (nitrate, sulphate and ammonium salts and organic matter). These secondary particle concentrations are estimated based on EMEP data, which are interpolated to a finer spatial resolution. For the temporal evolution it is assumed that the concentrations of secondary particulate matter will exhibit the same relative changes as the emissions of the corresponding precursor gases.

Atmospheric chemistry

The model accounts for the transformation of NO_x to NO_2 in the atmosphere according to the following formula based on [3] calibrated to measurements in Switzerland.

$$[NO_2] = \frac{A \cdot [NO_x]}{[NO_x] + B} + C \cdot [NO_x]$$

A = 21.9 µg/m³

B = 34.6 µg/m³

C = 0.289

2.4.3 ADMS-Urban (IVL)

The Atmospheric Dispersion Modelling System (ADMS) has a version (ADMS-Urban) which is suitable for cities, which is a quasi-Gaussian plume air dispersion model. ADMS-Urban can take several different emissions sources into account, such as transport and industry (but industry was not included in this study), both as point, line, area, volume and grid sources [4]. The following sections describe input to the model in this project.

Emission data

Emission factors for NO_x and $PM_{2.5}$ in different scenarios (see section 3 for description) are received for light and heavy vehicles from the previous task, for each road link in the city.

The traffic emissions (for each pollutant) are then distributed to a grid (where each grid cell could contain several road links), using the following equation

$$E_i = \sum_{j=1}^{\mathrm{N_i}} EF_j \cdot veh_j \cdot l_j,$$

where E_i are the emissions in grid cell i, $\mathrm{N_i}$ is the number of road links in grid cell i, EF_j is the emission factor for road link j in the grid cell [g/vehicles/km], veh_j is the number of vehicles for road link j [vehicles] and l_j is the length of road link j [km].

[5] European Monitoring and Evaluation Programme (EMEP) MSC-W modelled air concentrations and depositions.

http://www.emep.int/mscw/mscw_moddata.html

Due to a limitation in the model, only 3000 grid cells could be used. With a grid cell size of 50 x 50 meters, and 54 grid cells in each direction, an area of 2.7 x 2.7 km is studied.

Meteorology

Hourly data for wind speed, wind direction, air temperature, relative humidity, short wave radiation and precipitation is input to the model. The data is from a meteorological station in Gothenburg [5] and for 2019. For the scenarios for 2030, the same meteorology is used.

Background and chemistry

The background data for $PM_{2.5}$ is obtained by taking the yearly average from a measure station located at the north border of the domain [6]. The model is run once without background to compute the contribution to the background of traffic emissions from $PM_{2.5}$. This contribution is then subtracted from the yearly average for the background, and the result is used as the new background.

For NO_x, O_3 and SO_2, hourly background data is obtained from a run of the EMEP MSC-W model [7].

The background data then interacts with the traffic emissions according to reactions between NO_x and O_3, see [4] for details. For 2030, the background data is assumed to be the same as for 2019.

2.4.4 Urban Strategy – USAIR module (TNO)

In The Netherlands, the evaluation of the effect of spatial plans on air quality has to be done according to the Air Quality Assessment Regulation (2007). Three complementary standard calculation methods (SRMs) are prescribed: SRM-1 for roads in the built environment (~urban), SRM-2 for motorways, and SRM-3 for point and area sources (latest changes see [8]). The air quality model employed here for Amsterdam is basically an interactive version of SRM-1 and SRM-2 called "USAIR". It is running on a platform called Urban Strategy[6].

Emission data

Emission data for traffic is a multiplication of the intensity and emission factor for each road segment for each vehicle class. The intensities are weekday averages for four vehicle categories: light vehicles (<3.5t) (passenger cars + vans), medium duty freight transport (3.5-20t), heavy-duty freight transport (>20t) and buses. They are derived from an implementation of the Amsterdam traffic model on the Urban Strategy platform. Emission factors are derived from the national values, as published by the Dutch National Institute for Public Health and the Environment (RIVM) [9]. These are based on TNO VERSIT+ (latest version: SRM version 2022-03-29).

The method is described in [10]. This version introduces aging for older passenger cars. Dependent on the year (2020 or 2030), vehicles with certain Euro emission standards are attributed to increased emission levels, based on the knowledge obtained from recent

[6] Urban Strategy was developed as an interactive calculation and demonstration tool for municipalities, to help decision making around spatial planning. It is basically a framework for communication between existing models such as noise, air quality and safety. The air quality module is a 'live recalculation' version of the Urbis III model.

studies [11]. The effect of uCARe measures is expressed as a reduction of VERSIT+ emission factors, following the procedure described in paragraph 3.4.

To calculate the annual average concentrations of NO_2 and PM_{10}, the traffic emissions are combined with background data from the Generic Concentration Netherlands (GCN) maps, which have a resolution of 1x1 km. The GCN maps contain total emissions of all sources, including traffic. To avoid double counting, the contribution of the traffic in these maps is subtracted.

The annual average concentrations of NO_2 and PM_{10} are calculated with two different models, one for urban roads (method SRM1) and one for rural roads and highways (method SRM2). SRM1 has a high spatial resolution around roads, and a lower resolution further from the roads. In SRM2, dispersion is calculated across a longer range (5 km as opposed to 60 m) and takes into account local meteorological profiles as well. For SRM1, the receptors are positioned perpendicular to the road axis, starting at the distance between the road axis and the edge of the sidewalk, see Figure 5.

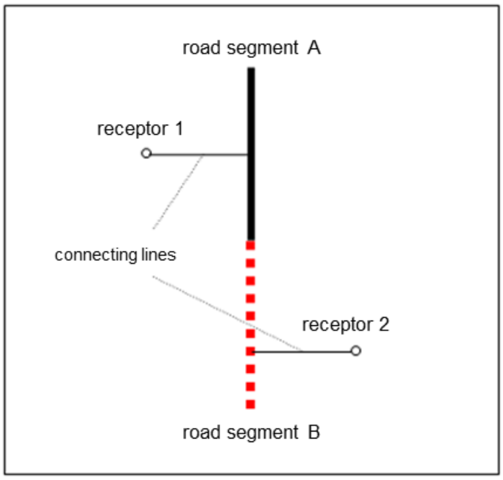


Figure 5. Situation diagram for urban roads

The concentration is calculated for receptors at a distance of up to 30 to 60 m from the road axis, dependent on the distance of the facades, and at a pitch distance of 10 m in longitudinal direction. Shielding by buildings is implemented using four street canyon types (see Figure 6).

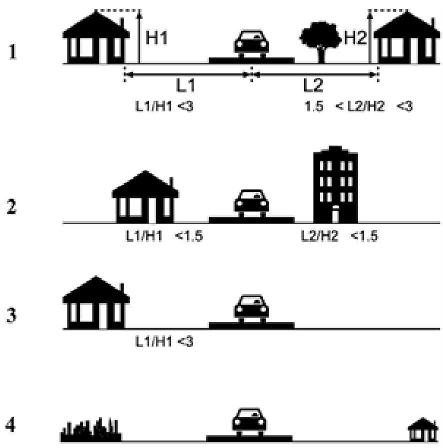


Figure 6. Street canyons

SRM2 adds the contributions of all road sections in a radius of 5 km around the receptor, see Figure 7. These receptors are placed in a regular grid of 10 x 10 m as well.

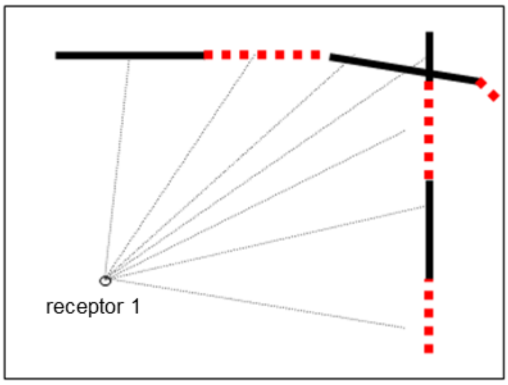


Figure 7. Situation diagram for non-urban roads

Meteorological data

Multi-year meteodata (year-year) of stations Schiphol and Eindhoven are used, as prescribed by the Air Quality Assessment Regulation (2007).

For wind, urban calculations account for the average annual wind speed at a location, which uses a 1x1 km map, interpolated between Schiphol airport and Eindhoven measurements. A terrain roughness coefficient is used as a correction factor. For motorways, 12 wind directions are distinguished. Concentration contributions are weighted by their annual occurrence. The ozone concentrations, important for the calculation of the NO to NO_2 conversion, are dependent on the wind direction.

3 Input data

3.1 General introduction

The air quality models introduced in section 2.4 require emission and meteorological input data. The focus of this chapter is on emission inputs, and among these on road transport emission input: This represents the input of interest, which differs between the scenarios – all other input data remain constant.

The format of the required road transport emission input data varies by air quality model:

- PolluMap (used for Zurich) requires absolute emission inputs
- ADMS-Urban (used for Gothenburg) requires emission factors for heavy and light vehicles, plus the average daily traffic volume of these two categories
- Urban Strategy (used for Amsterdam) requires emission factors per vehicle category per road type.

The road transport emission models used to calculate the input also differ between the case studies:

- For the Gothenburg and Zurich case studies, the Handbook of Emission Factors for Road Transport, Version 4.2 [12] is used.
- For the Amsterdam case study, VERSIT+ is used, emission factors SRM version 2022-03-29, method description report version 2022 [10].

The common approach for all case studies is to derive so-called "delta emission factors" (delta EF), i.e. relative improvements, expressed in % of the default average emission factors for passenger cars (PC), for the two scenarios evaluated. These scenarios correspond to those evaluated in Deliverable 4.2 (D4.2) of the uCARe research program [13]:

- The "best-case" scenario assumes the perfect implementation of all interventions considered (see Table 5). This is mostly theoretical: the interventions in the "ecodrive" intervention group, i.e. acceleration, braking, gear shifting etc. were simulated using the "super-eco" mode in the uCARe PHEM model; for the maintenance, AC and cold start intervention groups, the maximum feasible implementation is assumed.
- The "most-likely" scenario assumes a realistic degree of implementation of the interventions, which is based on comparisons of driving patterns before and after training in the uCARe pilot studies and surveys carried out either within or outside the research program.

The selection of interventions considered in the "best-case" and "most-likely" scenarios corresponds to the lines with the entry "Best-case, Most-likely" in the column "Overall Intervention" in Table 5. In both scenarios the same measures are accounted for, in the best-case scenario, it is assumed that the full potential is achieved, whereas in the most-likely scenario a more realistic assumption of implementation is considered. More detailed information can be obtained from D4.2, particularly sections 3.2 and 4.

Table 5. Summary of individual interventions and intervention groups

Intervention	Abbreviation	Intervention group	Overall Intervention
Default driving by untrained drivers	Default	Default	Default
Correct tire pressure/ use most efficient tires	Tire	Maintenance	Best-case, Most-likely
Remove roof boxes, no extra load etc.	Load		Best-case, Most-likely
Reduce A/C use	AC	AC	Best-case, Most-likely
Optimal shifting	Shift	Ecodrive	Best-case, Most-likely
Avoid excessive speed	Speed		Best-case, Most-likely
Accelerate smoothly	Acceleration		Best-case, Most-likely
Brake gently/ use engine brakes	Brake		Best-case, Most-likely
Do not idle more than 30 seconds	Idling	Idling	Best-case, Most-likely
Avoid heavy traffic	Traffic	Traffic	Best-case, Most-likely
Avoid cold starts	Cold start	Cold start	Best-case, Most-likely
Avoid unnecessary driving	Drive less		
Purchase new cleaner and more efficient car	New car		

As an output of D4.2, so-called "base emission factors" (i.e. emission factors normalized to a vehicle with 50'000 km cumulative mileage and at 20°C ambient temperature) are available for both scenarios, and for each HBEFA traffic situation and each HBEFA passenger car subsegment. A "traffic situation" in HBEFA is defined by area type (urban or rural), road type, speed limit, and level of service (LOS, i.e. 5 traffic level density classes from freeflow to gridlock traffic jam). A "subsegment" is a vehicle type defined by vehicle category (in this case, passenger car), drivetrain technology (such as petrol, diesel, battery-electric vehicle (BEV), etc.), and emission standard (such as Euro-3, Euro 6ab, etc.).

These base emission factors for the two scenarios, as well as the default base emission factors from HBEFA 4.2, were weighted by the vehicle kilometre share of each subsegment in the fleet for each case study location and for the reference years 2020 (2019 for Gothenburg) and 2030. This way, average uncorrected passenger car emission factors for each pollutant, each traffic situation and both reference years were obtained – uncorrected in the sense that they represent PC averages but are still normalized to 50'000 km cumulative mileage and at 20°C ambient temperature.

The delta EFs were then derived as the ratio of the resulting average EF of each scenario to the HBEFA 4.2 default minus 1:

$$\Delta EF_{Pollutant,traffic\,sit.} = \frac{EFScen_{Pollutant,traffic\,sit.}}{EFDefault_{Pollutant,traffic\,sit.}} - 1$$

with

$\Delta EF_{Pollutant,traffic\,sit.}$	=	Delta emission factor, the average for PC, by pollutant and traffic situation [%]
$EFScen_{Pollutant,traffic\,sit.}$	=	Scenario emission factor, the average for PC, by pollutant and traffic situation [g/km]
$EFDefault_{Pollutant,traffic\,sit.}$	=	Default HBEFA 4.2 emission factor, the average for PC, by pollutant and traffic situation [g/km]

These delta EFs were then applied to the corrected HBEFA 4.2 emission factors (i.e. considering aging and temperature effects) for each road segment (containing the information on the area, road type, and speed limit, i.e. the static parameters of the traffic situations) and the share of the average daily traffic (ADT) in each LOS (the dynamic parameter of the traffic situations) per road segment. This way, absolute emission factors in g/km for each road link, LOS and scenario resulted, which could be multiplied with ADT and the number of days per year to obtain emissions.

Figure 8 summarizes the methodology graphically.

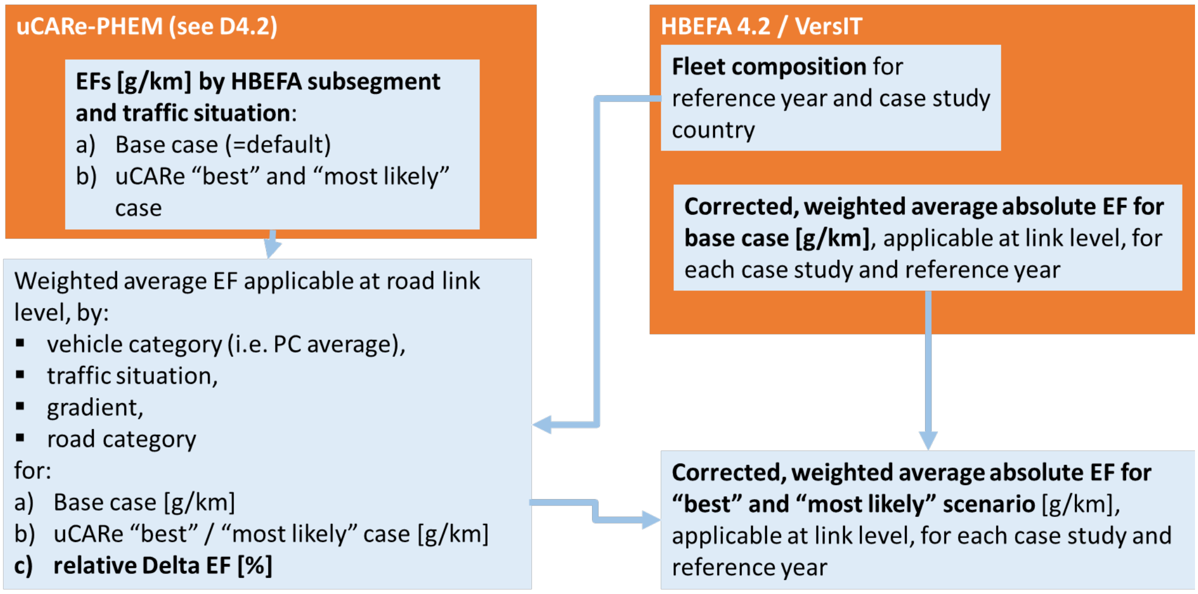


Figure 8. Methodology to derive input road transport emission factors for passenger cars under the two uCARe scenarios.

The average mileage shares of the different traffic situations, particularly of the LOS in each speed limit class, are shown in Figure 9 based on the six countries covered in HBEFA. The shares in the focus areas of the three case studies differ from this average, of course, but Figure 9 gives a good impression of typical LOS shares per speed limit class.

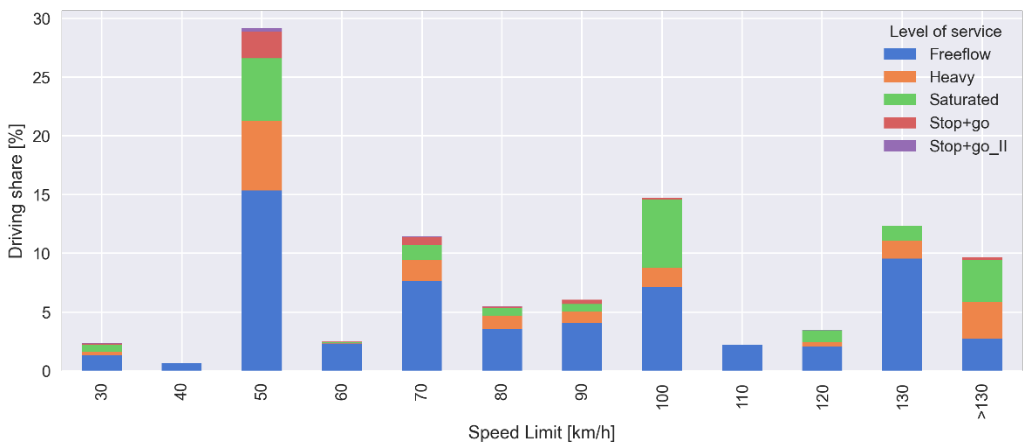


Figure 9. European average traffic situation shares (expressed as % of total PC mileage, based on traffic situation shares from six countries covered in HBEFA).

For all other vehicle categories besides PC (i.e. light commercial vehicles, trucks, buses, coaches, motorcycles), emissions were calculated using the default emission factors, resulting in identical emissions for the base case and the two scenarios which is in line with the assumption that the uCARe interventions affect PC only.

The detailed implementation differs by case study and is described in the following subchapters.

3.2 Implementation in Zurich

For the Zurich case study, HBEFA 4.2 [12] was used for road transport emission modelling. The emissions resulting from the steps described in the previous chapter were used directly as air quality modelling input in PolluMap.

Road network and traffic volume inputs were available from a previous study [1]. They were based on the output of the Matsim agent-based traffic model [14], which contains traffic volumes for all existing road segments in Switzerland. Mileages for 2015 were scaled so the totals for 2015 match the mileages from the official national statistics [15, 16]; to derive mileages for 2020 and 2030, the 2015 mileages were scaled using development factors by vehicle category based on the Swiss reference scenario in HBEFA [12]. HBEFA traffic situation classifications had been added in [1]. The road traffic mileages in the total and focus area, are respectively shown in Table 6 and Table 7.

Emissions for the default scenario (without uCARe interventions) that had been modelled in [1] based on HBEFA Version 4.1 were recalculated with Version 4.2 [12] for the present study; for the uCARe intervention scenarios, the methodology outlined in the previous chapter was applied. Emission results are summarized in Table 10 (total area), Table 13 and Table 14 (focus area).

Table 6. Mileages by road type and vehicle category [million veh.km/a] in the total area.

Road type	Pass. car	LCV	Coach	Urban bus	Motorcycle	HGV	TOTAL
Motorway	191.3	21.3	0.6	0.0	6.6	11.2	**231.1**
Trunk road	73.1	7.0	0.3	0.5	3.6	2.0	**86.5**
Distributor	415.3	27.2	0.4	1.9	27.4	5.7	**477.9**
Collector	252.7	17.3	0.3	1.3	18.5	3.8	**294.0**
Access	73.0	4.4	0.1	0.3	5.7	0.8	**84.2**
TOTAL	**1,005.4**	**77.2**	**1.6**	**4.0**	**61.9**	**23.5**	**1,173.6**

Table 7. Mileages by road type and vehicle category [million veh.km/a] in the focus area.

Road type	Pass. car	LCV	Coach	Urban bus	Motorcycle	HGV	TOTAL
Motorway	3.0	0.3	0.0	0.0	0.1	0.1	**3.5**
Trunk road	29.8	3.4	0.1	0.3	1.5	0.9	**35.9**
Distributor	159.8	9.4	0.1	0.7	10.3	2.2	**182.6**
Collector	120.9	9.4	0.2	0.8	8.3	2.3	**141.9**
Access	34.3	1.9	0.0	0.1	2.5	0.4	**39.3**
TOTAL	**347.8**	**24.5**	**0.4**	**1.9**	**22.7**	**5.9**	**403.2**

3.3 Implementation in Gothenburg

For the Gothenburg case study, HBEFA 4.2 [12] was used for road transport emission modelling, as in the Zurich case study. However, the ADMS-Urban air quality model used for the Gothenburg case study, for simplicity uses emission factors for heavy and light vehicles along with the average daily traffic volume of these two categories. The emissions resulting from HBEFA for the six HBEFA road vehicle categories (PC, light commercial vehicles, trucks, buses, coaches, motorcycles) were aggregated to light and heavy vehicles and divided by the corresponding mileage, in order to obtain "implied" emission factors for the vehicle classes required by the air quality model.

Road network and traffic volume inputs originate from the Gothenburg city air pollutant emission database for 2019 [17]. The mileages for 2030 were derived by using development factors by vehicle category based on the Swedish reference scenario in HBEFA [12]. The network and traffic volumes were classified by HBEFA traffic situation parameters using the following inputs:

- Road types and speed limits were adapted from the input road network [17];
- Rural/urban areas were classified based on the built-up areas geodata from Statistics Sweden [18];
- Gradients were derived from the digital elevation model (DEM) from [19];
- LOS shares were adapted by road type, speed limit, and rural/urban area from the Swedish country data in HBEFA 4.2 [12].

The road traffic mileages in the total and focus area, are respectively shown in Table 8 and Table 9.

Table 8. Mileages by road type and vehicle category [million veh.km/a] in the total area.

Road type	Pass. car	LCV	Coach	Urban bus	Motorcycle	HGV	TOTAL
Motorway	468.5	62.3	4.4	19.1	5.7	48.3	**608.3**
Trunk road	800.1	106.2	5.2	25.4	9.8	72.4	**1019.1**
Distributor	505.0	66.8	2.0	10.5	6.2	36.2	**626.7**
Collector	7.6	1.0	0.0	0.2	0.1	0.5	**9.4**
Access	370.7	49.0	1.3	9.3	4.5	27.6	**462.4**
TOTAL	**2151.9**	**285.3**	**12.9**	**64.5**	**26.3**	**185.0**	**2725.9**

Table 9. Mileages by road type and vehicle category [million veh.km/a] in the focus area.

Road type	Pass. car	LCV	Coach	Urban bus	Motorcycle	HGV	TOTAL
Motorway	9.5	1.3	0.1	0.2	0.1	0.9	**12.1**
Trunk road	54.9	7.3	0.5	1.5	0.7	6.1	**71.0**
Distributor	54.4	7.3	0.2	1.0	0.7	3.4	**67.0**
Collector	0.0	0.0	0.0	0.0	0.0	0.0	**0**
Access	41.9	5.6	0.2	0.9	0.5	3.3	**52.4**
TOTAL	**160.7**	**21.5**	**1.0**	**3.6**	**2.0**	**13.7**	**202.5**

3.4 Implementation in Amsterdam

The HBEFA 4.2 delta emission factors were translated to inputs for the Urban Strategy Air model, in such a way that the detailed knowledge about the Amsterdam traffic and of Dutch emission factors could be used in the best way. The following steps were taken:

- A translation was made between HBEFA Subsegment (fuel, Euro standard) to VERSIT+ class (see Annex C). In some instances, multiple subsegments were linked to a single VERSIT class, sometimes multiple VERSIT classes were linked to a single subsegment, but most often the relation is 1:1.

- For three road types (urban, rural and motorway), the Dutch traffic composition was linked to the list of HBEFA subsegments (in % of total kilometres for each subsegment) for 2020 and for 2030.
- For each Dutch traffic situation (SRM * speed category), the best HBEFA traffic situation was determined (see Annex C). Also, each of these were assigned one of the 13 road types (level of service, speed limit). All HBEFA traffic situations selected were for 0° inclination, so flat terrain.
- Next, for each selected traffic situation, a vehicle subsegment-weighted Dutch emission factor was calculated, using the prevalence (% km) of step 3 for the appropriate road type. Emission factors are, in principle time independent. However, for euro 3 onwards, emission factors including aging were applied, which is different for 2020 and 2030.
- The HBEFA reduction percentages per scenario per year were weighted by subsegments for each selected traffic situation.
- These weighted reduction percentages were applied to the emission factors calculated in step 4.

The result is a table of emission factors with 24 columns (NO_2, NO_x, PM_{10} and $PM_{2.5}$, 3 scenarios, 2 years) and 23 rows (Dutch traffic situation). This table forms the input to the dispersion model. The assignment of each road to one of the Dutch traffic situations as well as the traffic intensities are derived from a detailed traffic model developed with the city of Amsterdam.

Note that the aforementioned procedure was done only for passenger cars. All other vehicle categories are not affected, in other words, the standard (SRM) emission factors are used.

4 Results

In the following sections, average changes in emissions and air pollutant concentrations are described and the maps of air pollutant concentrations are presented for each of the three cities.

In each subsection, the reduction in emissions and air pollutant concentrations are evaluated and compared for the different scenarios and years. In addition, the corresponding concentration maps and the maps of the changes in air pollutant concentrations compared to the baseline scenario are presented for each city.

For Zurich, the effect of the measures on the background concentration is also presented.

4.1 Zurich

4.1.1 Reduction in emissions

Total emissions of PM_{10}, $PM_{2.5}$ and NO_x as well as contribution of road transport in the total area of Zurich are shown in Figure 10 and Table 10. The contribution of road transportation decreases substantially in the best-case scenario for all pollutants. In the most-likely scenario, only a minor impact is observed for PM_{10} and $PM_{2.5}$ since no substantial reduction of the non-exhaust emissions of PM_{10} and $PM_{2.5}$ is expected due to the measures accounted for in the most-likely scenario. For NO_x the impact is slightly higher, but clearly lower than in the best-case scenario (Figure 10).

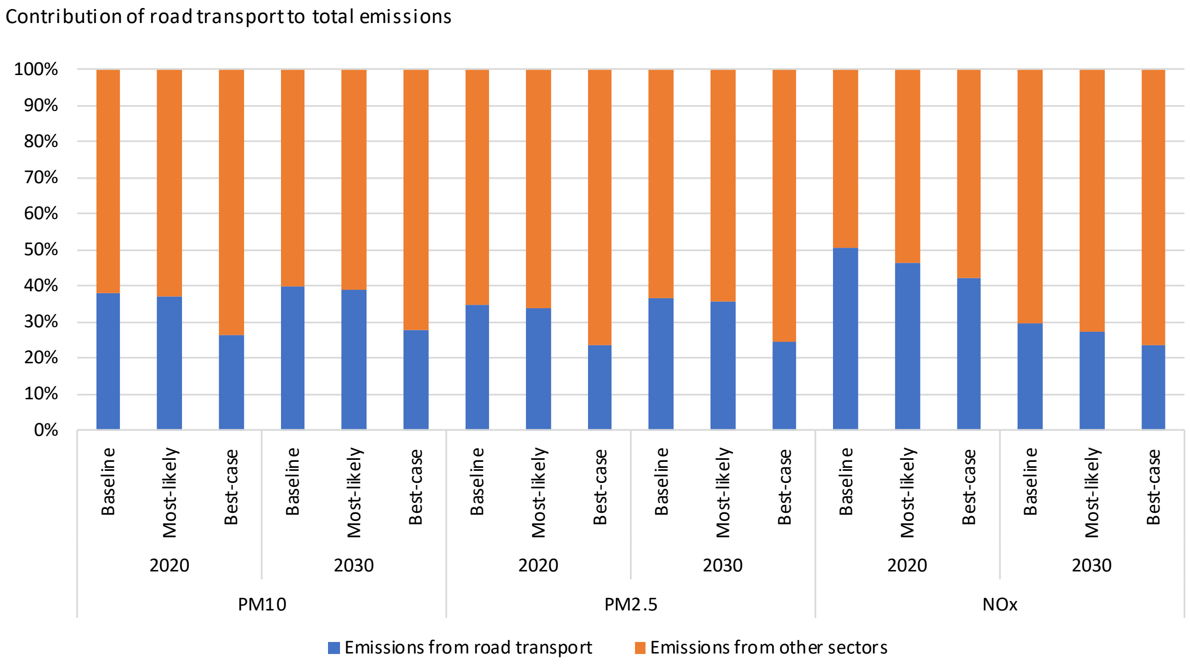


Figure 10. Contribution of road transportation to total emissions 2020 and 2030 in the city of Zurich (total area).

Table 10. Emissions 2020 and 2030 in Zurich (total area).

			Baseline scenario			Most-likely scenario			Best-case scenario		
	Year	Unit	PM_{10}	$PM_{2.5}$	NO_x	PM_{10}	$PM_{2.5}$	NO_x	PM_{10}	$PM_{2.5}$	NO_x
Total emissions	2020	t	136	66	1061	134	65	974	114	56	903
Emissions from road transport	2020	t	52	23	539	50	22	452	31	13	382
Share of road transport	2020	%	38%	35%	51%	37%	34%	46%	27%	24%	42%
Total emissions	2030	t	132	59	750	131	59	722	111	50	688
Emissions from road transport	2030	t	53	22	225	51	21	197	31	12	163
Share of road transport	2030	%	40%	37%	30%	39%	36%	27%	28%	25%	24%

4.1.2 Reduction in air pollutant concentration

The reduction in air pollutant concentration after implementation of the interventions in 2020 as compared to the baseline scenario is shown in Figure 11 and Figure 12. The main observations are the following:

- The largest absolute differences in concentrations are observed for NO_2.
- For PM_{10} and $PM_{2.5}$ differences in air pollutant concentrations are very small in the most-likely scenario. Only in the best-case scenario, a substantial reduction is observed along the road network, with a 90th-percentile range of -2.3 to -1 μg PM_{10}/m^3 (see Figure 11).
- The distribution of the differences in air pollutant concentration is left skewed for all pollutants and scenarios. Large differences are observed only along the road network whereas other areas are less affected (see maps in section 4.1.5 and section 4.1.6).

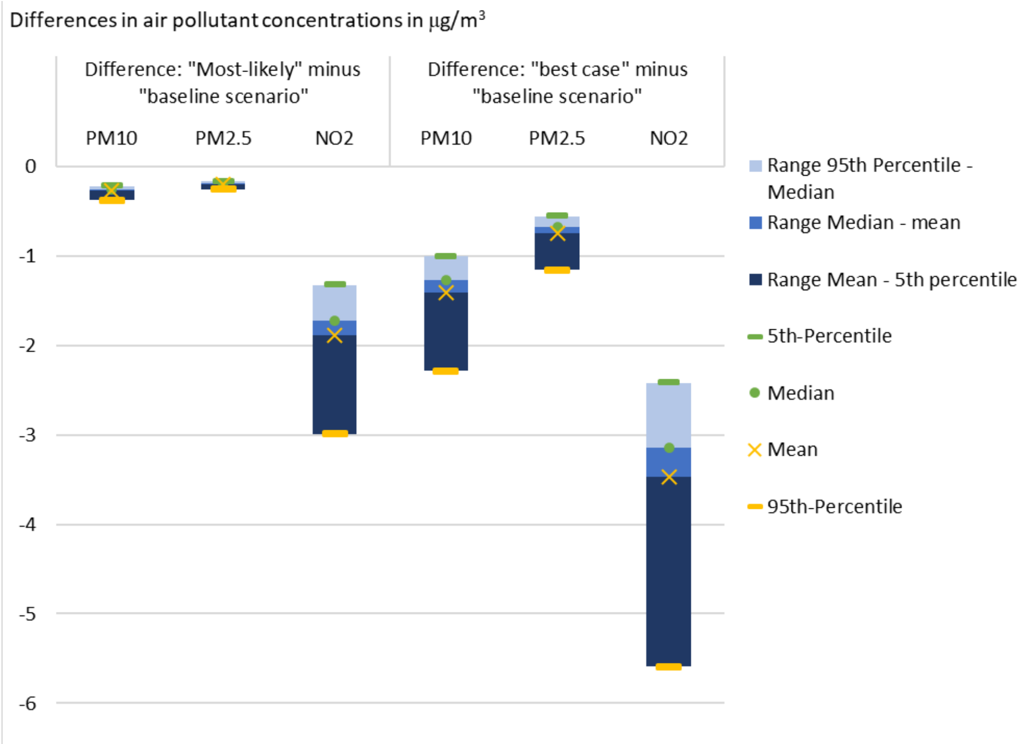


Figure 11. Differences in air pollutant concentrations with respect to the baseline scenario 2020 in the city of Zurich (focus area).

The reduction of air pollutant concentrations in 2030 with respect to the baseline scenario is shown in the figure below. The main results are the following:

- Due to the smaller share of emissions from road transportation in 2030 as compared to 2020 (see Figure 10) also the changes in air pollutant concentrations with respect to the base scenario are smaller (see Figure 12) as compared to 2020 (see Figure 11).
- The largest absolute differences in concentrations are observed for NO_2.
- For PM_{10} and $PM_{2.5}$ differences in air pollutant concentrations are very small in the most-likely scenario. Only in the best-case scenario, a substantial reduction is observed along the road network, with a 90^{th}-percentile range of -2.2 to -0.8 µg PM_{10}/m^3 (see Figure 11).
- The distribution of the differences in air pollutant concentration is left skewed for all pollutants and scenarios. Large differences are observed only along the road network whereas other areas are less affected (see maps in section 4.1.5 and section 4.1.6).

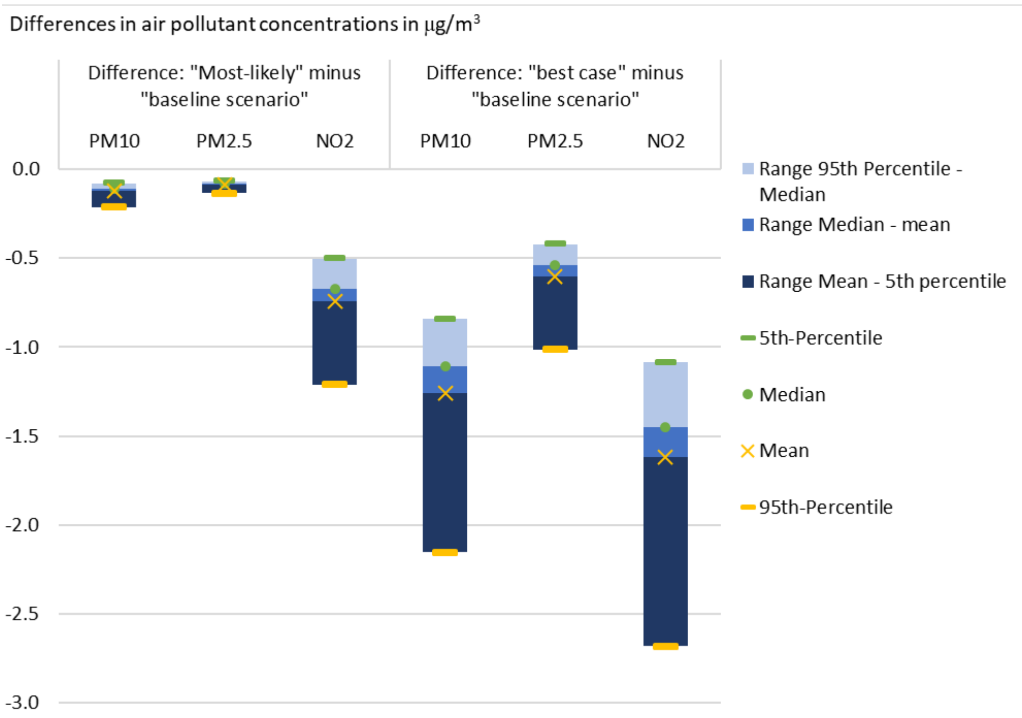


Figure 12. Differences in air pollutant concentrations with respect to the baseline scenario 2030 in the city of Zurich (focus area).

The statistics of the distribution of the changes in air pollutant concentrations with respect to the baseline scenario are summarized in Table 11.

Table 11. Statistics of differences in total air pollutant concentration 2020 and 2030 in the city of Zurich (focus area)

		Difference: "Most-likely" minus "baseline scenario"			Difference: "Best-case" minus "baseline scenario"		
	Unit	PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$	NO_2
2020							
Mean difference	µg/m³	-0.3	-0.2	-1.9	-1.4	-0.7	-3.5
Mean difference	%	-1.8%	-1.9%	-7.5%	-9.2%	-7.0%	-13.9%
Median of differences	µg/m³	-0.3	-0.2	-1.7	-1.3	-0.7	-3.1
95th-Percentiles	µg/m³	-0.4	-0.3	-3.0	-2.3	-1.2	-5.6
5th-Percentiles	µg/m³	-0.2	-0.2	-1.3	-1.0	-0.6	-2.4
2030							
Mean difference	µg/m³	-0.1	-0.1	-0.7	-1.3	-0.6	-1.6
Mean difference	%	-0.9%	-0.9%	-4.4%	-8.7%	-6.1%	-9.5%
Median of differences	µg/m³	-0.1	-0.1	-0.7	-1.1	-0.5	-1.5
95th-Percentiles	µg/m³	-0.2	-0.1	-1.2	-2.2	-1.0	-2.7
5th-Percentiles	µg/m³	-0.1	-0.1	-0.5	-0.8	-0.4	-1.1

4.1.3 Contribution of reduction in background concentration

The model applied for Zurich does not only account for the direct impact of interventions on road transportation within the city but also for the impact on the background concentrations, which accounts for the import of pollutants from outside the study area. It is assumed that the contribution of road transportation to the background concentration is equal to the contribution to direct emissions (e.g. if road transport emissions account for 40% of total emissions, they also account for 40% of the background concentration). This simplified assumption allows to assess the potential impact of measures implemented outside of Zurich on the background concentrations observed in Zurich.

For PM_{10} and $PM_{2.5}$ the contribution of the changes in the background concentration could be seen in Table 12. In 2020, a mean difference of -0.3 μg/m³ is observed, and 70% of the observed change is due to changes in the background concentration and 30% is due to the local implementation.

In the most-likely scenario in 2020, the contribution of the change in background concentration to the mean difference is highest (70%-73%) due to the small impact of the implemented measures. In the best-case scenario, the contribution of the reduction in background concentration is substantially lower (42%-48%). A similar pattern is observed for 2030, but with a lower contribution from the background concentration[7].

Table 12. Contribution of background concentration 2020 and 2030.

			Difference: "Most-likely" minus "baseline scenario"		Difference: "Best-case" minus "baseline scenario"	
	Year	Unit	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Mean difference in total air pollutant concentration	2020	μg/m³	-0.3	-0.2	-1.4	-0.7
Contribution of background concentration	2020	%	70%	73%	42%	48%
Mean difference in total air pollutant concentration	2030	μg/m³	-0.1	-0.1	-1.3	-0.6
Contribution of background concentration	2030	%	53%	63%	33%	37%

[7] For NO_2, it is not possible to indicate an average contribution of the background concentration, since due to the conversion of NO_x to NO_2, the contribution would need to be calculated spatially differentiated, which was not possible within the framework of this study.

4.1.4 Comparison of emission reduction and reduction in air pollutant concentration

In most scenarios, the relative reduction in total emissions is larger than the relative difference in average air pollutant concentrations (Figure 13, Table 13 and Table 14). For comparison, the change in emissions from road transportation are also shown (dark blue bars). Due to the long-range transport of air pollutants some of the emission reduction achieved locally reduces air pollutant concentration outside of the study area. Therefore, on average, the reduction in terms of emissions is larger than the change in local air pollutant concentration.

On the other hand, the model also accounts for importing air pollutants from outside the study area. This can lead to slightly larger changes in air pollutant concentrations as compared to changes in direct emissions, as can be seen for NO_2 in 2030. The impact of the interventions on background concentrations is estimated based on simplifying assumptions. To assess the impact more thoroughly, further research would be necessary.

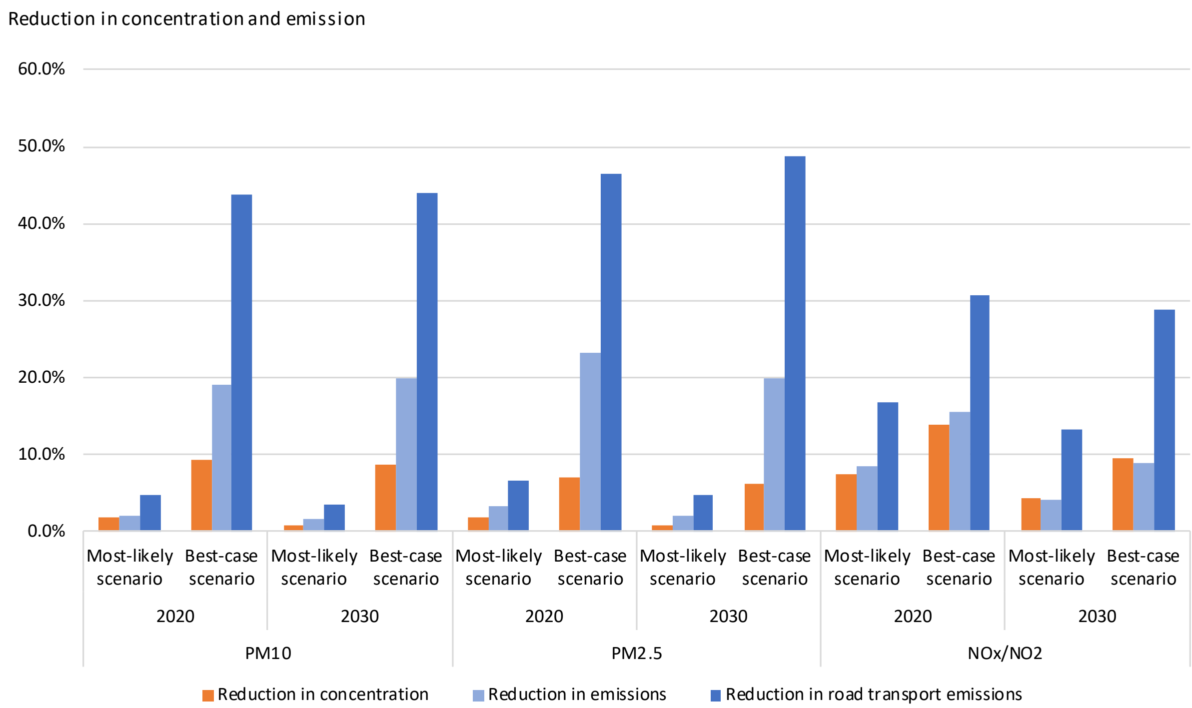


Figure 13. Comparison of changes in total emissions (light blue), road transport emissions and air pollutant concentration in the two scenarios for 2020 and 2030 in the city of Zurich (focus area).

Table 13. Emissions and mean air pollutant concentrations 2020 for focus area.

2020	Unit	Baseline scenario			Most-likely scenario			Best-case scenario		
Emissions		PM_{10}	$PM_{2.5}$	NO_x	PM_{10}	$PM_{2.5}$	NO_x	PM_{10}	$PM_{2.5}$	NO_x
Total emissions	t	43	16	380	42	16	348	35	12	321
Emissions from road transport	t	18.8	8.0	192	17.9	7.5	159	10.6	4.5	133
Reduction of total emissions compared to baseline scenario	%	-	-	-	2%	3%	9%	19%	23%	16%
Air pollutant concentration		PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$	NO_2
Mean	µg/m³	15	11	25	15	10	23	14	10	22
Reduction of average concentration compared to baseline scenario	%	-	-	-	2%	2%	8%	9%	7%	14%

Table 14. Emissions and mean air pollutant concentrations 2030 for focus area.

2030	Unit	Baseline scenario			Most-likely scenario			Best-case scenario		
Emissions		PM_{10}	$PM_{2.5}$	NO_x	PM_{10}	$PM_{2.5}$	NO_x	PM_{10}	$PM_{2.5}$	NO_x
Total emissions	t	42	18	266	41	18	255	34	15	242
Emissions from road transport	t	19.2	7.5	81	18.5	7.1	71	10.7	3.9	58
Reduction of total emissions compared to baseline scenario	%	-	-	-	2%	2%	4%	20%	20%	9%
Air pollutant concentration		PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$	NO_2
Mean	µg/m³	15	10	17	14	10	16	13	9	15
Reduction of average concentration compared to baseline scenario	%	-	-	-	1%	1%	4%	9%	6%	9%

The maps of the air pollutant concentration and the maps of the differences in air pollutant concentrations with respect to the baseline scenario are shown in sections 4.1.5 (NO_2) and 4.1.6 (PM_{10}). The results for $PM_{2.5}$ are shown in Annex A.

4.1.5 Maps of NO_2-concentration

Figure 14 - Figure 17 show NO_2 concentrations and the maps of the differences in the air pollutant concentration with respect to the baseline scenario for the city of Zurich. The maps show the total area, for which air pollutant concentration was simulated and the focus area of the statistical analysis as documented above, is shown in black.

In the best-case scenario, substantially lower emissions are observed as compared to the baseline scenario, for both 2020 and 2030. The largest absolute changes are observed along the roads with heavy traffic. In the baseline scenario 2020 the limit value of the annual mean concentration of 30 $\mu g/m^3$ is exceeded at several locations, whereas in the best-case scenario exceedances are observed at fewer locations.

Since the model accounts for the impact of the interventions on the background concentrations (i.e. imports from outside the modelling area), the concentrations in the surrounding areas further away from the roads are also reduced in the best-case scenario.

A substantial change in concentration is observed between 2020 and 2030 in both scenarios. Therefore, the impact of the interventions is substantially smaller in 2030 as compared to 2020.

The concentration maps for the most-likely scenario are shown in Annex B.

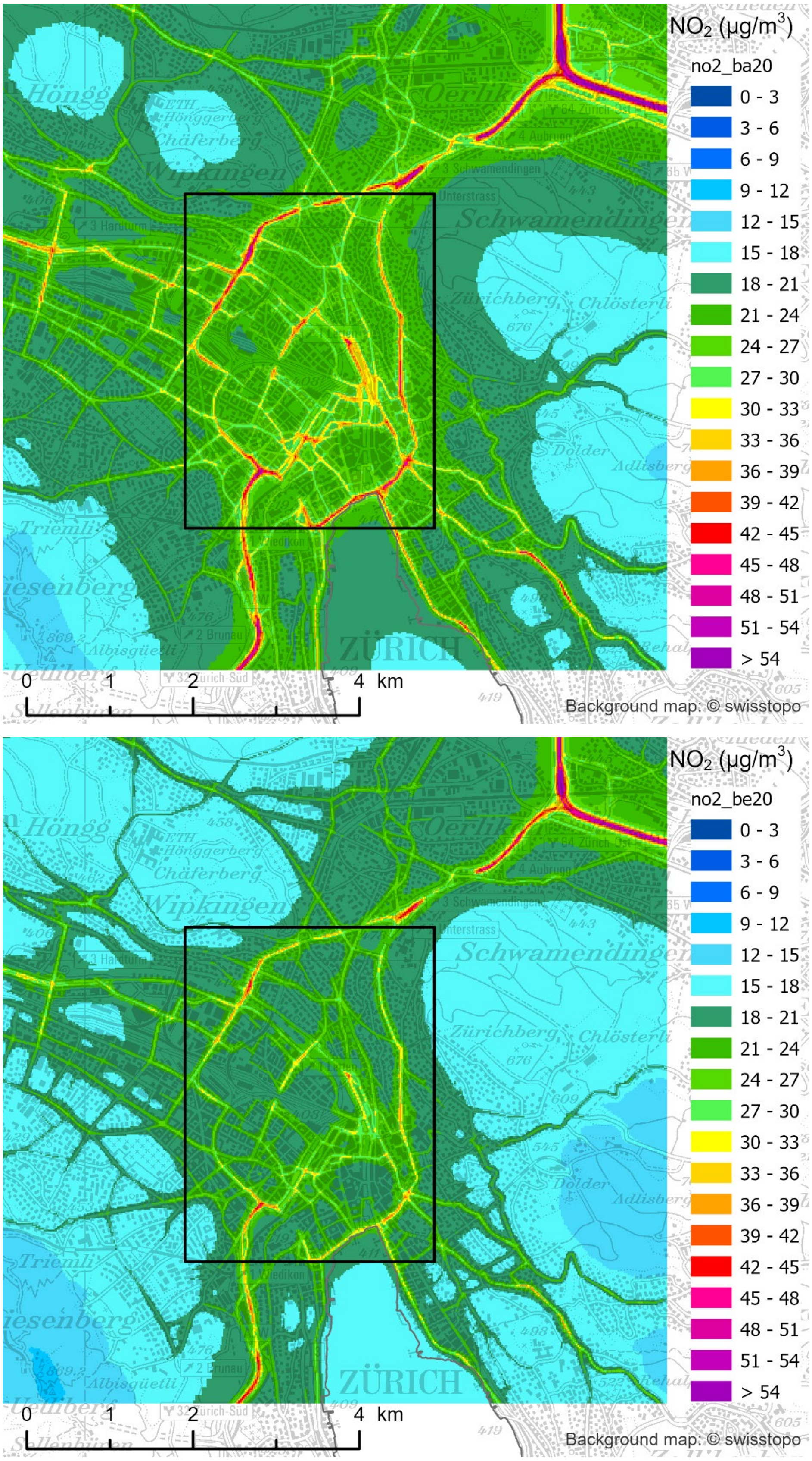


Figure 14. NO_2 concentration in the baseline scenario (top) and in the best-case scenario (bottom) in 2020 in the city of Zurich.

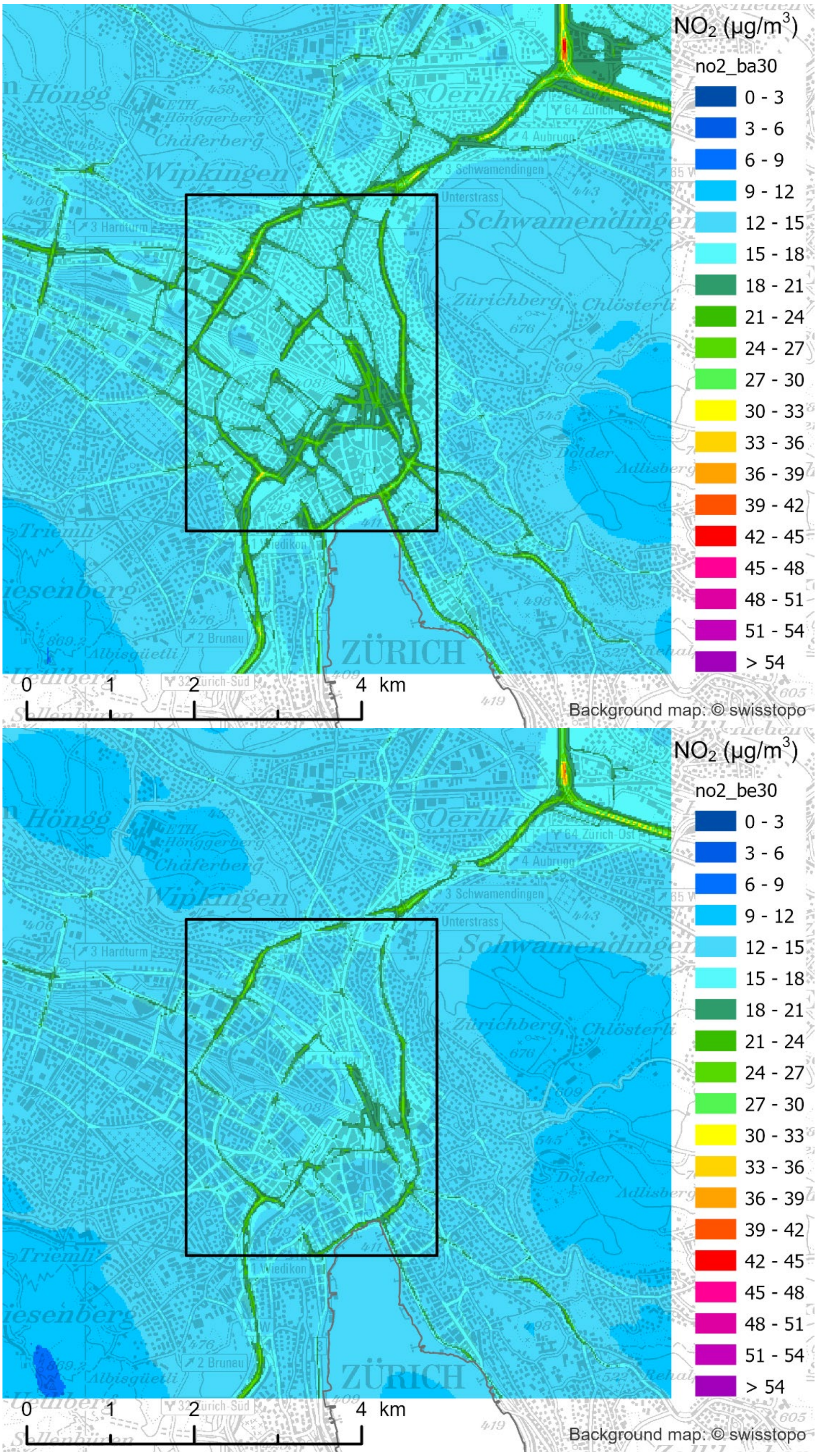


Figure 15. NO_2 concentration in the baseline scenario (top) and in the best-case scenario (bottom) in 2030 in the city of Zurich.

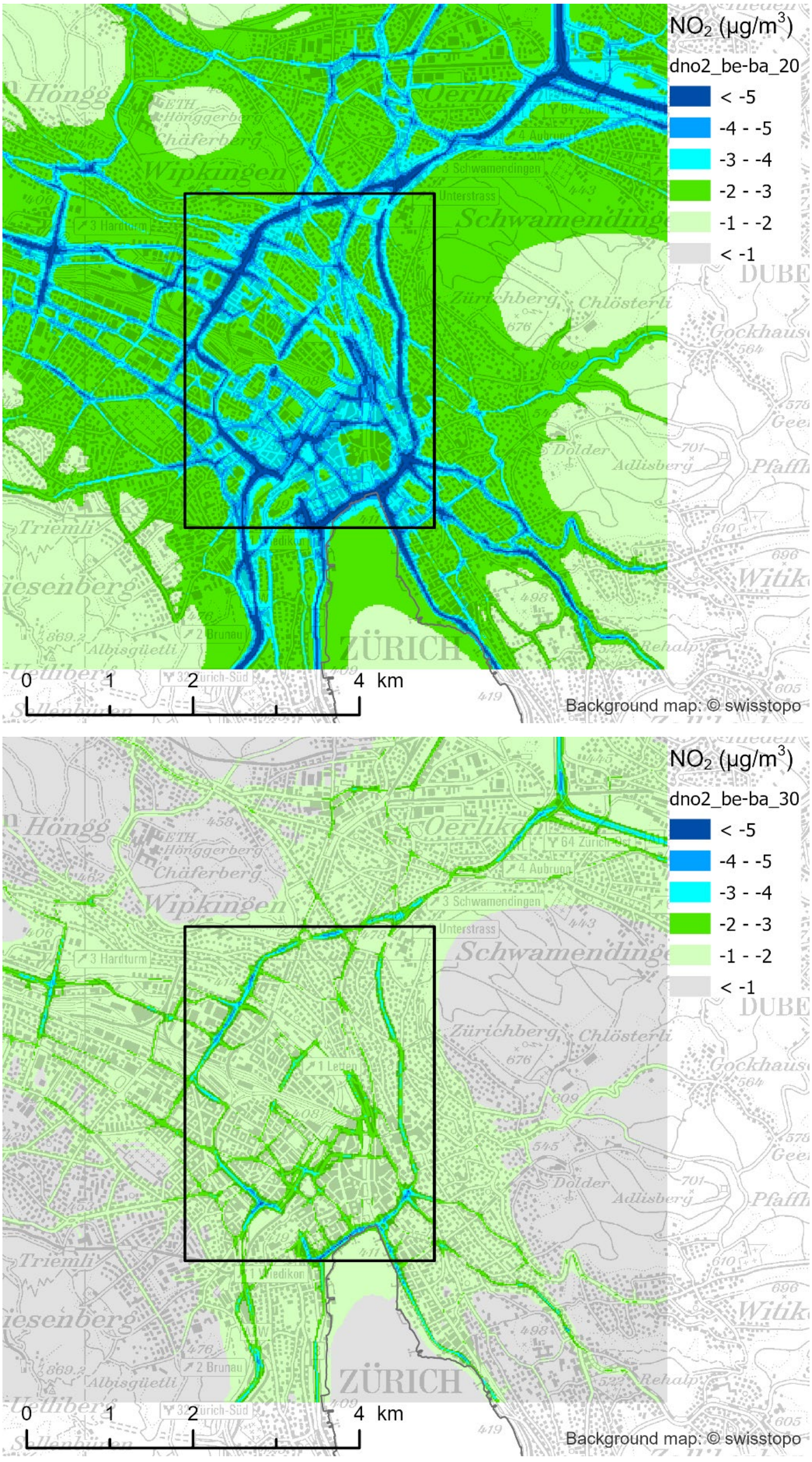


Figure 16. Differences in NO_2 concentration best-case scenario with respect to the baseline scenario in 2020 (top) and 2030 (bottom).

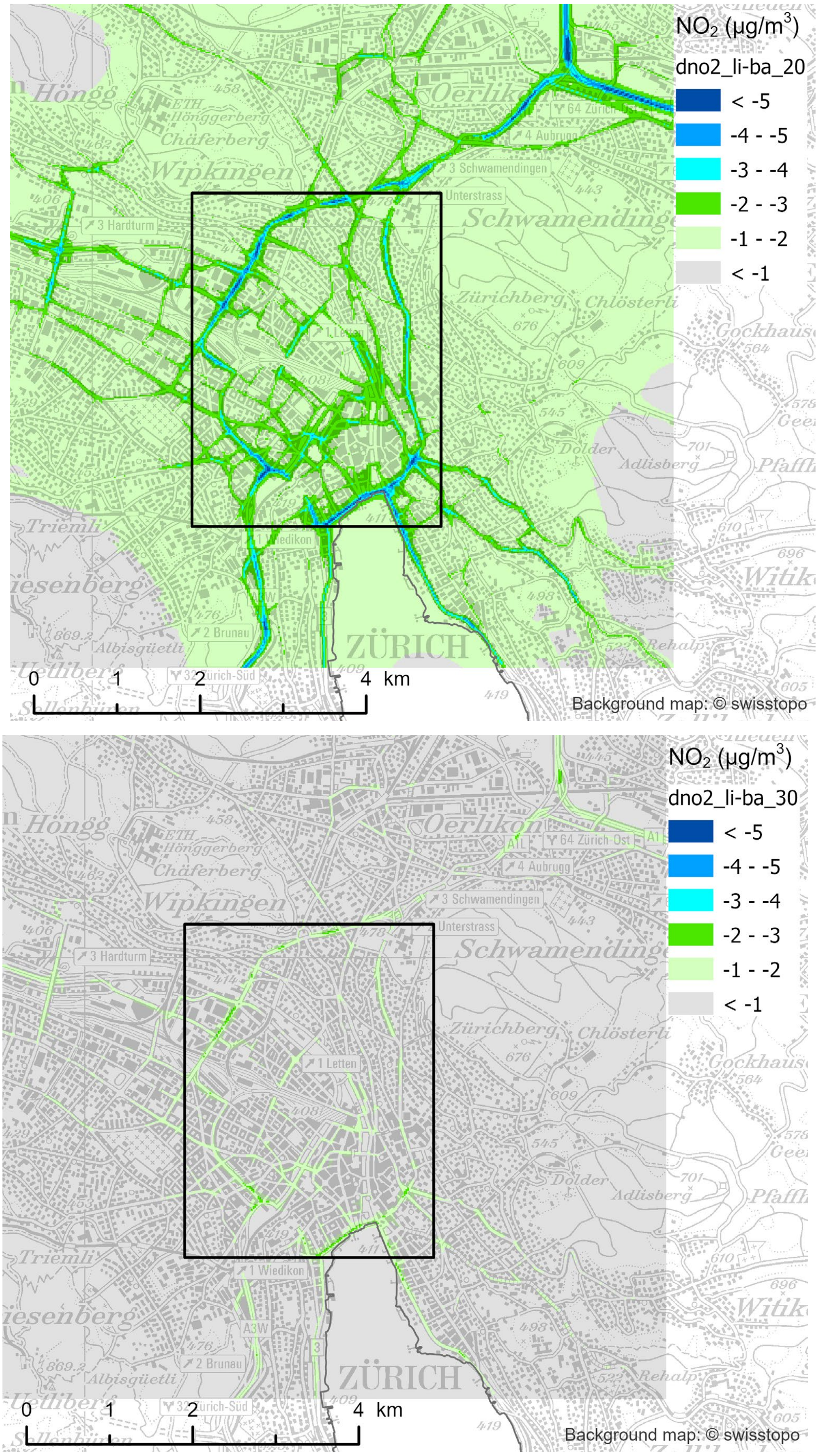


Figure 17. Differences in NO_2 concentration: most-likely scenario with respect to the baseline scenario in 2020 (top) and 2030 (bottom).

4.1.6 Maps of PM_{10}-concentration

Figure 18 - Figure 20 show PM_{10} concentrations and the maps of the differences in the air pollutant concentration with respect to the baseline scenario for the city of Zurich. The maps show the total area, for which air pollutant concentration was simulated and the focus area of the statistical analysis as documented above, is shown in black.

In the best-case scenario, considerably lower emissions are observed as compared to the baseline scenario, for both 2020 and 2030. The largest absolute changes are observed along the roads with heavy traffic. In the baseline scenario 2020 the limit value for the annual mean concentration of 20 µg/m³ is exceeded at several locations, whereas in the best-case scenario exceedances are observed at fewer locations.

Since the model accounts for the impact of the interventions on the background concentrations (i.e. imports from outside the modelling area), also the concentrations in the surrounding areas further away from the roads are reduced in the best-case scenario.

The change in concentration between 2020 and 2030 is smaller than NO_2 in both scenarios. Therefore, the impact of the interventions is substantially smaller in 2030 as compared to 2020.

The concentration maps for the most-likely scenario are shown in Annex B.

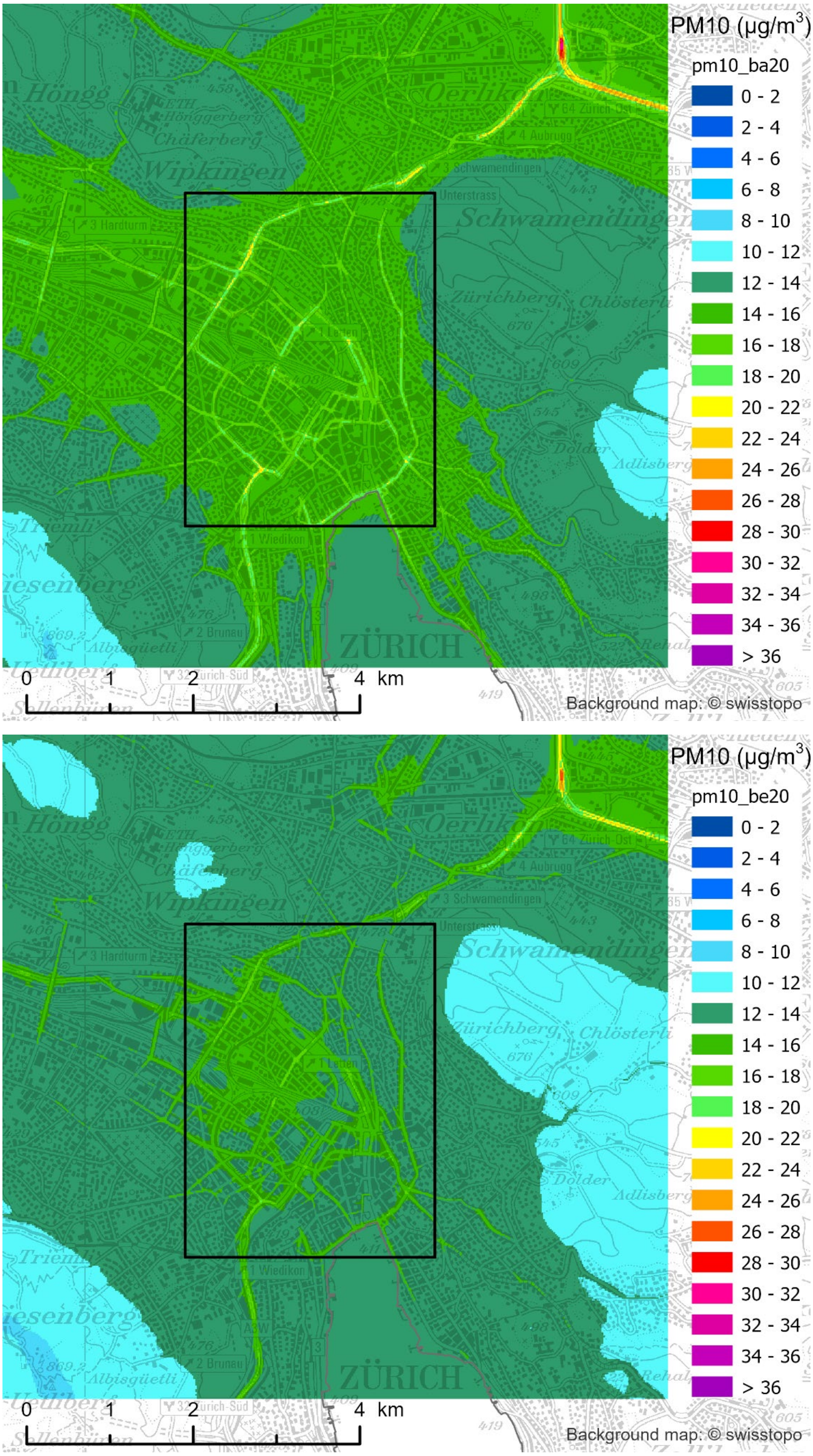


Figure 18. PM_{10}-concentration in the baseline scenario (top) and in the best-case scenario (bottom) in 2020 in the city of Zurich.

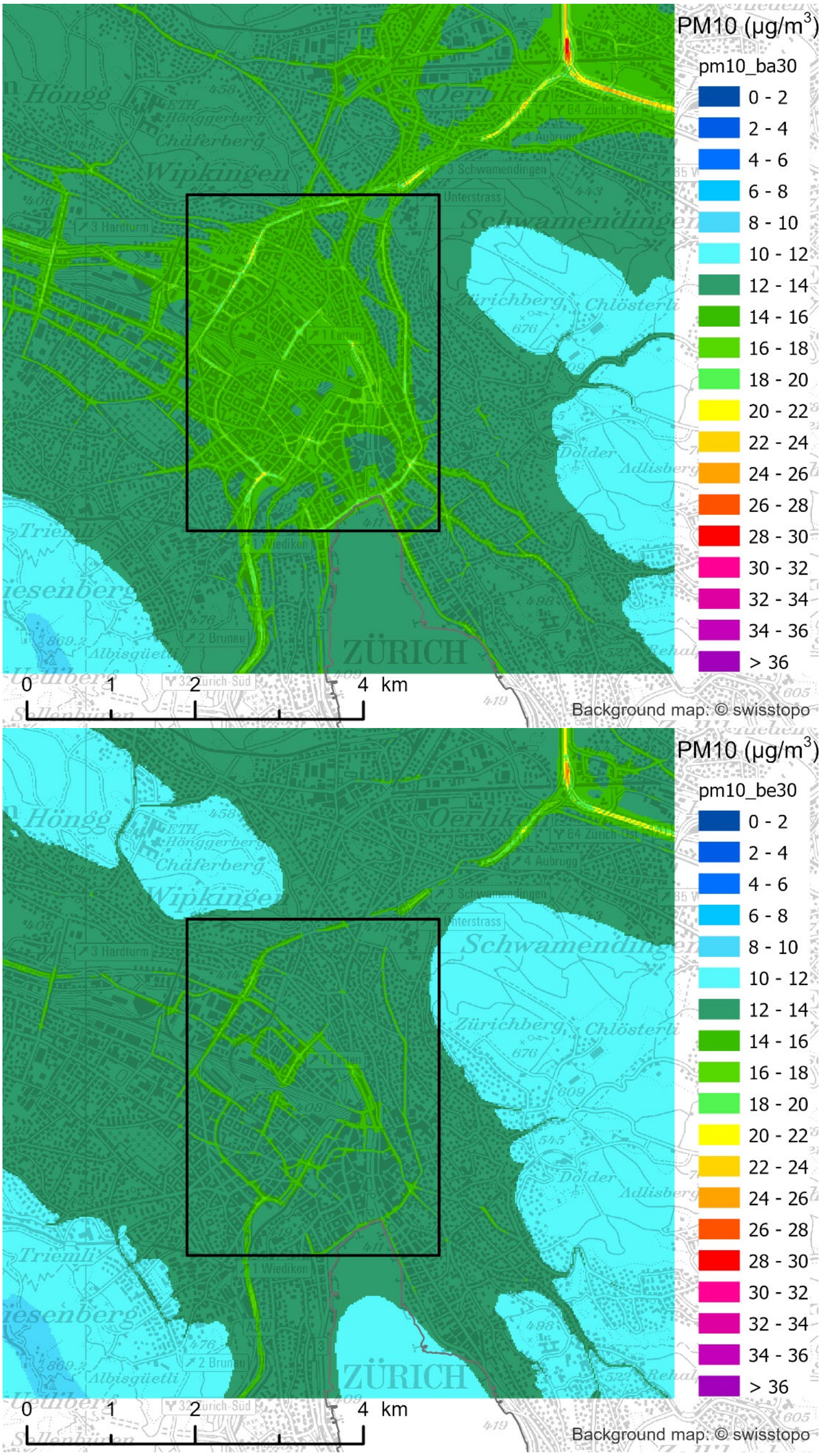


Figure 19. PM_{10} concentration in the baseline scenario (top) and in the best-case scenario (bottom) in 2030 in the city of Zurich.

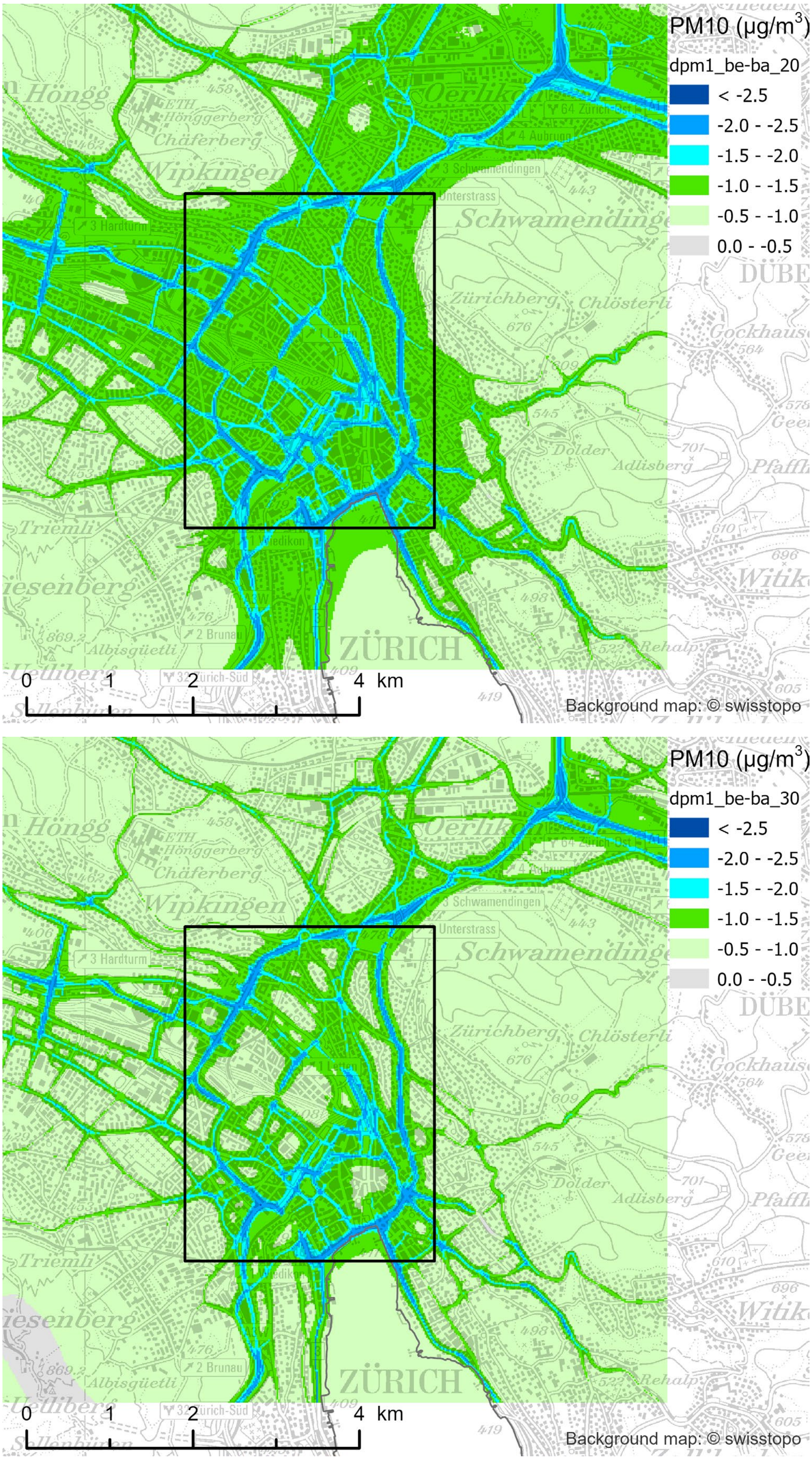


Figure 20. Differences in PM_{10}-concentration: best-case scenario with respect to the baseline scenario in 2020 (top) and 2030 (bottom).

The differences between the most-likely scenario and the baseline scenario are smaller than 1 μg PM_{10}/m^3 at all locations.

4.2 Gothenburg

4.2.1 Reduction in emissions

Road transport emissions of $PM_{2.5}$ and NO_x in the total area of Gothenburg are shown in Table 15. The road transport emissions decrease for both the most-likely and the best-case scenario.

Table 15. Emissions 2019 and 2030 in Gothenburg (total area).

			Baseline scenario		**Most-likely scenario**		**Best-case scenario**	
Emissions	Year	Unit	$PM_{2.5}$	NO_x	$PM_{2.5}$	NO_x	$PM_{2.5}$	NO_x
Emissions from road transport	2019	t	64.4	1724.7	62.8	1554.1	47.3	1433.3
Emissions from road transport	2030	t	57.9	530.8	57.6	482.7	41.1	439.1

4.2.2 Reduction in air pollutant concentration

In Figure 21, differences in air pollutant concentrations are shown with respect to the baseline scenario for 2019 and in Figure 22, the same is shown but for 2030. In Table 16, statistics of differences among the scenarios are presented. The findings are

- The largest absolute differences are for NO_2.
- For $PM_{2.5}$, differences in air pollutant concentrations are very small in the most-likely scenario. For the best-case scenario, a substantial reduction is observed along the road network with a 90th-percentile range of -0.263 to -0.034 µg $PM_{2.5}/m^3$ for 2019 and of -0.265 to -0.035 µg $PM_{2.5}/m^3$ for 2030.
- As in Zurich, the distribution of the differences in air pollutant concentration is left skewed for all pollutants and scenarios, since large differences are observed only along the road network (which could be seen in the maps in section 4.2.4 and section 4.2.5).

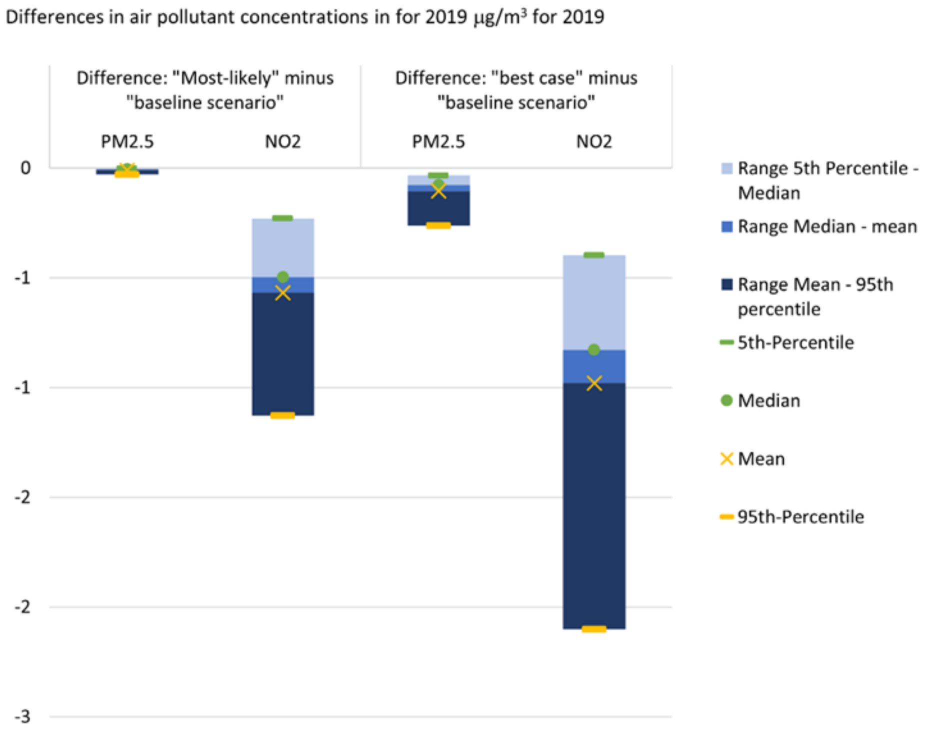


Figure 21. Differences in air pollutant concentrations with respect to the baseline scenario 2019 in the city of Gothenburg (focus area).

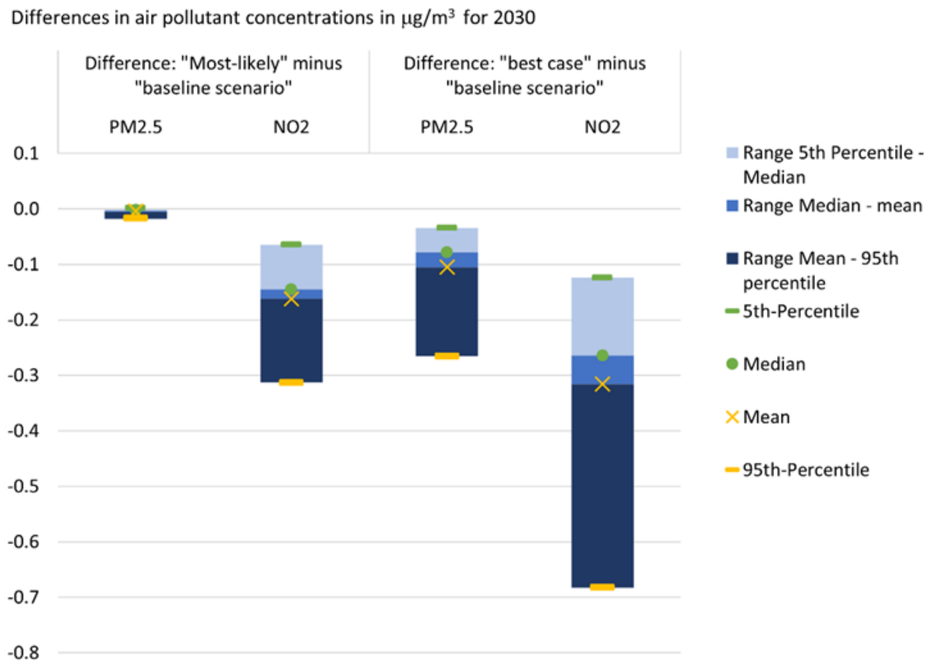


Figure 22. Differences in air pollutant concentrations with respect to the baseline scenario 2030 in the city of Gothenburg (focus area).

Table 16. Statistics of differences in total air pollutant concentration 2019 and 2030 in the city of Gothenburg (focus area).

	Unit	Difference: "Most-likely" minus "baseline scenario		Difference: "Best-case" minus "baseline scenario"	
		$PM_{2.5}$	NO_2	$PM_{2.5}$	NO_2
2019					
Mean difference	µg/m³	-0.010	-0.568	-0.105	-0.980
Mean difference	%	-0.14	-3.39%	-1.52%	-5.85%
Median of differences	µg/m³	-0.006	-0.498	-0.078	-0.829
95th-Percentiles	µg/m³	-0.031	-1.128	-0.263	-2.103
5th-Percentiles	µg/m³	-0.002	-0.230	-0.034	-0.398
2030					
Mean difference	µg/m³	-0.004	-0.162	-0.105	-0.316
Mean difference	%	-0.06	-1.25	-1.53	-2.43
Median of differences	µg/m³	-0.002	-0.145	-0.078	-0.265
95th-Percentiles	µg/m³	-0.016	-0.313	-0.265	-0.682
5th-Percentiles	µg/m³	0.002	-0.065	-0.035	-0.124

4.2.3 Comparison of emission reduction and reduction in air pollutant concentration

In all scenarios, the relative reduction in road emissions is larger than the relative difference in average air pollutant concentrations, which could be seen in Figure 23, Table 17 and Table 18. As for Zurich, some of the emission reduction achieved locally reduce air pollutant concentration outside the study area due to the long-range transport of air pollutants.

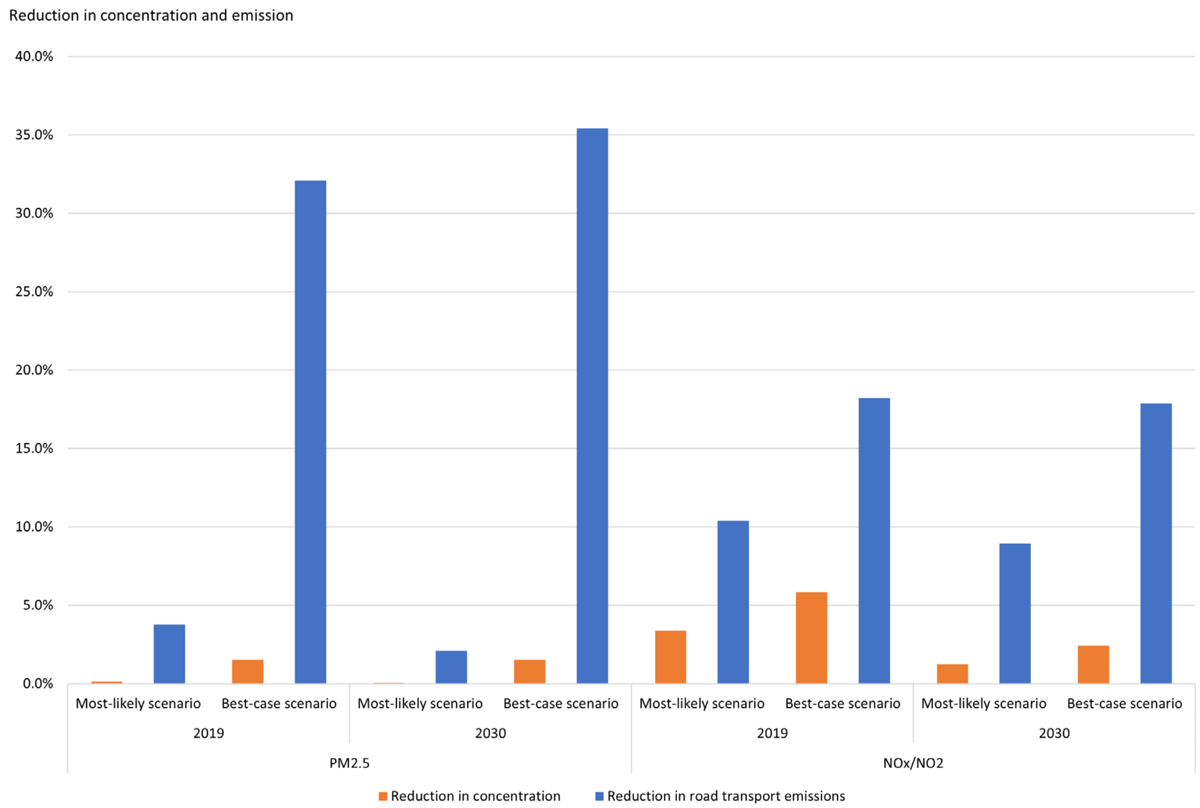


Figure 23. Comparison of emission reduction and reduction of air pollutant concentration in the two scenarios for 2019 and 2030 in the city of Gothenburg (focus area).

Table 17. Emissions and mean air pollutant concentrations 2019 for focus area in Gothenburg.

2019	Unit	Baseline scenario		Most-likely scenario		Best-case scenario	
Emissions		$PM_{2.5}$	NO_x	$PM_{2.5}$	NO_x	$PM_{2.5}$	NO_x
Emissions from road transport	t	5.3	139.5	5.1	125.0	3.6	114.1
Reduction of road transport emissions compared to baseline scenario	%	-	-	3.8	10.4	32.1	18.2
Air pollutant concentration			NO_2		NO_2		NO_2
Mean	µg/m³	6.90	16.76	6.89	16.19	6.80	15.78
Reduction of average concentration compared to baseline scenario	%	-	-	0.1	3.4	1.5	5.8

Table 18. Emissions and mean air pollutant concentrations 2030 for focus area in Gothenburg.

2030		Baseline scenario		Most-likely scenario		Best-case scenario	
Emissions		$PM_{2.5}$	NO_x	$PM_{2.5}$	NO_x	$PM_{2.5}$	NO_x
Emissions from road transport	t	4.8	42.5	4.7	38.7	3.1	34.9
Reduction of road transport emissions compared to baseline scenario	%	-	-	2.1	8.9	35.4	17.9
Air pollutant concentration			NO_2		NO_2		NO_2
Mean	µg/m³	6.87	12.99	6.87	12.83	6.77	12.68
Reduction of average concentration compared to baseline scenario	%	-	-	0.1	1.2	1.5	2.4

4.2.4 Maps of NO_2-concentration

Figure 24-Figure 27 show the annual mean NO_2 concentration for different scenarios for Gothenburg. Figure 24 shows baseline and best-case 2019, Figure 25 shows baseline and best-case 2030, Figure 26 shows the difference between best-case and baseline for 2019 and 2030 and Figure 27 shows the difference between most-likely and baseline for 2019 (2030 is not included since the difference for that year was below 1 µg/m^3 for all grid cells in the area). The emissions are higher for 2019, and highest for 2019 baseline. In the plots of the differences, it could be seen that the largest concentration reductions occur at the main roads, and that it is more effective to introduce the measures now than in 2030. The Swedish limit value of 40 µg/m^3 is exceeded at the large road to the right in the figures. The concentration maps for the most-likely scenario are shown in Annex B.

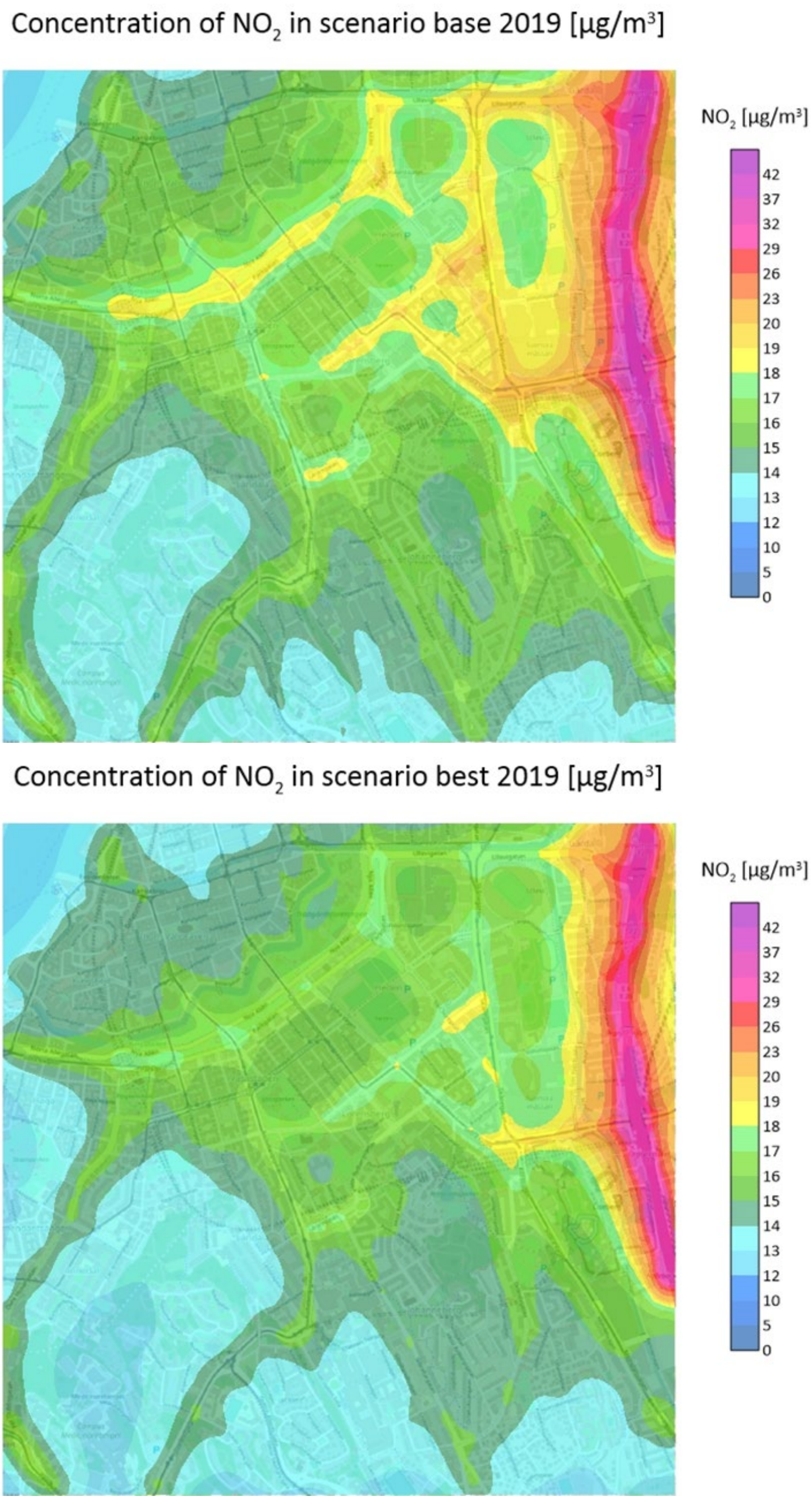


Figure 24. NO_2 concentration in the baseline scenario (top) and in the best-case scenario (bottom) in 2019 in the city of Gothenburg.

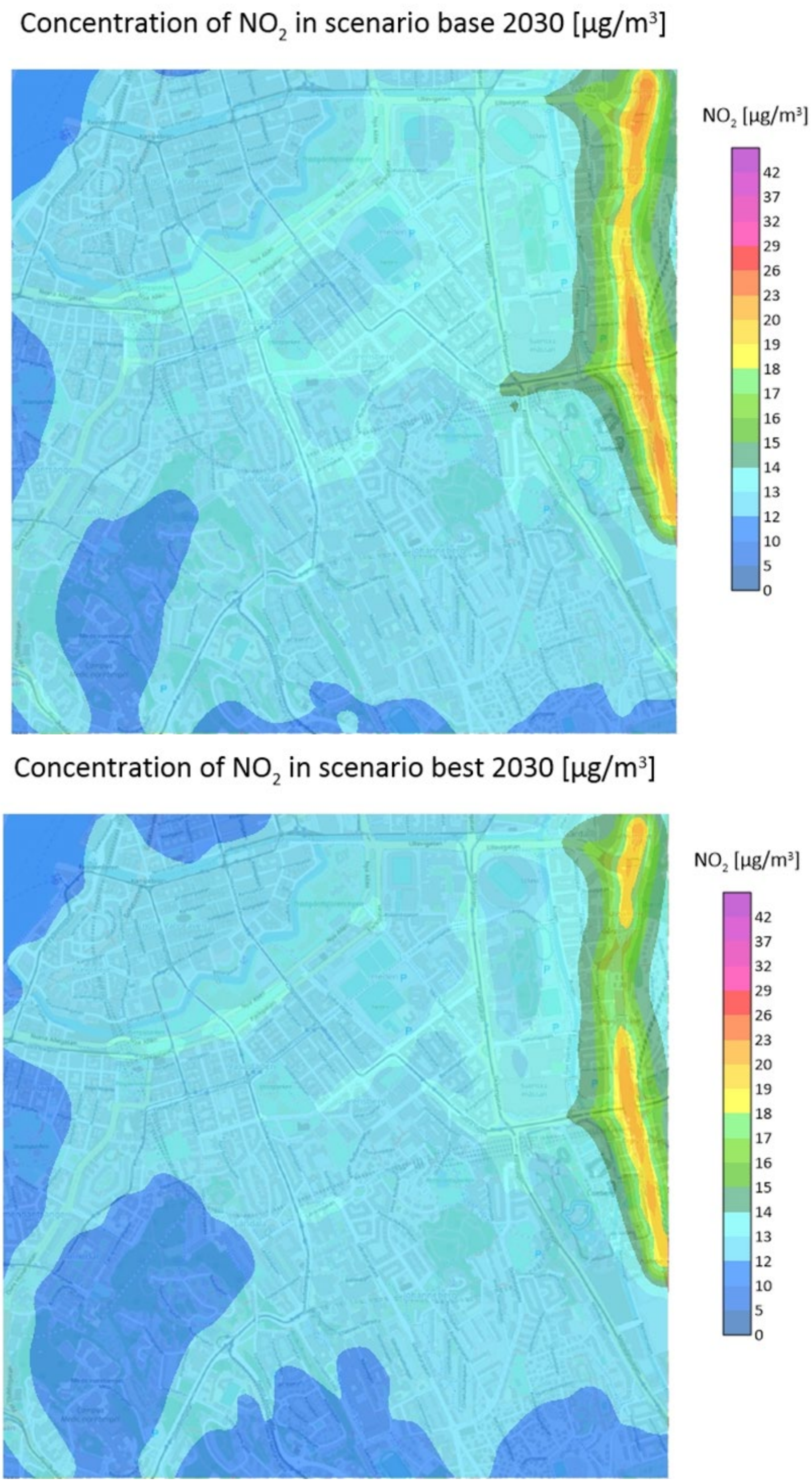


Figure 25. NO_2 concentration in the baseline scenario (top) and in the best-case scenario (bottom) in 2030 in the city of Gothenburg.

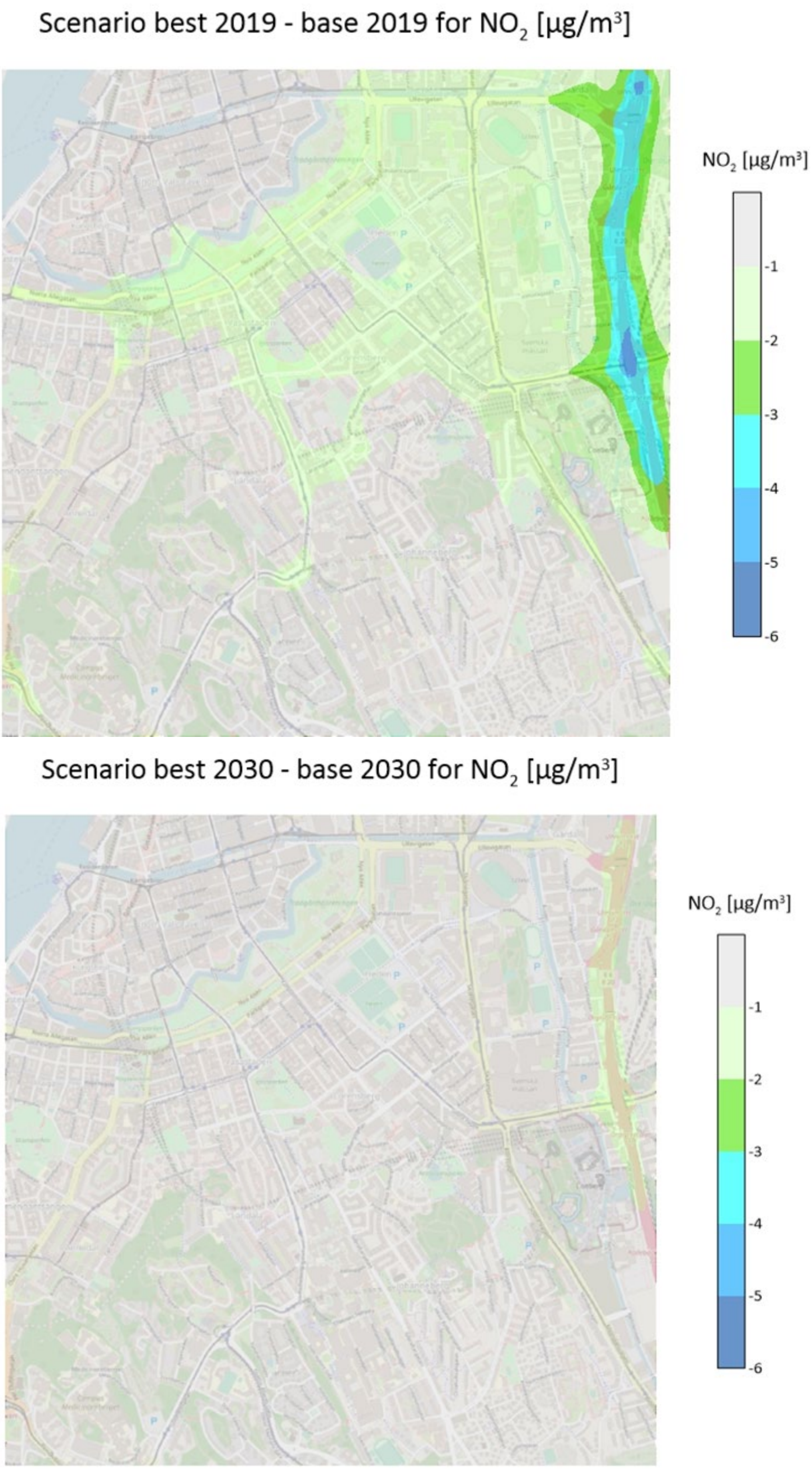


Figure 26. Differences in NO_2 concentration for best-case scenario with respect to the baseline scenario in 2019 (top) and 2030 (bottom).

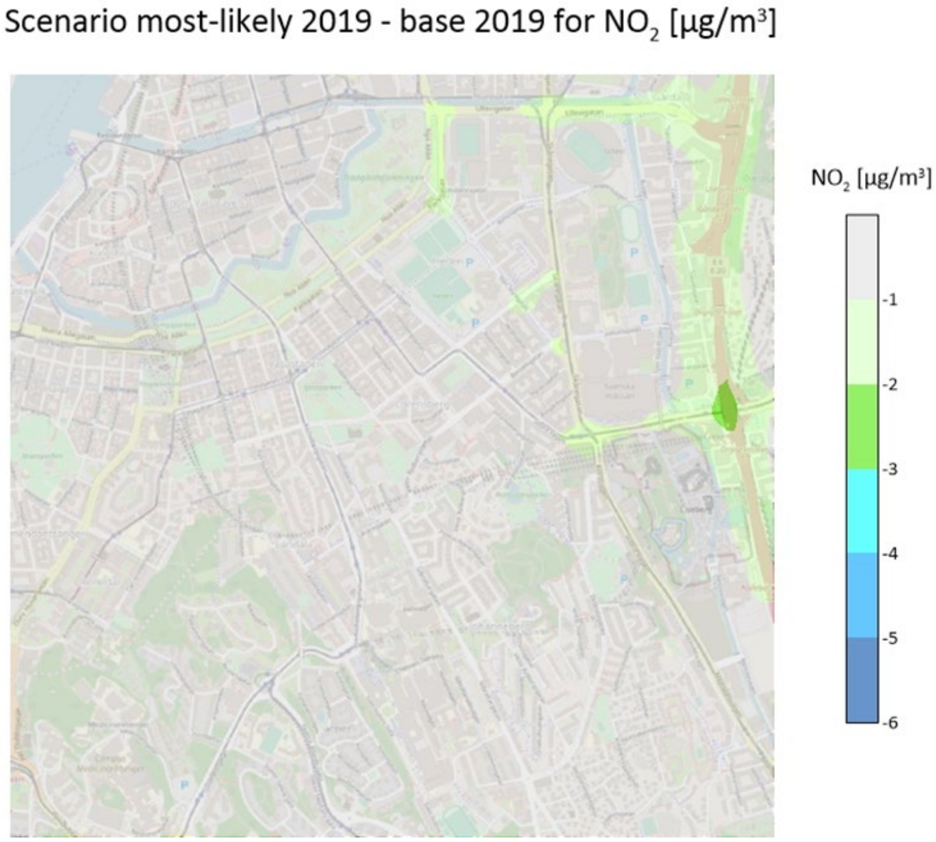


Figure 27. Differences in NO_2 concentration for most-likely scenario with respect to the baseline scenario in 2019.

4.2.5 Maps of $PM_{2.5}$-concentration

Figure 28-Figure 31 show the annual mean $PM_{2.5}$ concentration for different scenarios for Gothenburg. Figure 28 shows baseline and best-case 2019, Figure 29 shows baseline and best-case 2030, Figure 30 shows the difference between best-case and baseline for 2019 (2030 is not included since the difference for that year was below 1 μg/m^3 for all grid cells in the area) and Figure 31 shows the difference between most-likely and baseline for 2019 (2030 is not included since the difference for that year was below 1 μg/m^3 for all grid cells in the area).

The emissions are higher for 2019, and highest for 2019 baseline, but the emissions are still quite high in 2030, due to the non-exhaust emissions. In the plots of the differences, it could be seen that the largest concentration reductions occur at the main roads, and that the measures have a large effect in both years. The Swedish limit value of 25 μg/m^3 is not exceeded in the area. The concentration maps for the most-likely scenario are shown in Annex B.

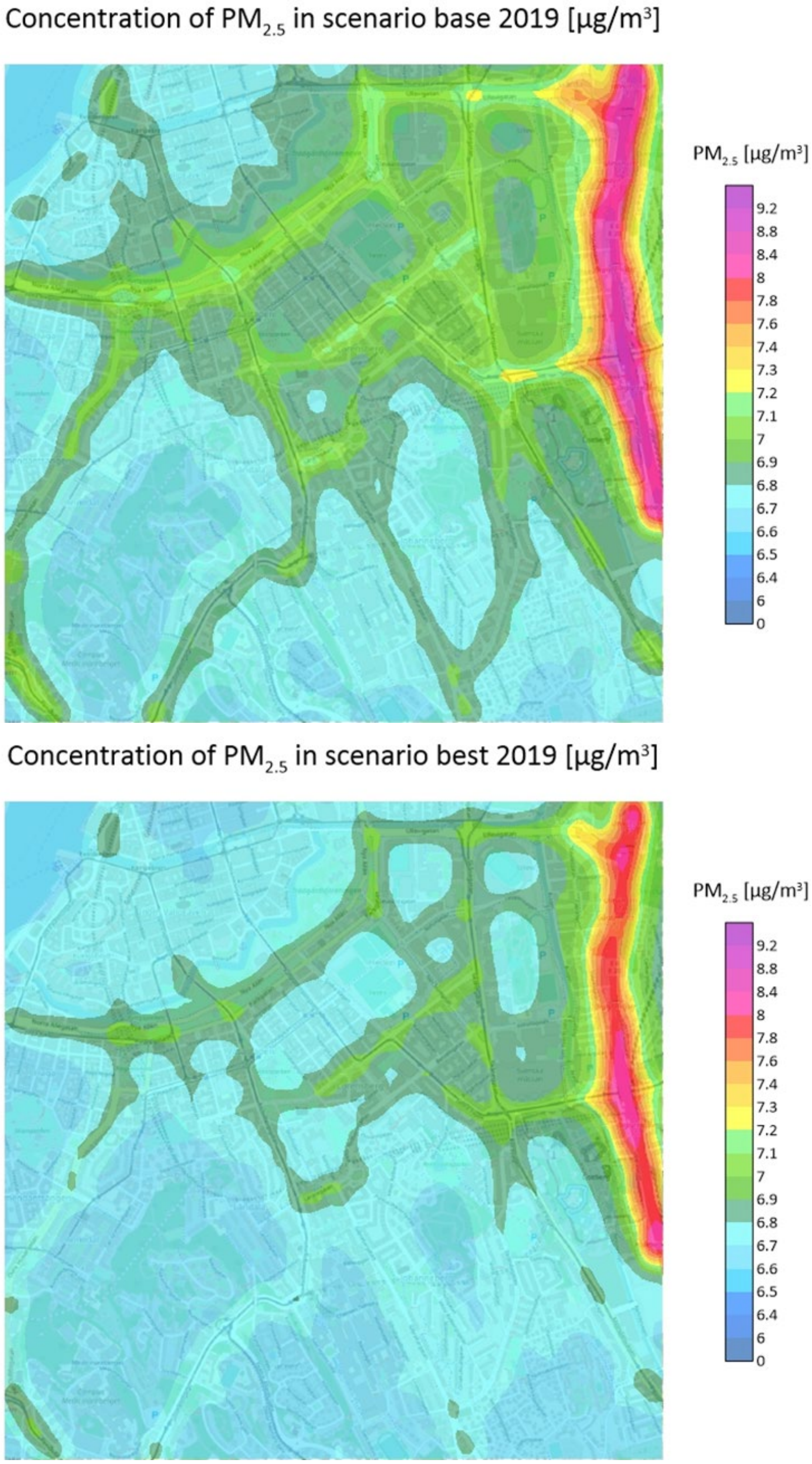


Figure 28. $PM_{2.5}$ concentration in the baseline scenario (top) and in the best-case scenario (bottom) in 2019 in the city of Gothenburg.

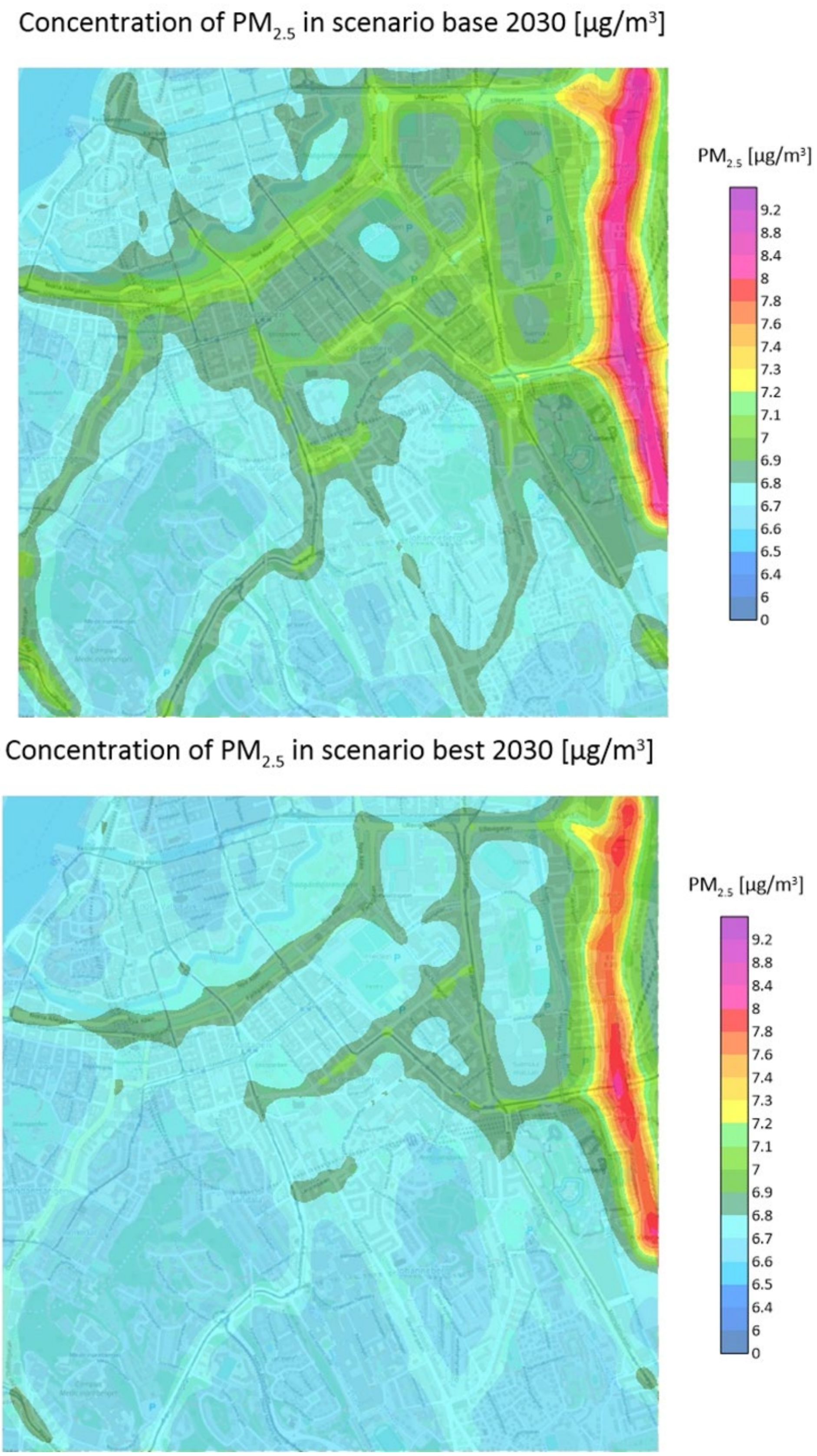


Figure 29. $PM_{2.5}$ concentration in the baseline scenario (top) and in the best-case scenario (bottom) in 2030 in the city of Gothenburg.

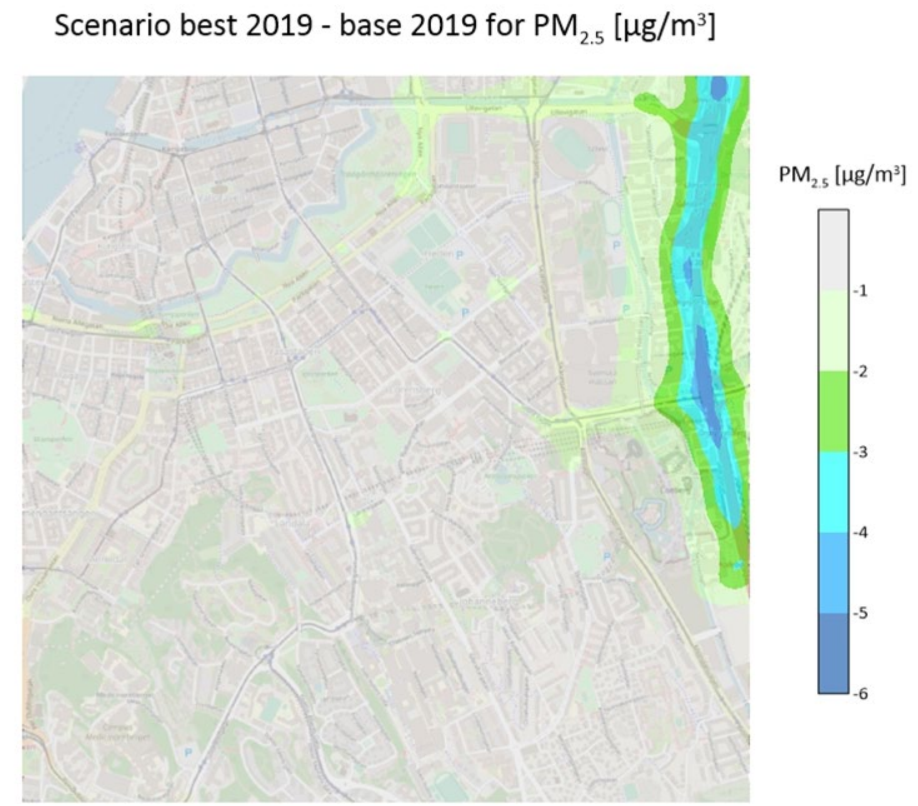


Figure 30. Differences in $PM_{2.5}$ concentration for best-case scenario with respect to the baseline scenario in 2019.

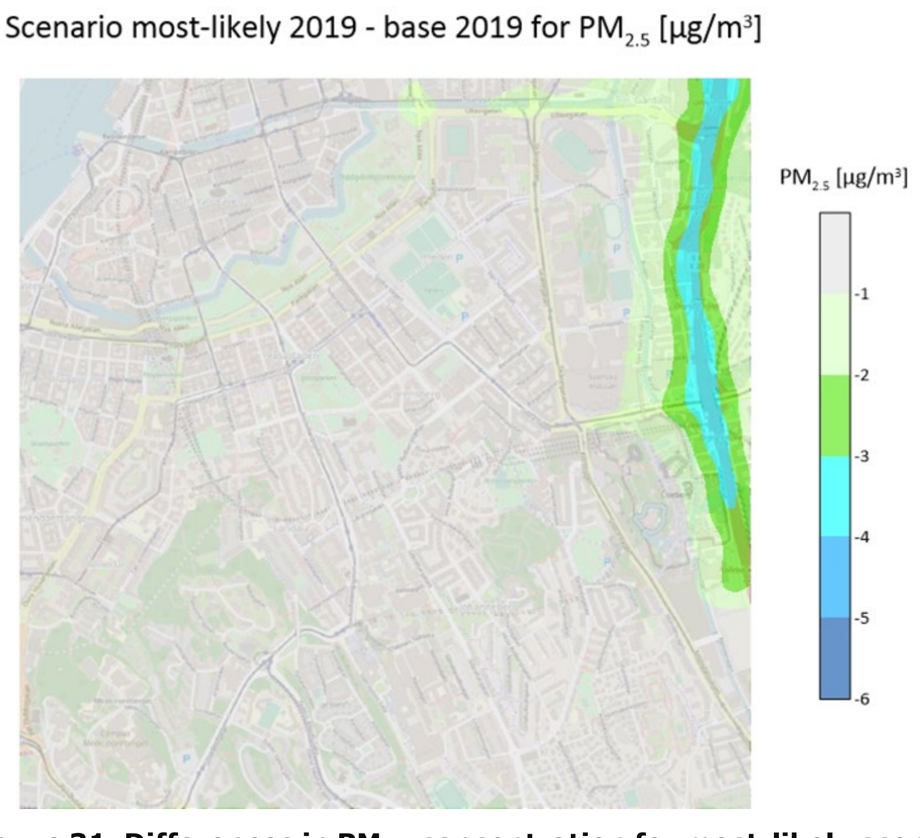


Figure 31. Differences in $PM_{2.5}$ concentration for most-likely scenario with respect to the baseline scenario in 2019.

4.3 Amsterdam

4.3.1 Reduction in emissions

Table 19 shows the total emissions in the Amsterdam area. The $PM_{2.5}$ emissions decrease by 14 and 19%, the other emissions around 4 and 7% (higher numbers for the best-case scenario).

Table 19. Emissions 2020 and 2030 for total area

	Year	Unit	Baseline scenario			Most-likely scenario			Best-case scenario		
			PM_{10}	$PM_{2.5}$	NO_x	PM_{10}	$PM_{2.5}$	NO_x	PM_{10}	$PM_{2.5}$	NO_x
Emissions from road transport	2020	t	113	43	2279	110	37	2157	104	35	2108
Emissions from road transport	2030	t	110	32	1547	108	29	1487	101	29	1464

4.3.2 Reduction in air pollutant concentration

The total road traffic emissions and the average concentrations in the Amsterdam focal area are shown in Table 20 (2020) and Table 21 (2030). Statistics on the concentration decreases for the most-likely and the best-case scenarios can be found in Table 22. On average across the entire area, the mean 2020 concentrations of the three compounds decrease only by a small percentage: less than 0.15% for particulates and around 0.6 and 0.8% for NO_2. As will become apparent in the graphs in 4.3.3, the fact that street canyons are accounted for plus the detailed traffic model input results in limited concentration decreases at many receptor points. The ratio among the 5-percentile, mean, median and 95-percentile in Table 22 confirms that significant concentration decreases only occur in a small part of the total study area.

For 2030 the effect of uCARe measures is smaller than for 2020, as can be expected.

Note that the statistics in the tables below were calculated over a non-regular grid of receptor points: the points are more concentrated close to the roads. This results in a slight upward bias compared to a situation where a regular grid was used.

Table 20. Emissions and mean air pollutant concentrations 2020 for focus area in Amsterdam.

2020	Unit	Baseline scenario			Most-likely scenario			Best-case scenario		
Emissions		PM_{10}	$PM_{2.5}$	NO_x	PM_{10}	$PM_{2.5}$	NO_x	PM_{10}	$PM_{2.5}$	NO_x
Total emissions	t									
Emissions from road transport	t	113	43	2279	110	37	2157	104	35	2108
Reduction of total emissions compared to baseline scenario	%	-	-	-	3%	14%	5%	8%	19%	7%
Air pollutant concentration		PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$	NO_2
Mean	µg/m³	18.6	10.8	21.2	18.6	10.8	21.0	18.6	10.8	21.0
Reduction of average concentration compared to baseline scenario	%	-	-	-	-0.04%	-0.14%	-0.60%	-0.09%	-0.17%	-0.81%

Table 21. Emissions and mean air pollutant concentrations 2030 for focus area in Amsterdam.

2030	Unit	Baseline scenario			Most-likely scenario			Best-case scenario		
Emissions		PM_{10}	$PM_{2.5}$	NO_x	PM_{10}	$PM_{2.5}$	NO_x	PM_{10}	$PM_{2.5}$	NO_x
Total emissions	t									
Emissions from road transport	t	110	32	1547	108	29	1487	101	29	1464
Reduction of total emissions compared to baseline scenario	%	-	-	-	2%	9%	4%	8%	11%	5%
Air pollutant concentration		PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$	NO_2
Mean	µg/m³	16.7	8.9	13.2	16.7	8.9	13.2	16.7	8.9	13.1
Reduction of average concentration compared to baseline scenario	%	-	-	-	-0.02%	-0.07%	-0.47%	-0.08%	-0.08%	-0.65%

Table 22. Statistics of differences in total air pollutant concentration 2020 and 2030 in the city of Amsterdam (focus area).

	Unit	Difference: "Most-likely" minus "baseline scenario"			Difference: "Best-case" minus "baseline scenario"		
		PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$	NO_2
2020							
Mean difference	µg/m³	-0.008	-0.015	-0.127	-0.017	-0.019	-0.172
Mean difference	%	-0.04%	-0.14%	-0.60%	-0.09%	-0.17%	-0.81%
Median of differences	µg/m³	-0.004	-0.010	-0.091	-0.005	-0.011	-0.120
95th-Percentiles	µg/m³	-0.030	-0.043	-0.370	-0.084	-0.064	-0.532
5th-Percentiles	µg/m³	-0.001	-0.003	-0.024	-0.001	-0.003	-0.032
2030							
Mean difference	µg/m³	-0.003	-0.006	-0.062	-0.017	-0.007	-0.086
Mean difference	%	-0.02%	-0.07%	-0.47%	-0.10%	-0.08%	-0.65%
Median of differences	µg/m³	-0.001	-0.003	-0.042	-0.006	-0.004	-0.056
95th-Percentiles	µg/m³	-0.015	-0.022	-0.201	-0.076	-0.028	-0.284
5th-Percentiles	µg/m³	-0.000	-0.001	-0.010	-0.002	-0.001	-0.014

The statistical information on concentration reductions in Figure 23 is shown once more, in a graphical way, in Figure 32 and Figure 33 (2020 and 2030 respectively). The largest absolute reductions are for NO_2. The same observation can be made as for Zurich and Gothenburg, that the distributions are skewed: the distance between mean and 95th percentile is much larger than the distance between mean and 5th percentile. This is due to the fact that large concentration reductions are observed only along the road network.

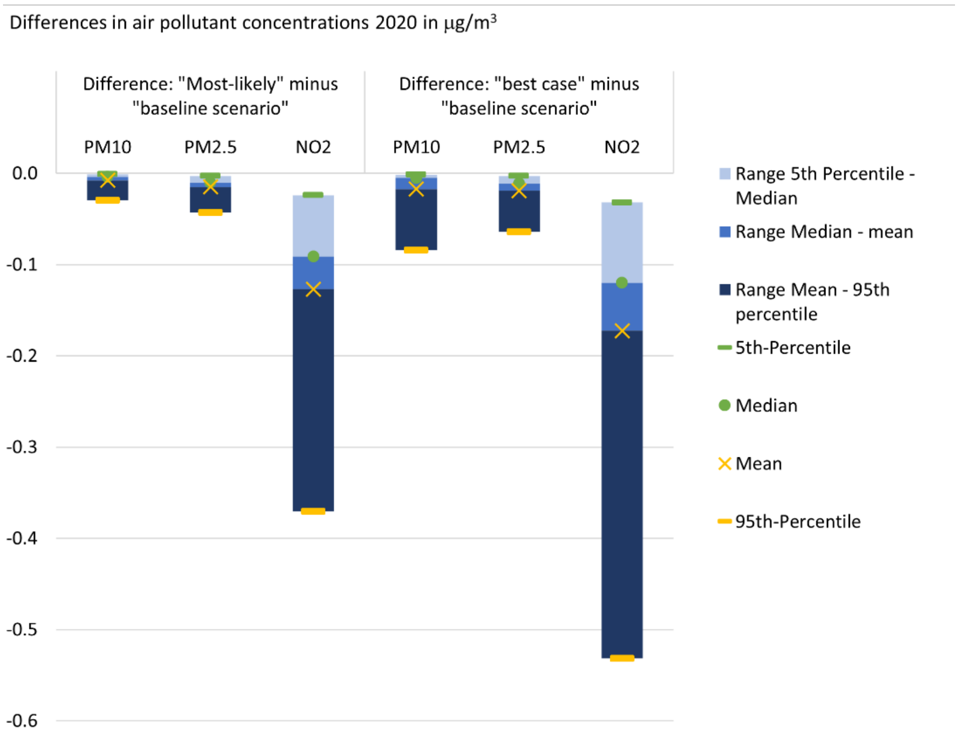


Figure 32. Differences in air pollutant concentrations with respect to the baseline scenario 2020 in the city of Amsterdam (focus area).

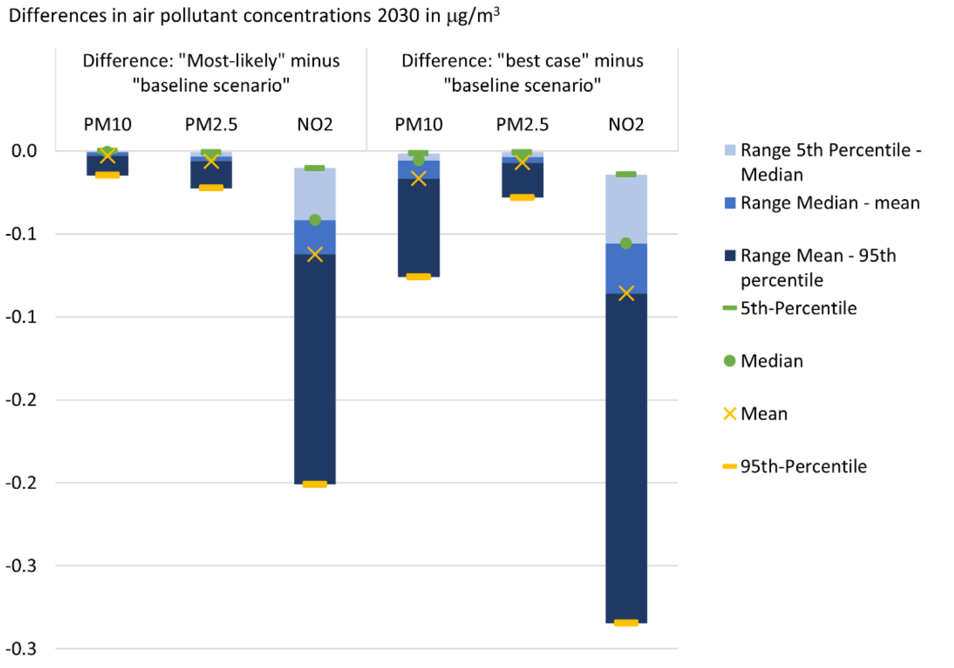


Figure 33. Differences in air pollutant concentrations with respect to the baseline scenario 2030 in the city of Amsterdam (focus area).

A separate effect of the background is not shown here for Amsterdam. The effect of emission reductions due to uCARe measures taken outside the city is assumed to be negligible. The rough estimation of traffic emissions in Amsterdam present in the GCN background maps (see Table 2) is subtracted entirely in the modelling process, to be replaced by the detailed traffic emissions calculated in this project.

4.3.3 Maps of NO_2-concentration

Figure 34, Figure 35 and Figure 36 show the annual mean NO_2 concentration for different scenarios for Amsterdam. The focus area is the municipality of Amsterdam and is visible by the coloured areas in the map. Along the main roads, concentration reductions up to 2 $\mu g/m^3$ are observed, similar to the other cities. In 2030, a significant reduction in concentrations of NO_2 is expected. As a result, the impact of uCARe measures will be smaller.

The maps for $PM_{2.5}$ are shown in Annex A. The concentration maps for the most-likely scenario are shown in Annex B.

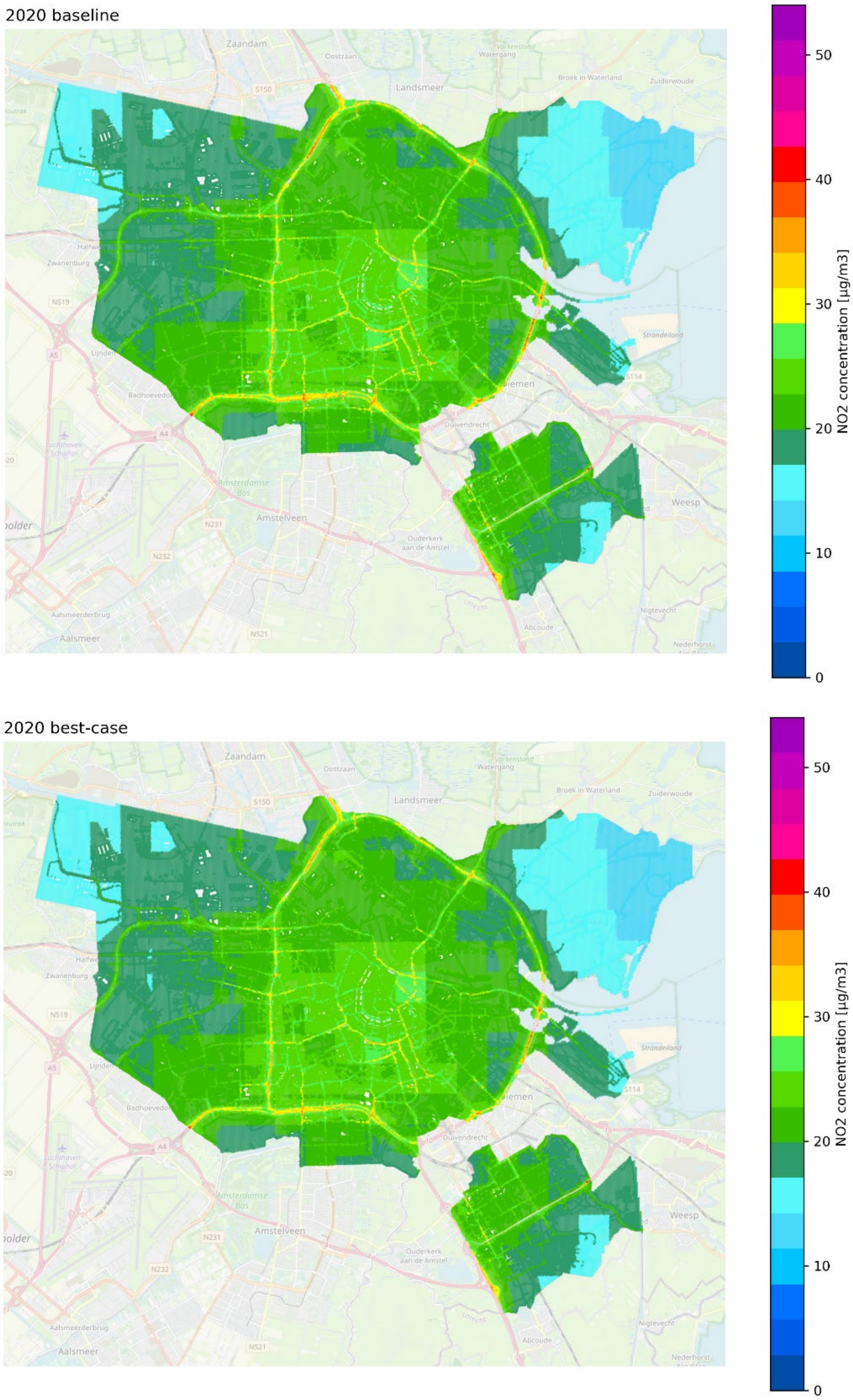


Figure 34. NO_2 concentration in the baseline scenario (top) and in the best-case scenario (bottom) in 2020 in the city of Amsterdam.

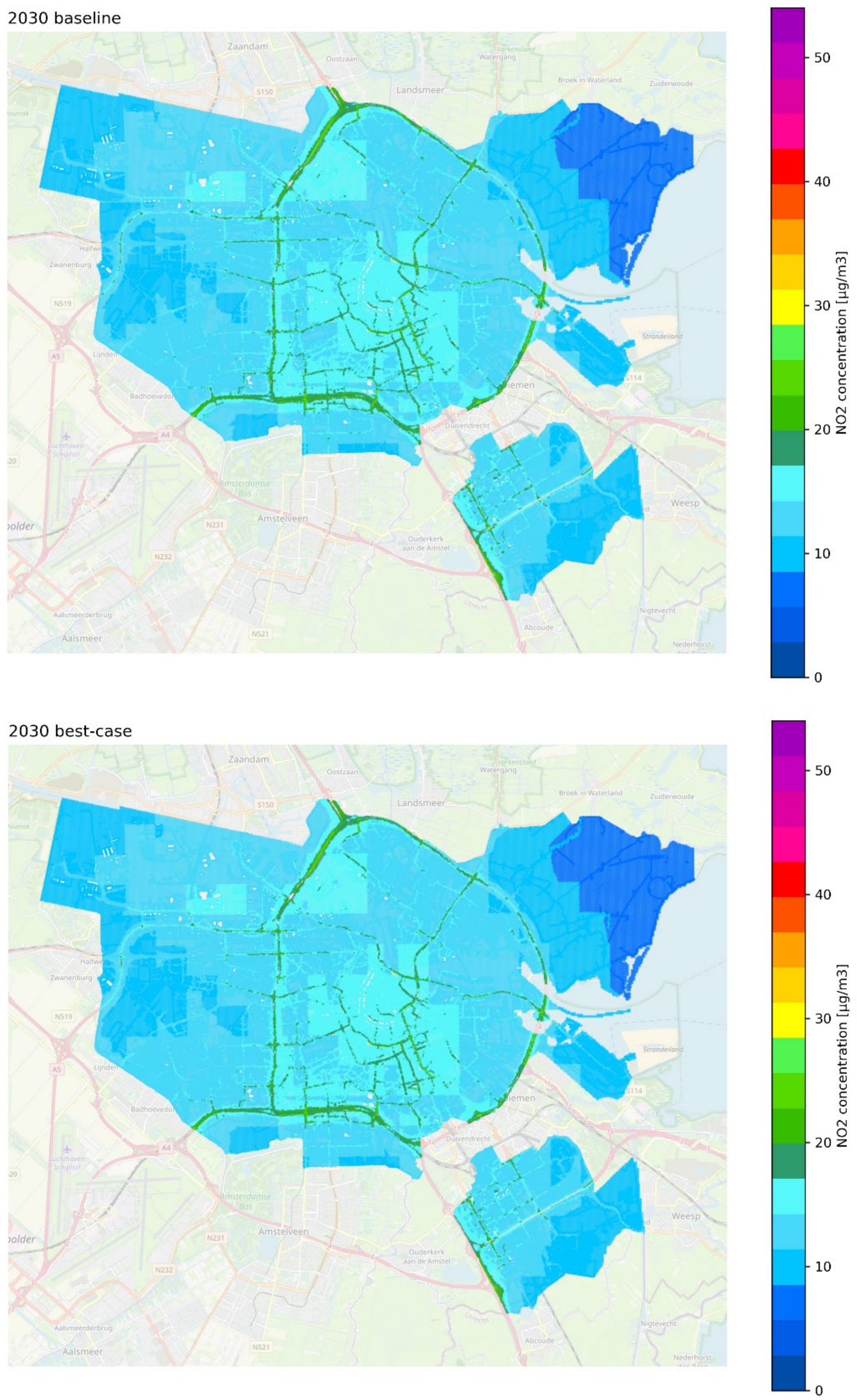


Figure 35. NO_2 concentration in the baseline scenario (top) and in the best-case scenario (bottom) in 2030 in the city of Amsterdam.

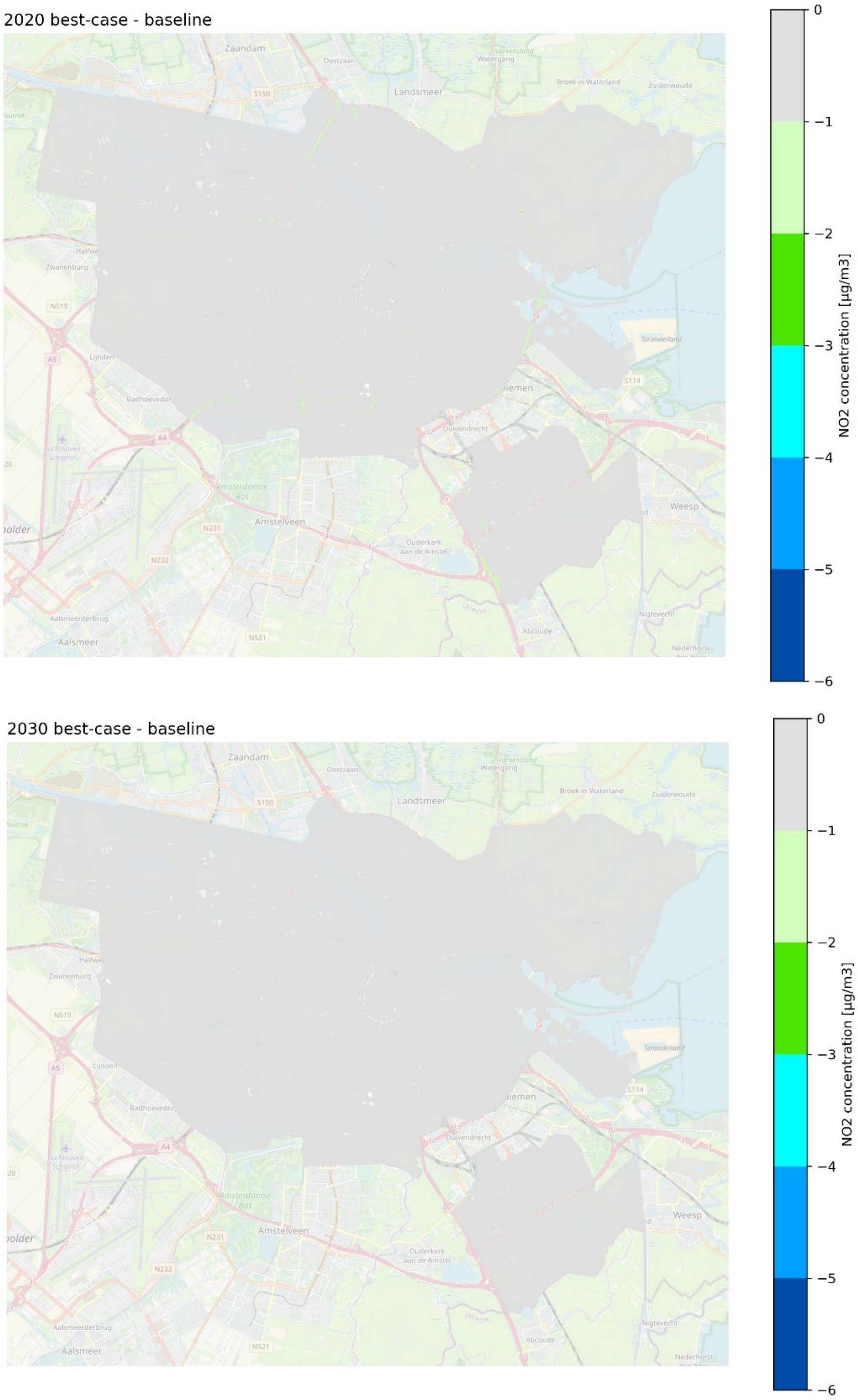


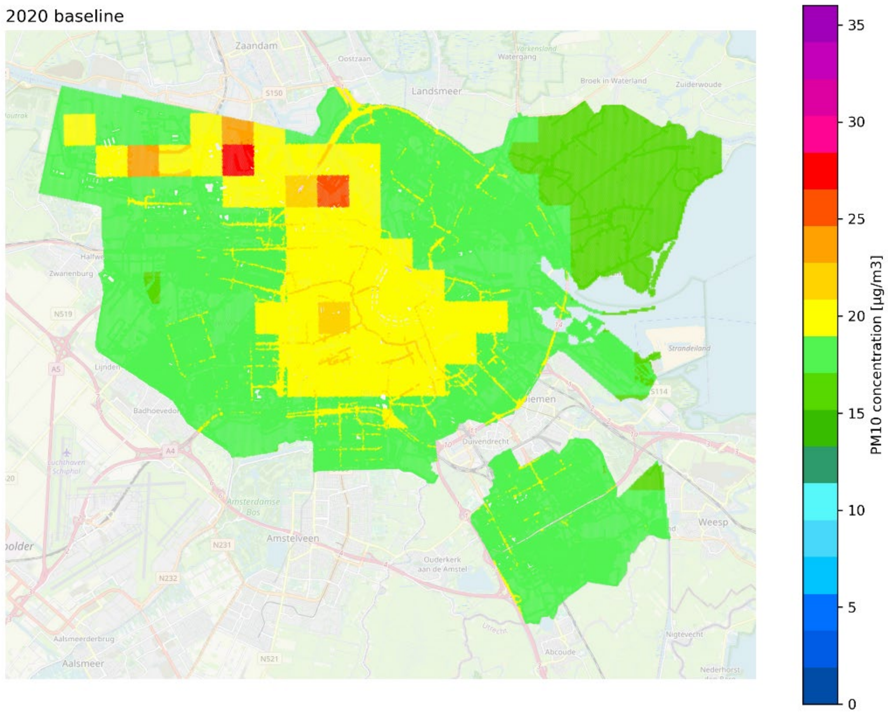
Figure 36. Differences in NO_2 concentration for best-case scenario with respect to the baseline scenario in 2020 (top) and 2030 (bottom).

4.3.4 Maps of PM_{10}-concentration

Figure 37, Figure 38 and Figure 39 show the annual mean PM_{10} concentration for different scenarios for Amsterdam. The focus area is the municipality of Amsterdam and is visible by the coloured areas in the map. The contribution of traffic to local PM_{10} concentrations is smaller than for NO_2.

Industry in the north-west harbour area of Amsterdam gives rise to high concentrations in that area, while households and other sources cause the entire densely populated area to have elevated concentrations of PM_{10} (yellow area for 2020). Some roads are visible though in 2020 and even in 2030, which means that traffic does have a significant influence on the concentrations in some locations. It can be expected however that the uCARe measures have less effect on the street level for PM_{10} than for NO_2.

The maps for $PM_{2.5}$ are shown in Annex A. The concentration maps for the most-likely scenario are shown in Annex B.



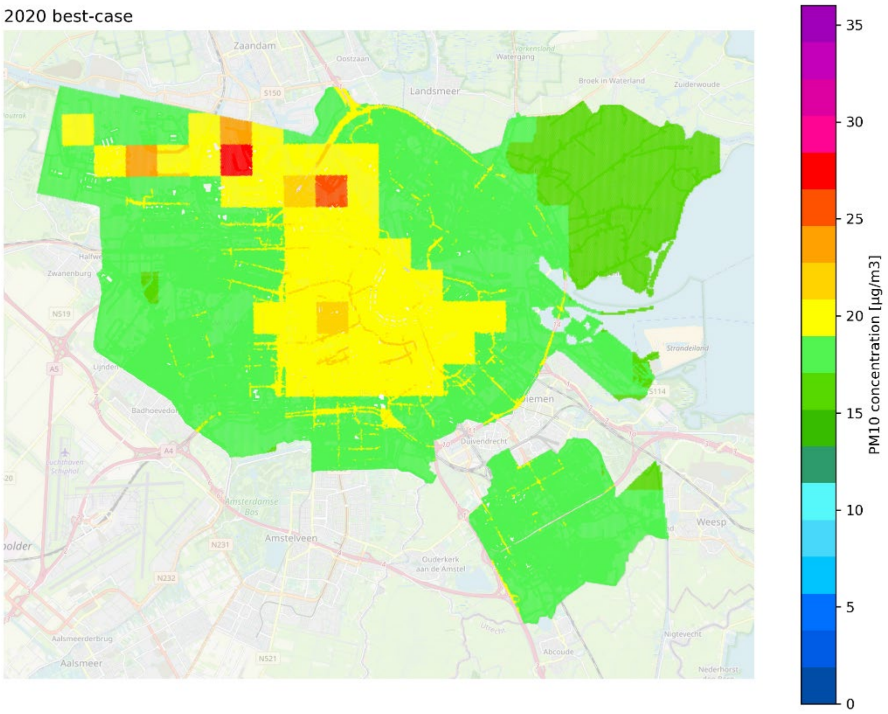
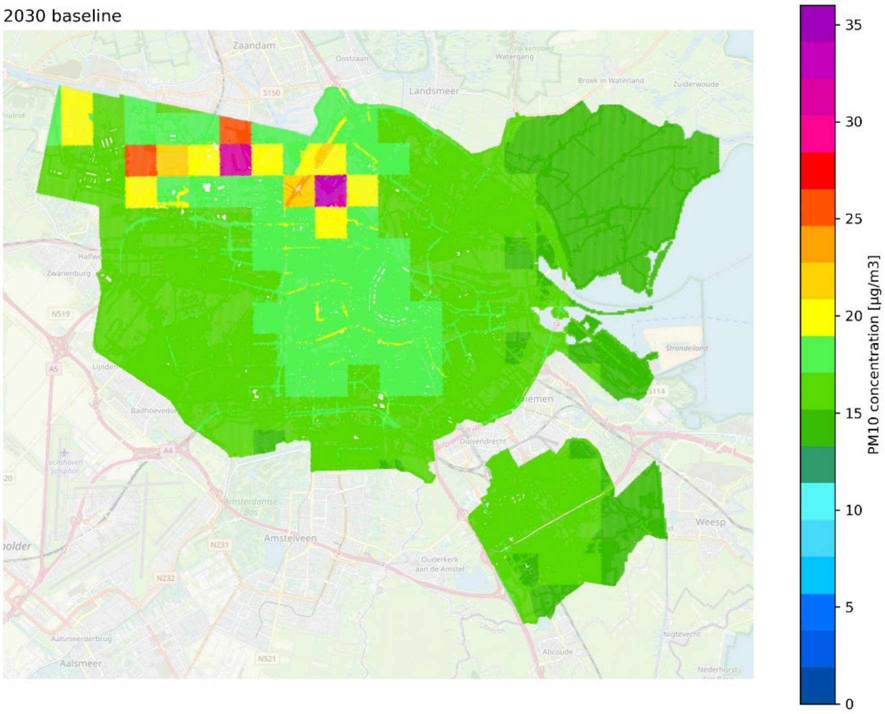


Figure 37. PM_{10}-concentration in the baseline scenario (top) and in the best-case scenario (bottom) in 2020 in the city of Amsterdam.



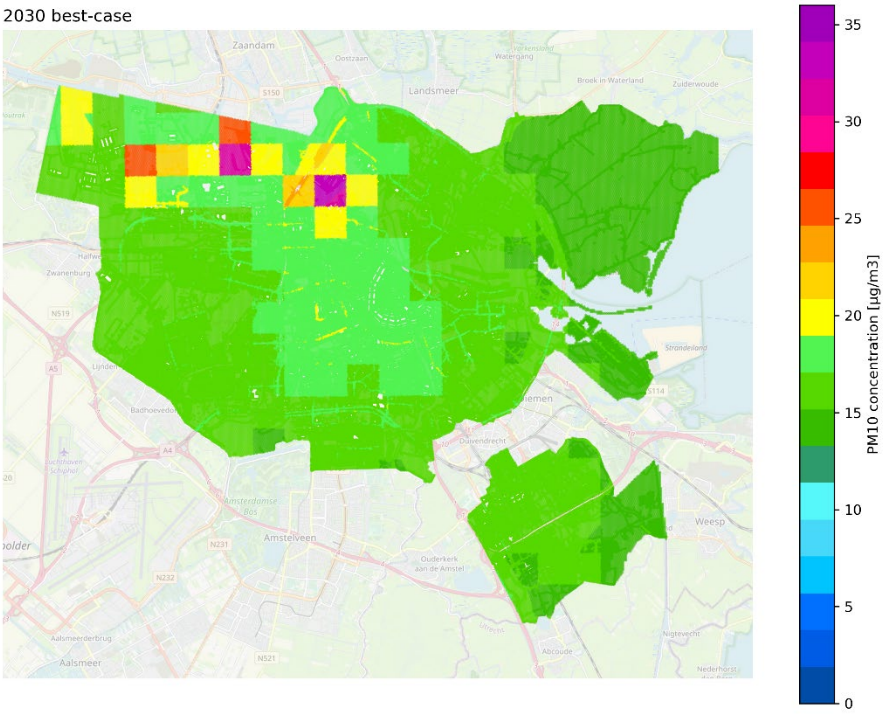


Figure 38. PM_{10}-concentration in the baseline scenario (top) and in the best-case scenario (bottom) in 2030 in the city of Amsterdam.

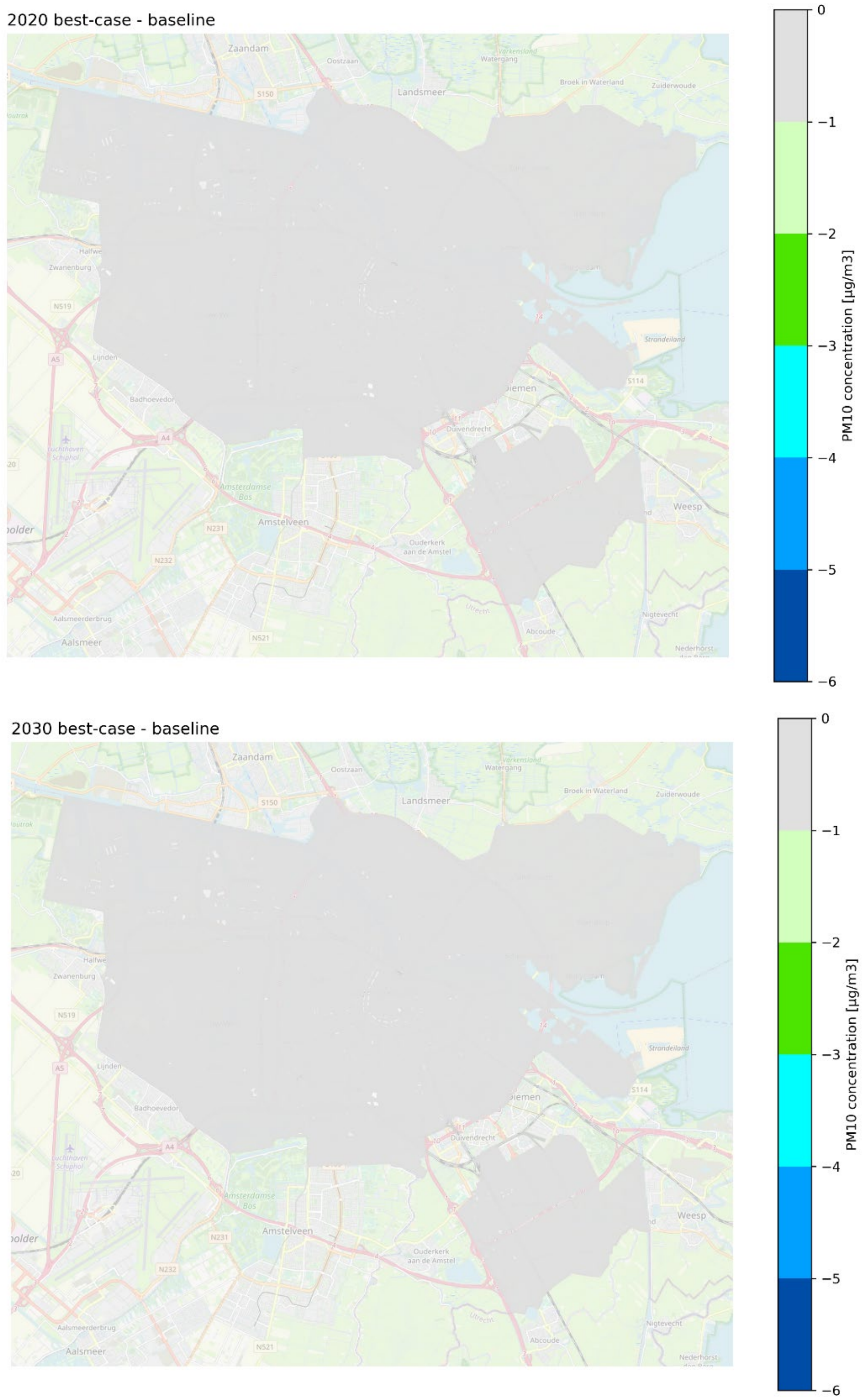


Figure 39. Differences in PM_{10} concentration for best-case scenario with respect to the baseline scenario in 2020 (top) and 2030 (bottom).

Maps of PM2.5 concentrations for Amsterdam are included in Annex A.

4.4 Comparison

Figure 40 shows a comparison of the reduction in air pollutant concentration among the cities and Figure 41 shows a comparison of the reduction in road emissions for the three cities. In Figure 42 and Figure 43, the differences in air pollutant concentrations with respect to the baseline scenario is shown for all cites for both years. It could be seen that the reductions generally are higher in Zurich than in Gothenburg and Amsterdam.

Reasons for that are believed to be that in the modelling for Zurich, the effect of measures on the background concentration is accounted for, which leads to a greater change in air pollutant concentration.

In addition, in the modelling for Amsterdam, the effect of street canyons is taken into account (which means that the reduction is large within the canyons but much smaller in the rest of the area that is shielded by the buildings). This leads to smaller changes in average concentrations.

Another reason for the larger absolute reductions in Zurich as compared to Gothenburg is that the air pollutant concentration levels in Gothenburg are lower than in Zurich. Therefore, an equal relative change will result in a smaller absolute change in Gothenburg.

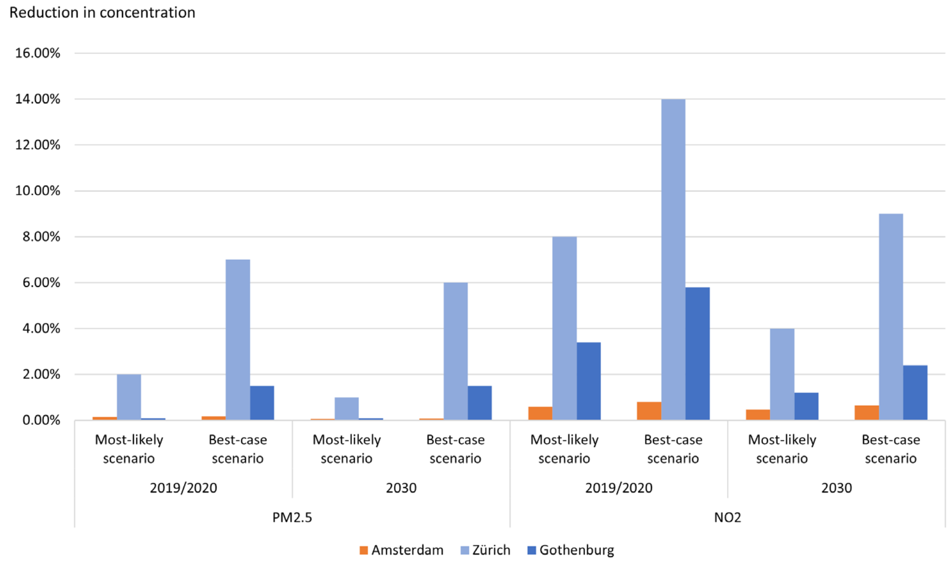


Figure 40. Comparison of reduction in air pollutant concentration for the three cities for different scenarios.

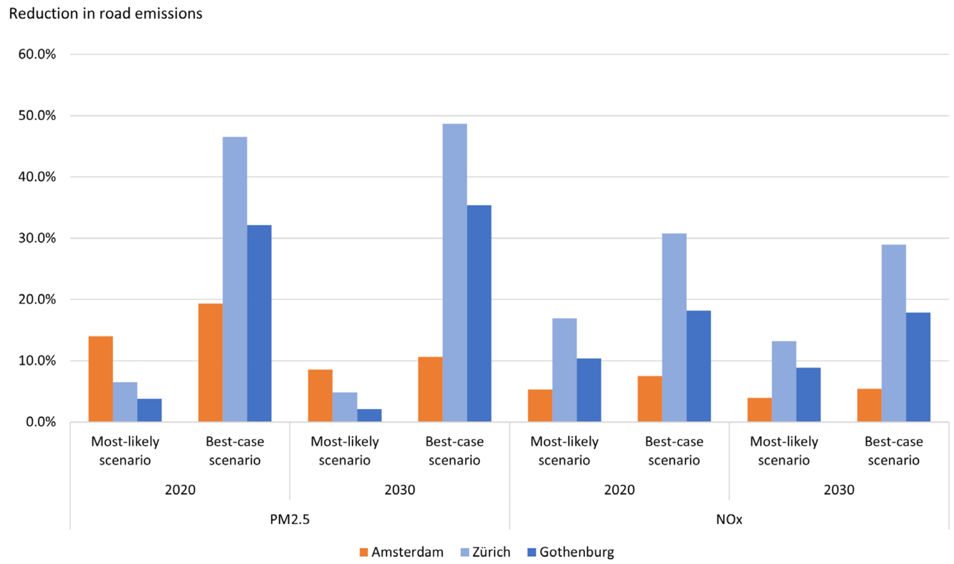
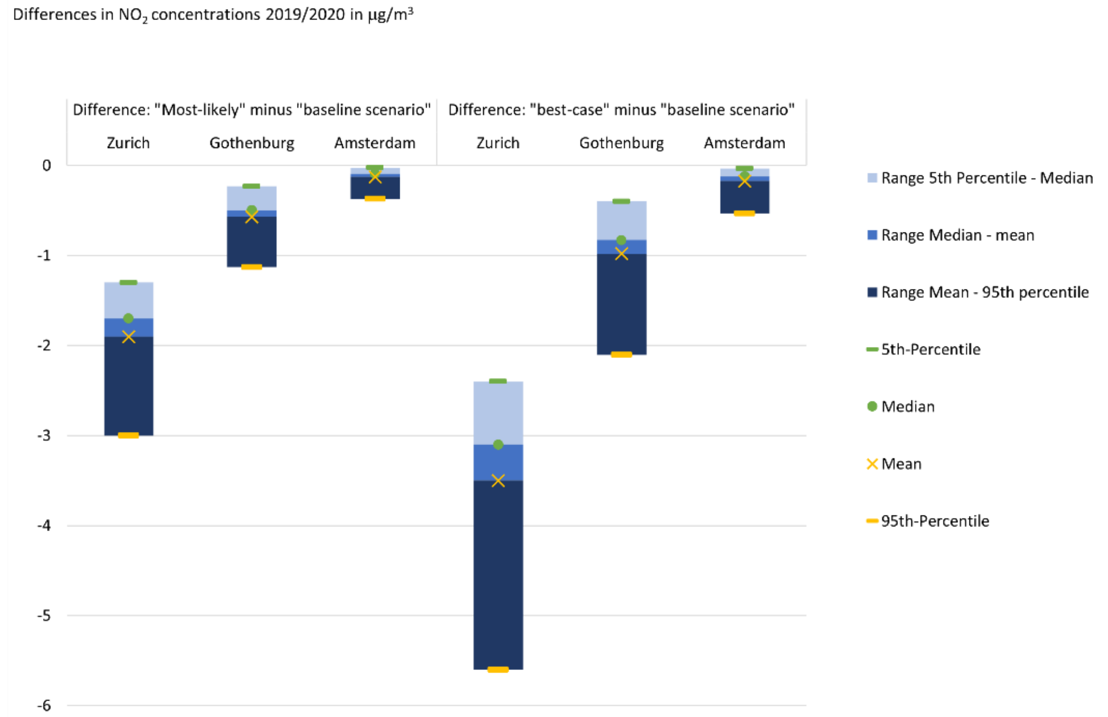


Figure 41. Comparison of reduction in road transport emissions in the three cities for different scenarios and years.



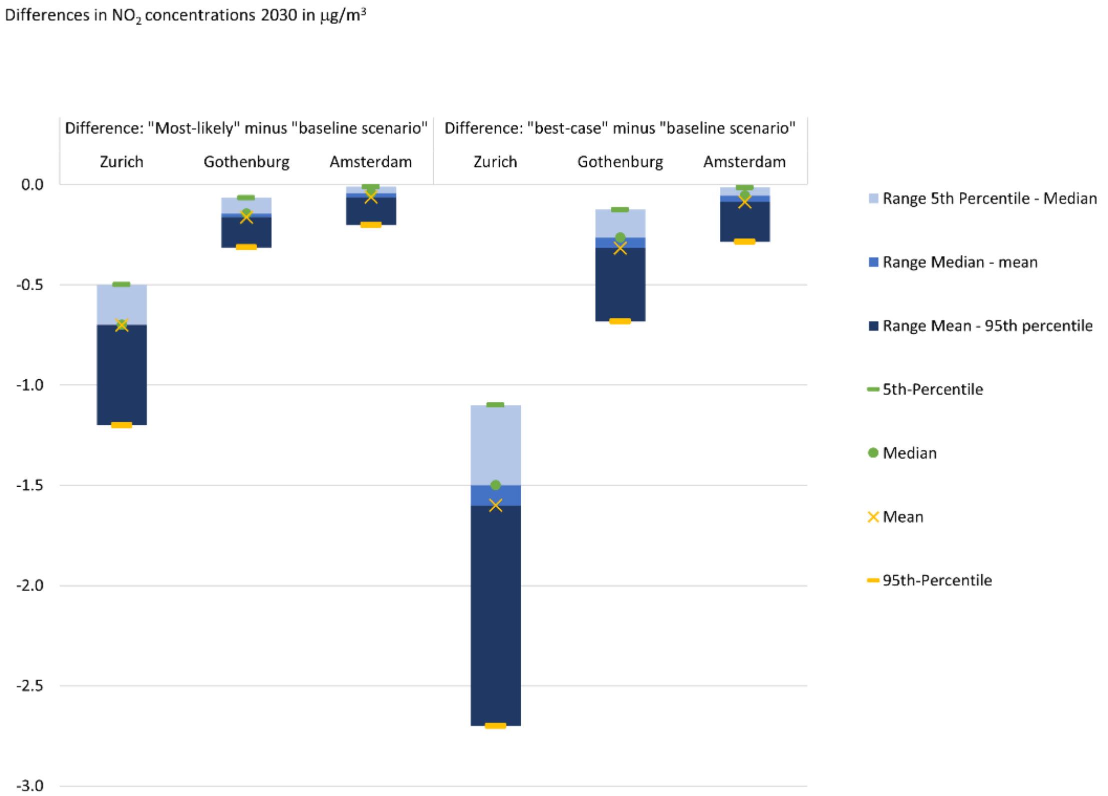
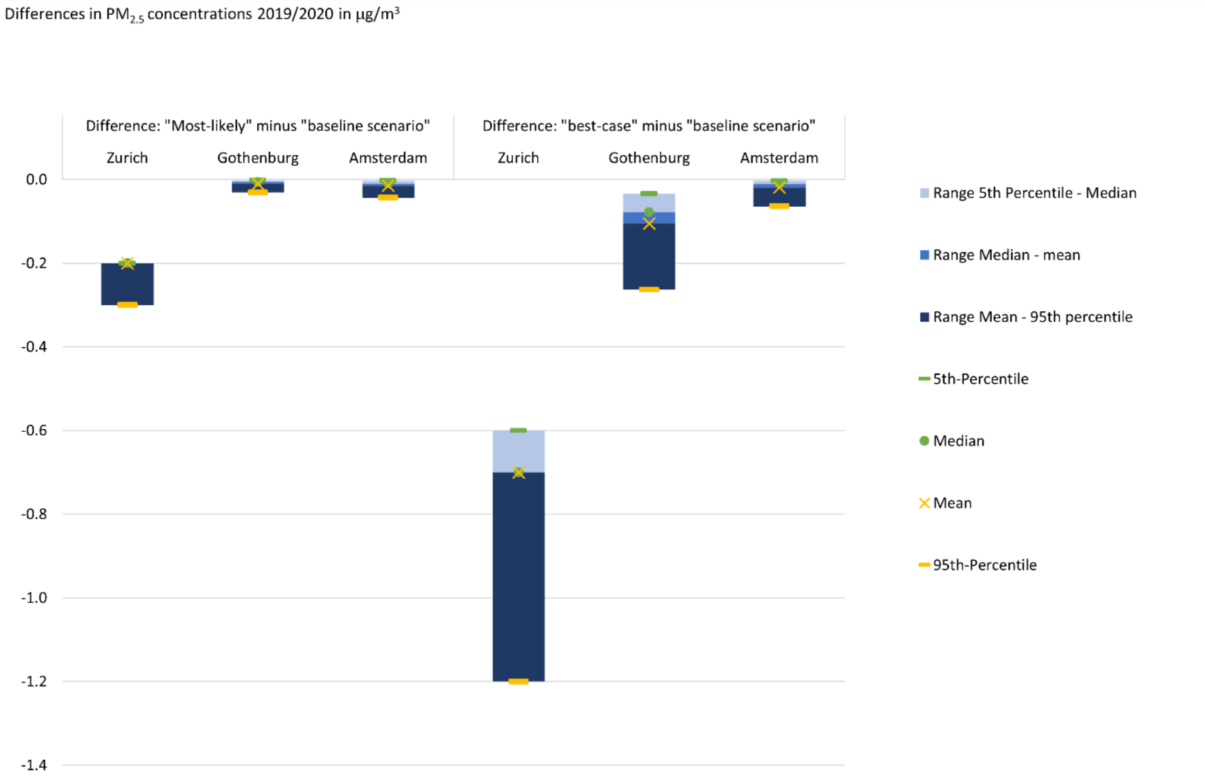


Figure 42. Differences in NO_2 concentrations with respect to the baseline scenario for all three cities in 2019/2020 (top) and 2030 (bottom).



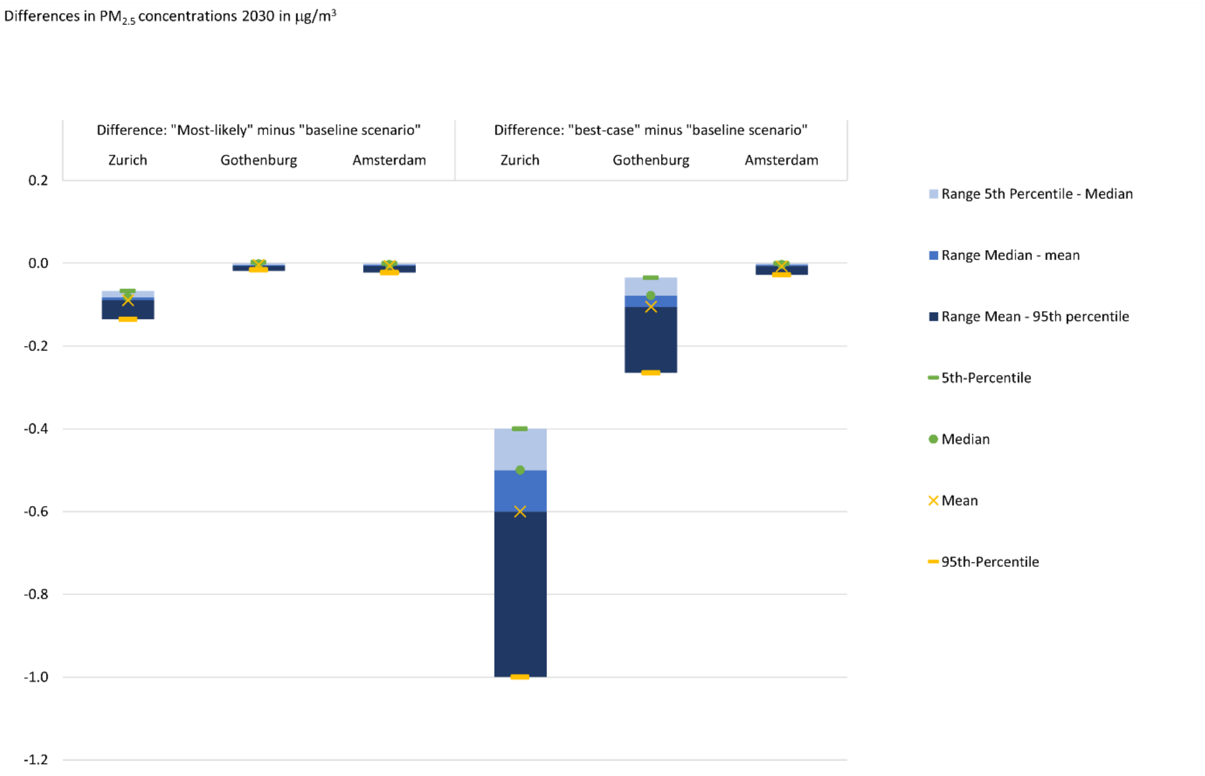


Figure 43. Differences in $PM_{2.5}$ concentrations with respect to the baseline scenario for all three cities in 2019/2020 (top) and 2030 (bottom).

5 Conclusions and recommendations

5.1 Conclusions

The three models applied show reductions of air pollutant concentrations due to the uCARe measures along the road network in the order of up to 5.6 µg NO_2/m^3 and up to 1.2 µg $PM_{2.5}/m^3$ (5^{th} percentile), depending on the city and the scenario.

Even in the most-likely scenario, a substantial reduction in air pollutant concentration can be achieved along the main roads in all of the investigated study areas. The study area focuses on the city centre, which is densely populated in all three cities. The emission reduction achieved by the measures therefore significantly reduces the population's exposure to high air pollutant concentrations.

The models differ primarily in the following aspects:

- Impact of interventions on background concentration: Only the model applied for Zurich takes into account the impact of interventions on the background concentration (i.e. on import of air pollutants from outside the modelling area). If measures are implemented not only in the three cities, but also in the surrounding areas and neighbouring countries, the background concentration will change as well. For Zurich it is assumed that road transportation contributes the same share to the background concentration as to total direct emissions in the three scenarios. Results show that the impact of the changes in background concentration is substantial, since the PM_{10}, $PM_{2.5}$ and NO_2 are transported over long distances. Therefore, they contribute substantially to the observed change in average concentrations. However, the contribution of the background concentration is based on simplifying assumptions, which would need to be assessed in more detail to assess the contribution of imported air pollutants more accurately.
- Accounting for street canyons: Street canyons lead to higher concentrations along the roads and lower concentrations further away from the roads, since they trap air pollution at the street level, compared to areas with lower building density. This effect is accounted for in Amsterdam, and in a simplified manner in Zurich (i.e. by differentiating three classes of building density), but not in Gothenburg. Results for Amsterdam show that accounting for the effect of street canyons strongly concentrates air pollution along the road network. The impact of the measures is therefore visible manly along the main roads, but not in areas that are shielded from the main roads.

5.2 Recommendations

City centres are densely populated, and the present study shows, that exposure to high air pollutants occurs mostly along the road network. The measures and interventions of both, the most-likely and the best-case scenarios, achieve a significant reduction of air pollutant concentrations along the roads, where limit values are still exceeded in some areas. They allow a targeted and effective reduction at locations with high concentrations of air pollutants.

For all three cities a substantial reduction of NO_2 and $PM_{2.5}$ concentration is observed already in the baseline scenario between 2020 and 2030. The main reason for the expected reduction of air pollutant emissions are the changes in the composition of the vehicle fleet since newer cars have lower emissions. The measures and interventions investigated within the uCARe project will therefore be more effective in the short term than in the long term.

This calls for a rapid implementation of the proposed measures and interventions. The idea of the uCARe project indeed was to elaborate measures which can be implemented quickly, since new emission limits for cars, such as the expected EURO 7, take rather long to show full benefits due to the time needed for fleet renewal.

This study focuses on potential changes in emissions due to reduction measures performed by the driver. Part of these reductions may also be achieved by traffic measures (such as enabling smoother driving with fewer stops at red lights).

Furthermore, this study shows the importance of applying different types of models. To accurately assess impacts of measures on air pollutant concentrations, the model needs to account for the effect of street canyons, and an accurate assessment of the impact on background concentrations is necessary.

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7 Annex A: $PM_{2.5}$-concentration maps

7.1 Zurich

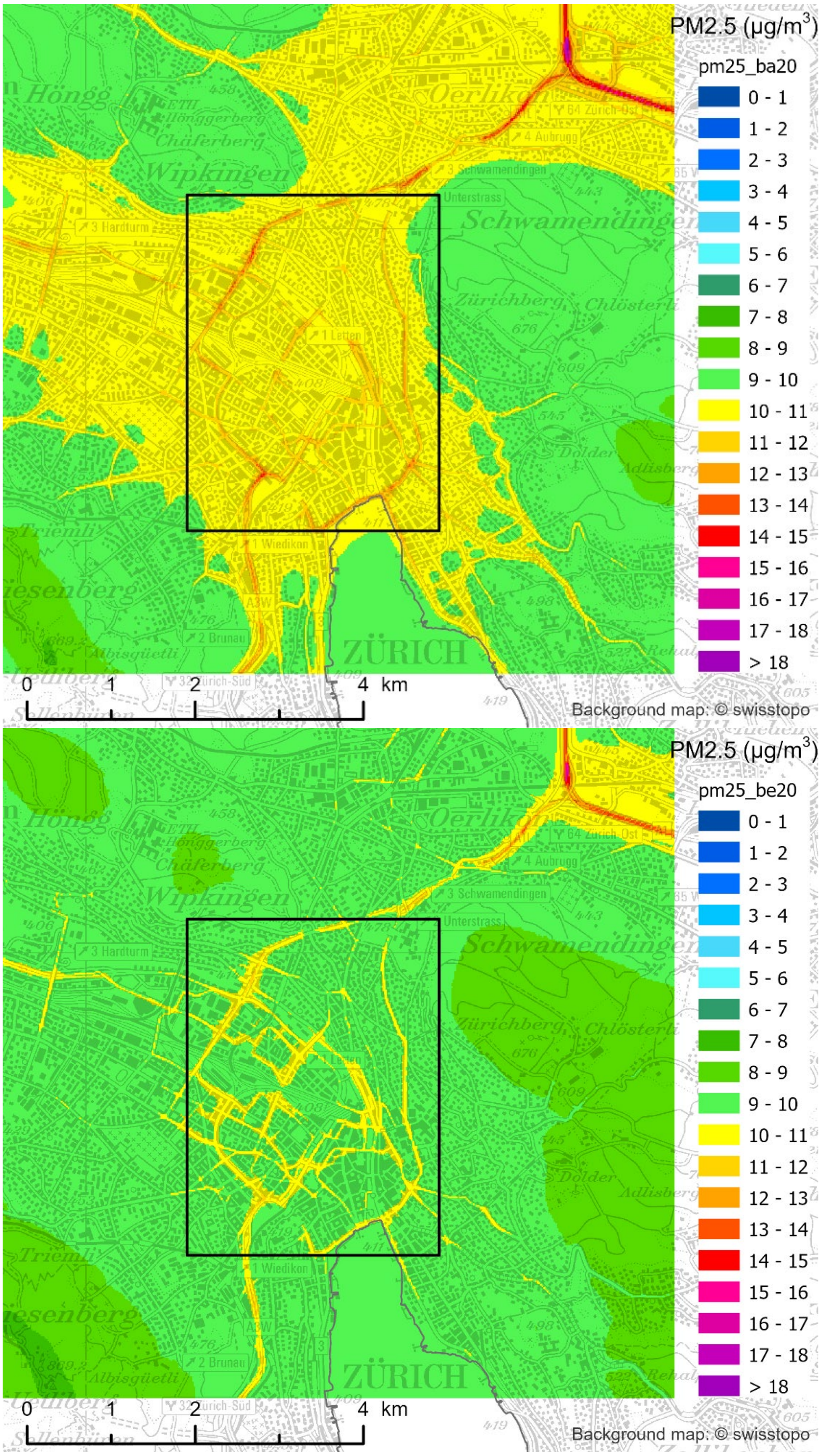


Figure 44. $PM_{2.5}$ concentration in the baseline scenario (top) and in the best-case scenario (bottom) in 2020 in the city of Zurich.

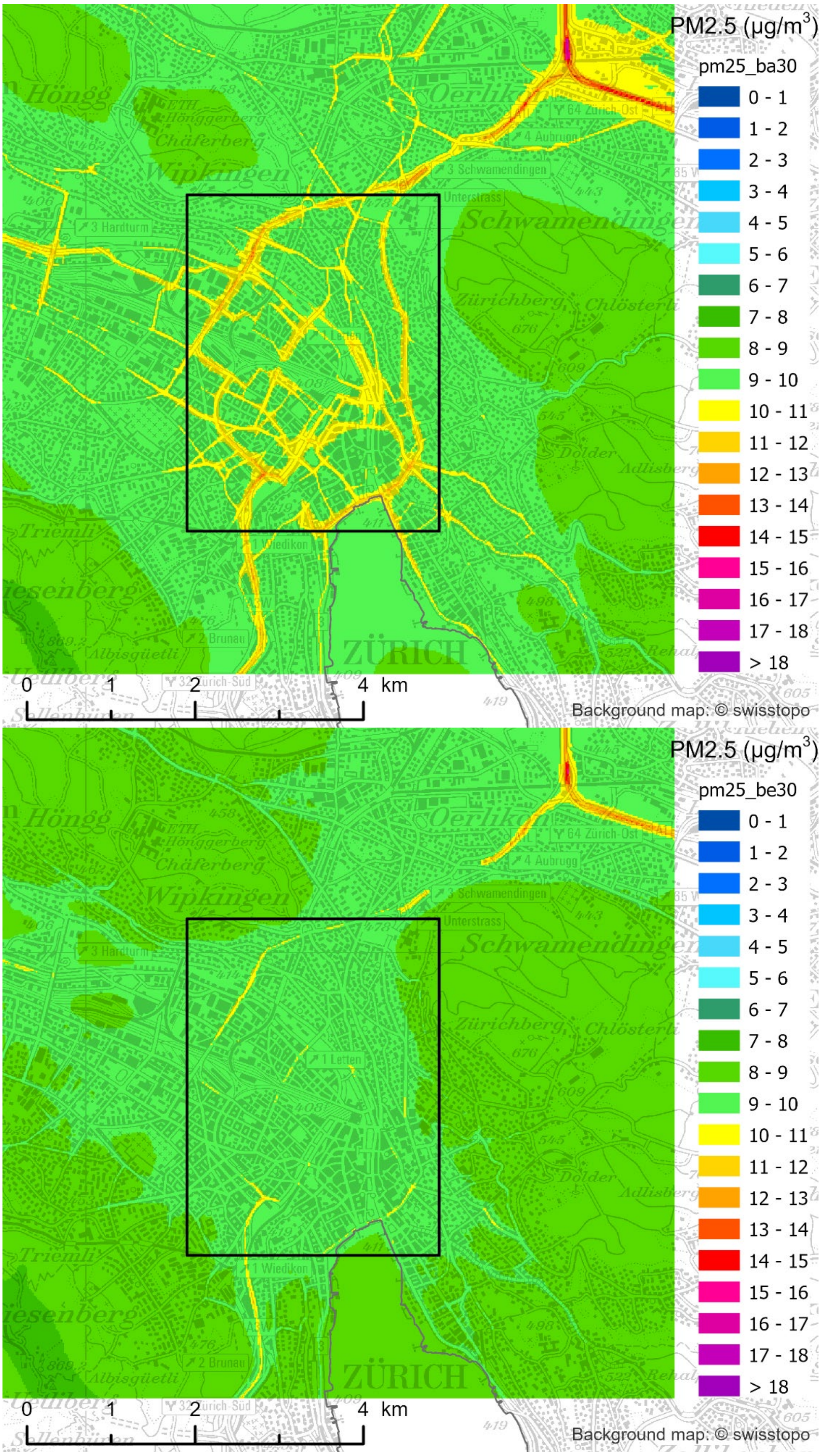


Figure 45. $PM_{2.5}$ concentration in the baseline scenario (top) and in the best-case scenario (bottom) in 2030 in the city of Zurich.

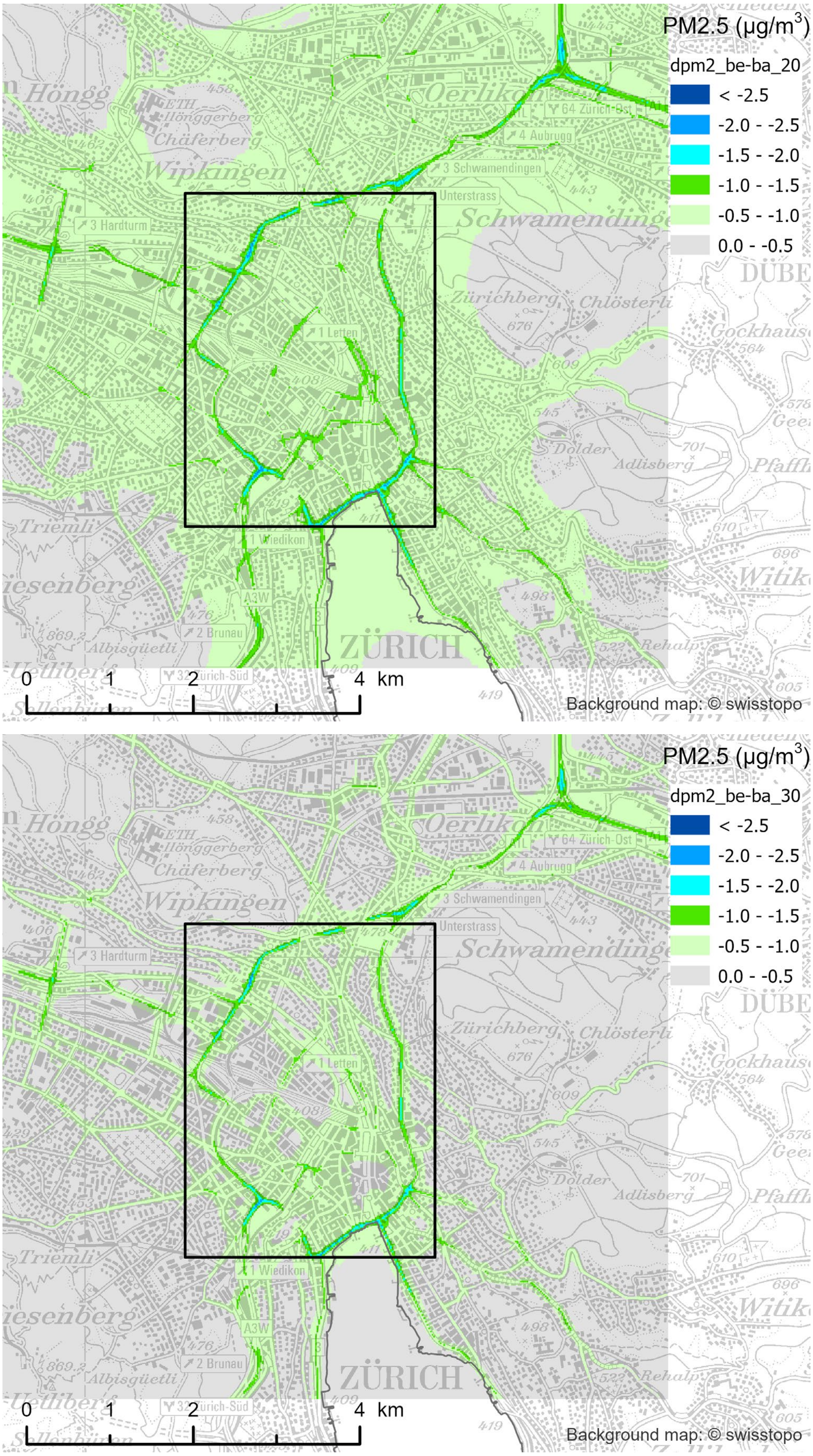


Figure 46. Differences in $PM_{2.5}$-concentration with respect to the baseline scenario in 2020 (top) and 2030 (bottom).

7.2 Amsterdam

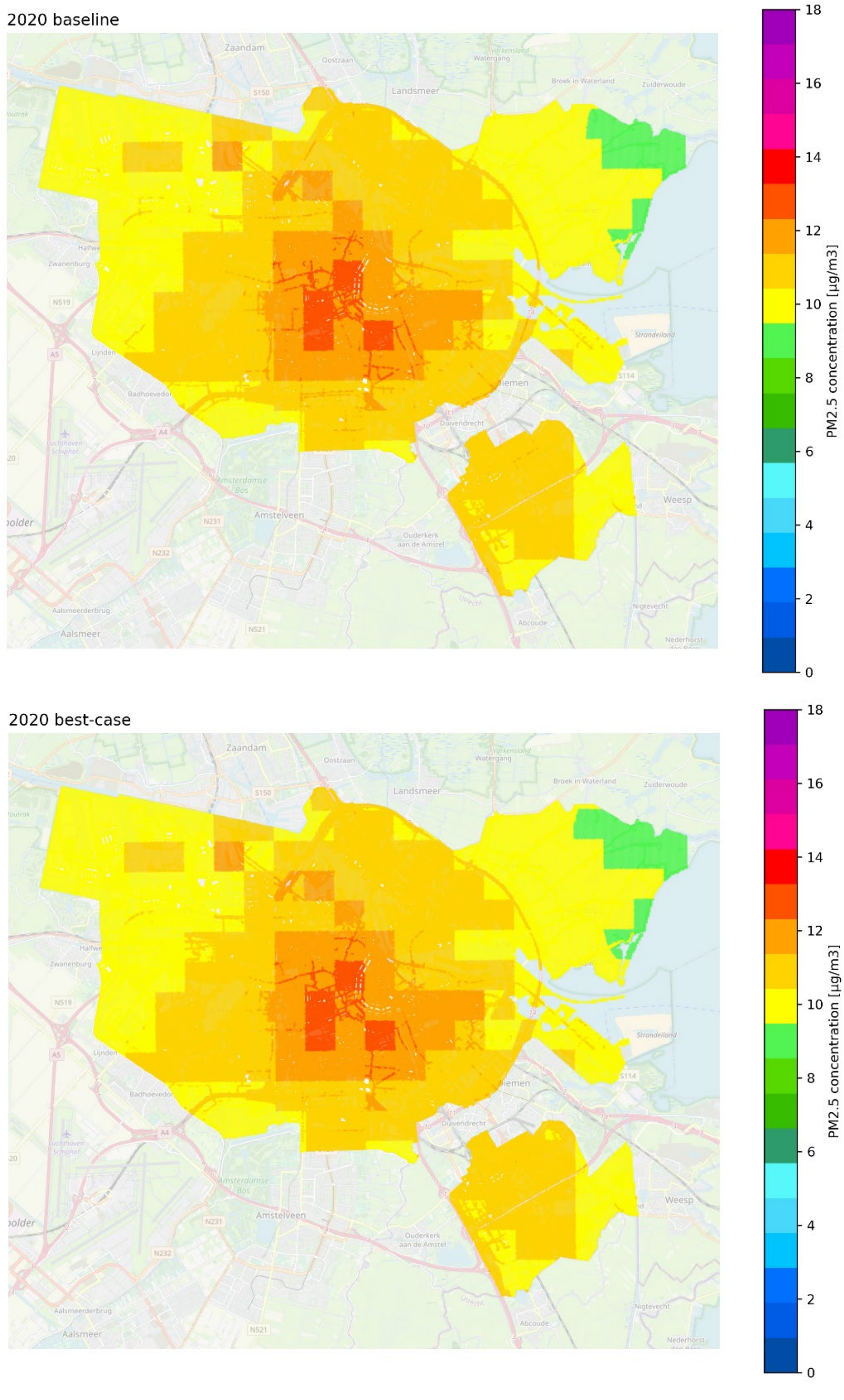


Figure 47. $PM_{2.5}$ concentration in the baseline scenario (top) and in the best-case scenario (bottom) in 2020 in the city of Amsterdam.

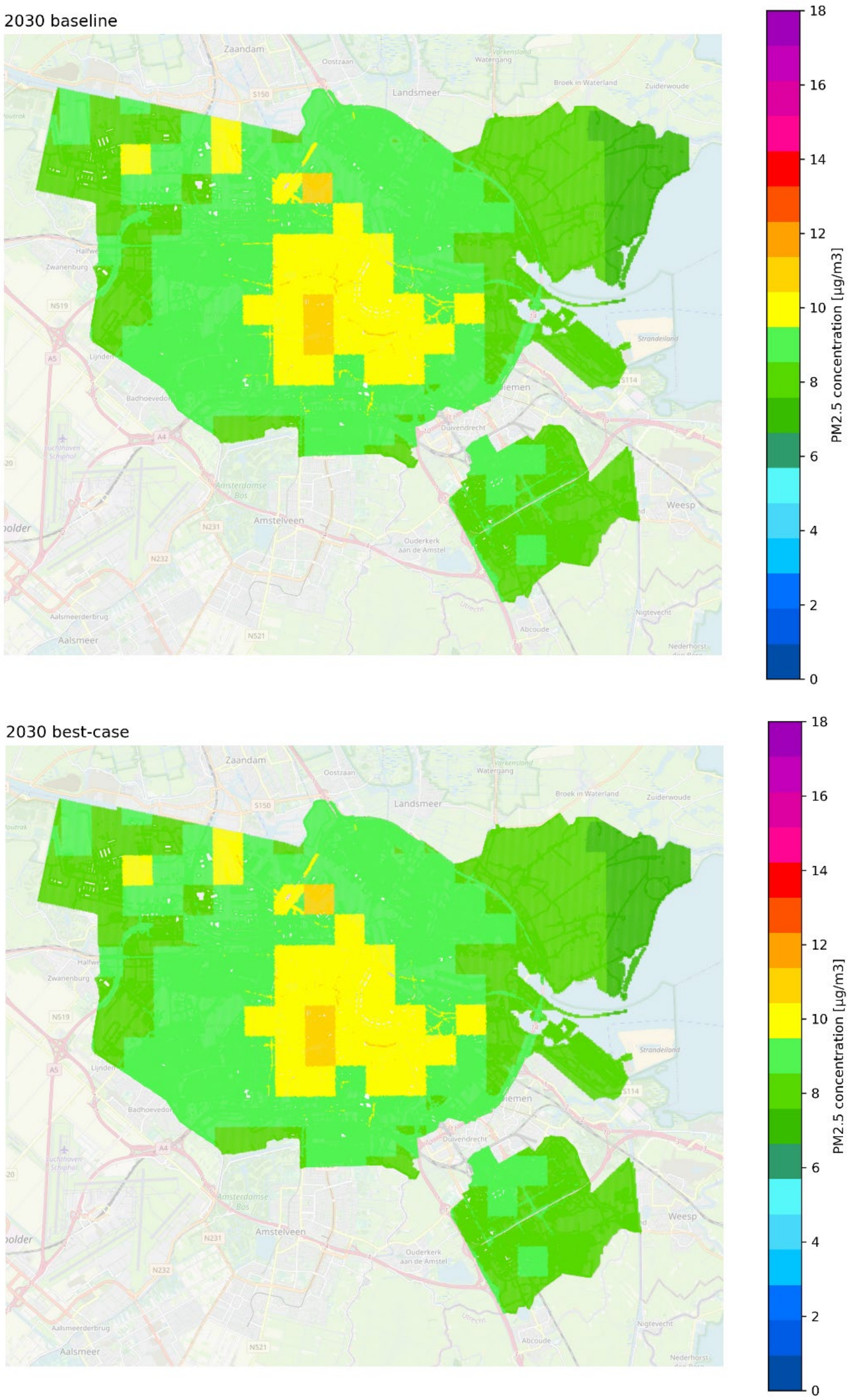


Figure 48. $PM_{2.5}$ concentration in the baseline scenario (top) and in the best-case scenario (bottom) in 2030 in the city of Amsterdam.

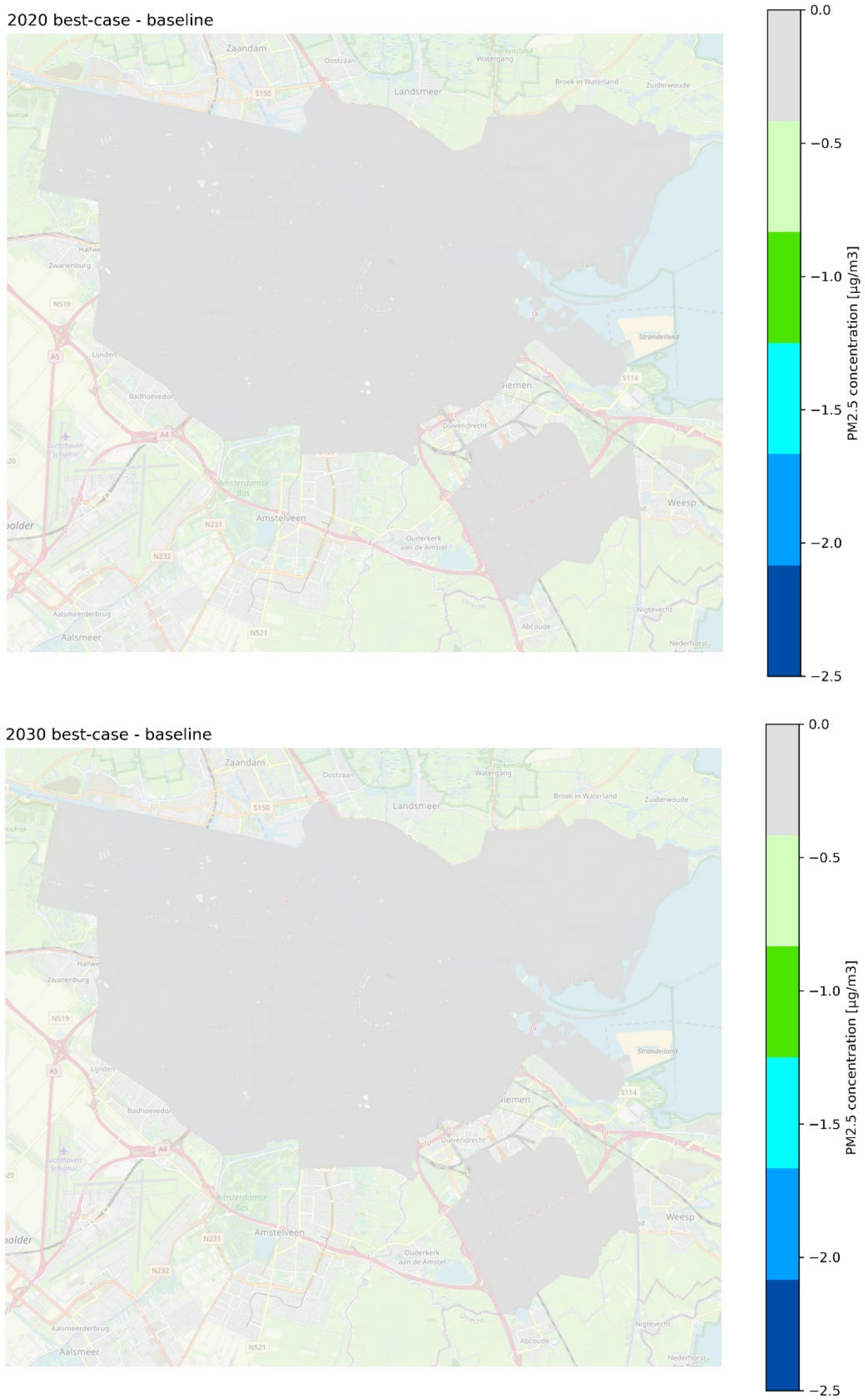


Figure 49. Differences in $PM_{2.5}$-concentration with respect to the baseline scenario in 2020 (top) and 2030 (bottom) in the city of Amsterdam.

8 Annex B: Concentration maps most-likely scenario

8.1 Zurich

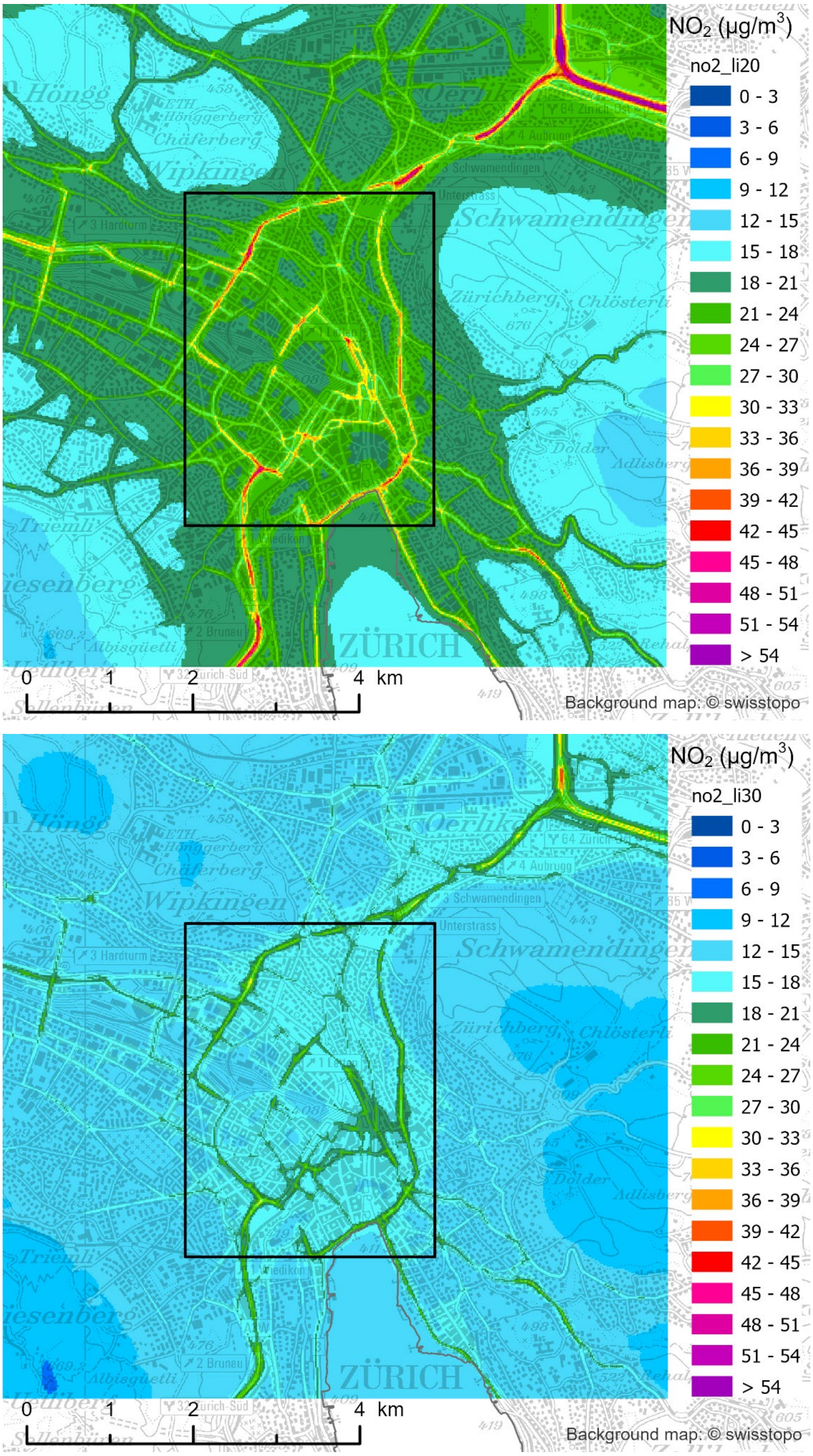


Figure 50. NO_2 concentration in the most-likely scenario 2020 (top) and 2030 (bottom) in the city of Zurich.

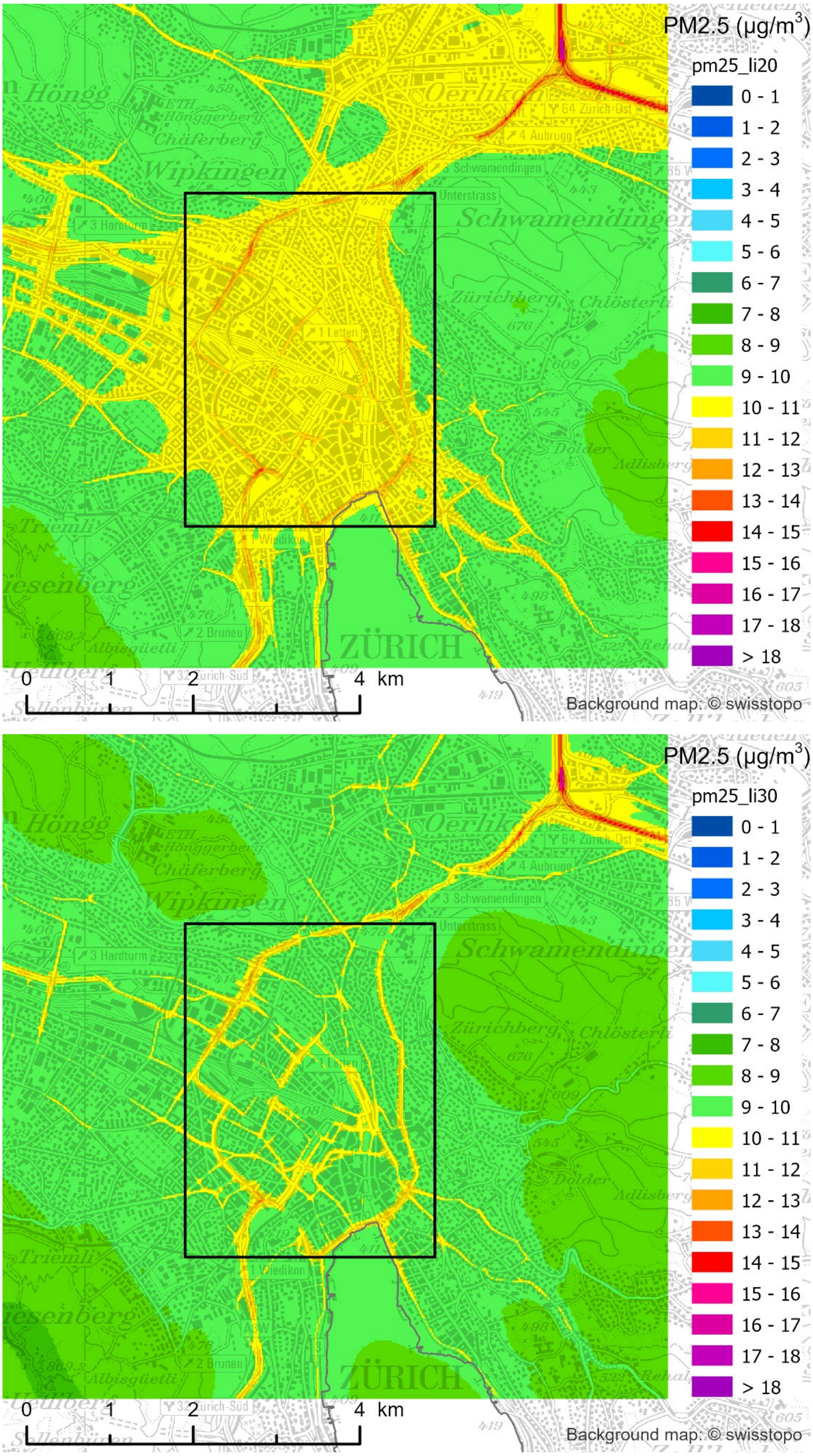


Figure 51. $PM_{2.5}$ concentration in the most-likely scenario 2020 (top) and 2030 (bottom) in the city of Zurich.

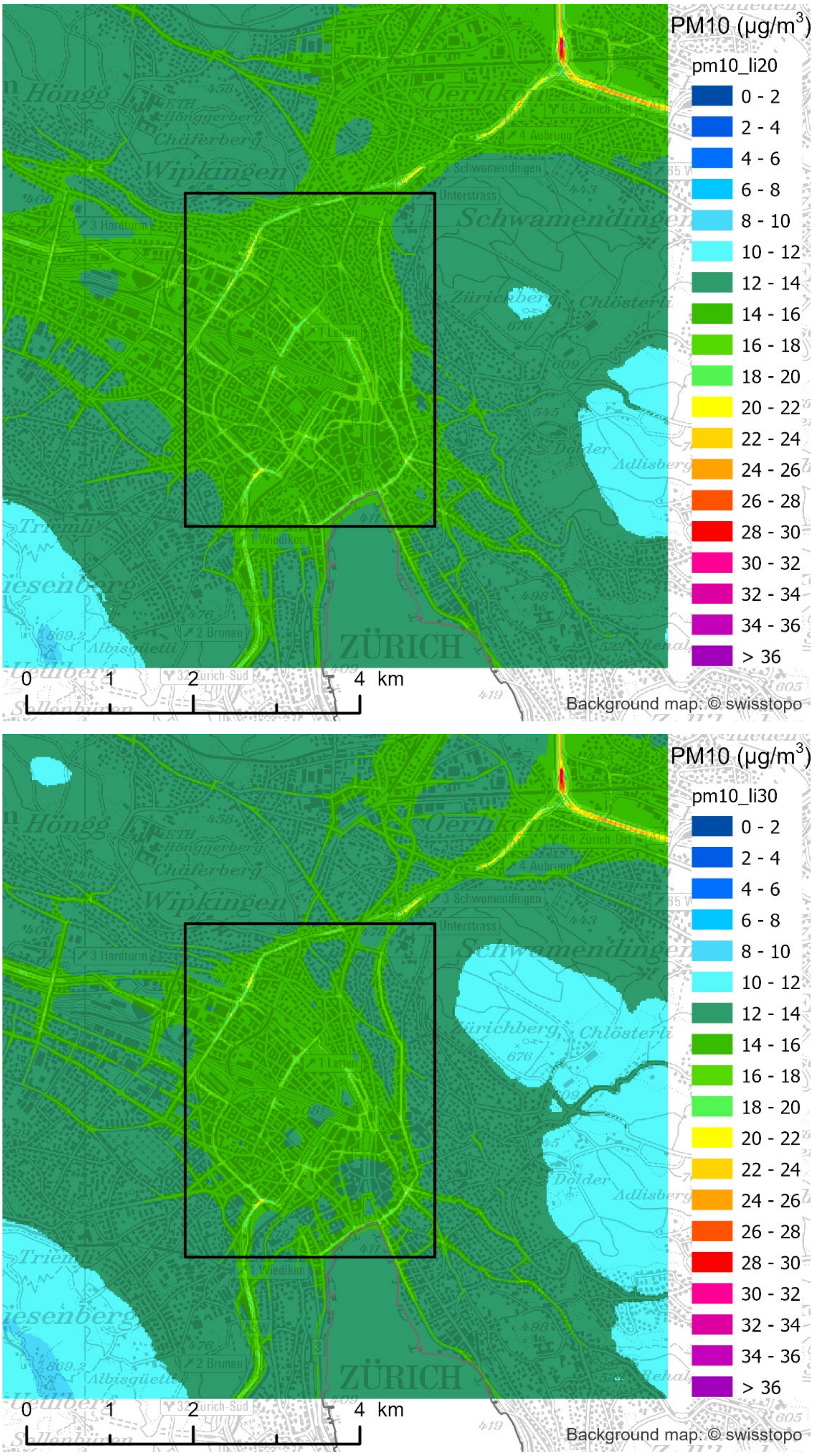


Figure 52. PM_{10} concentration in the most-likely scenario 2020 (top) and 2030 (bottom) in the city of Zurich.

8.2 Gothenburg

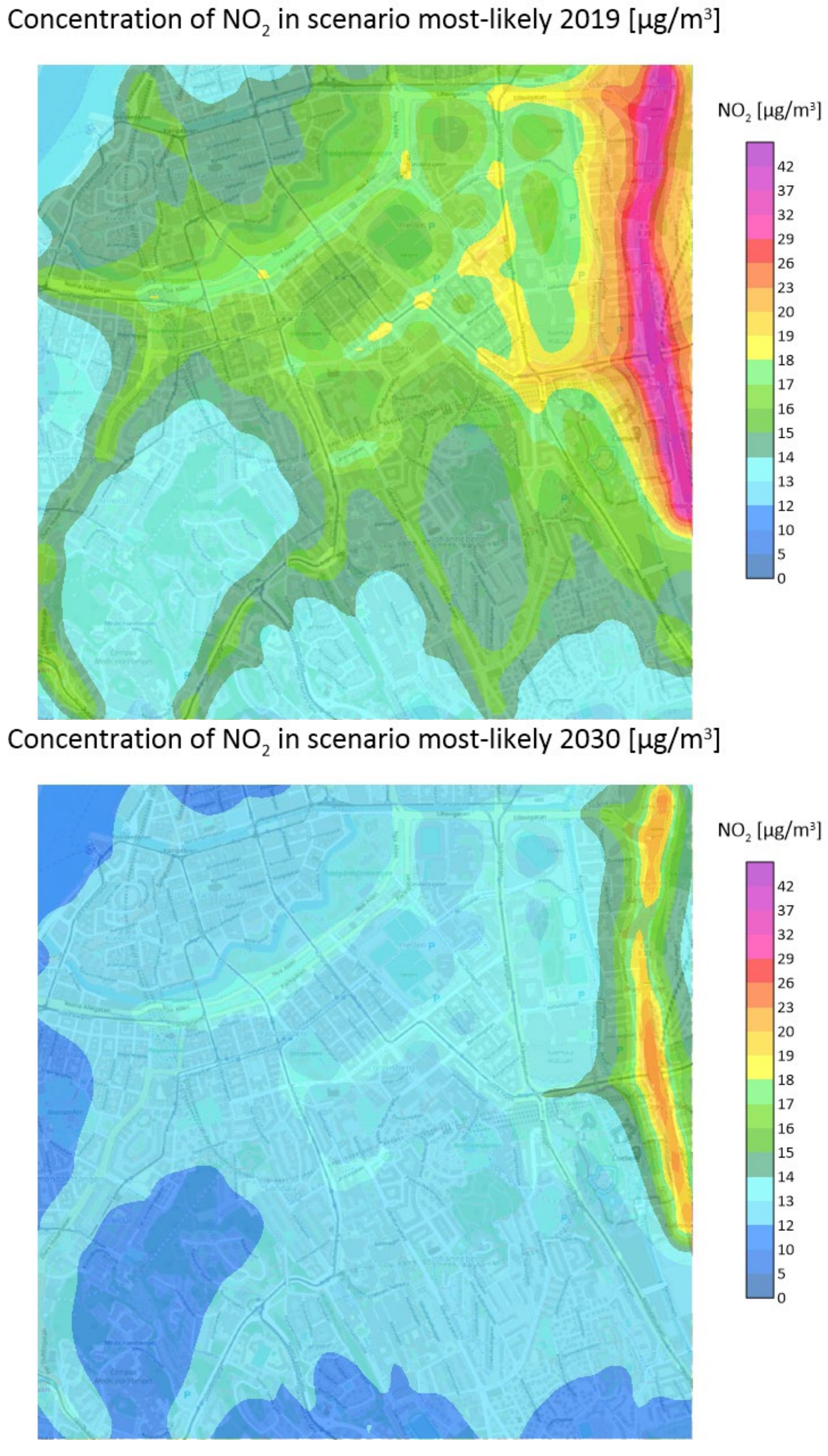
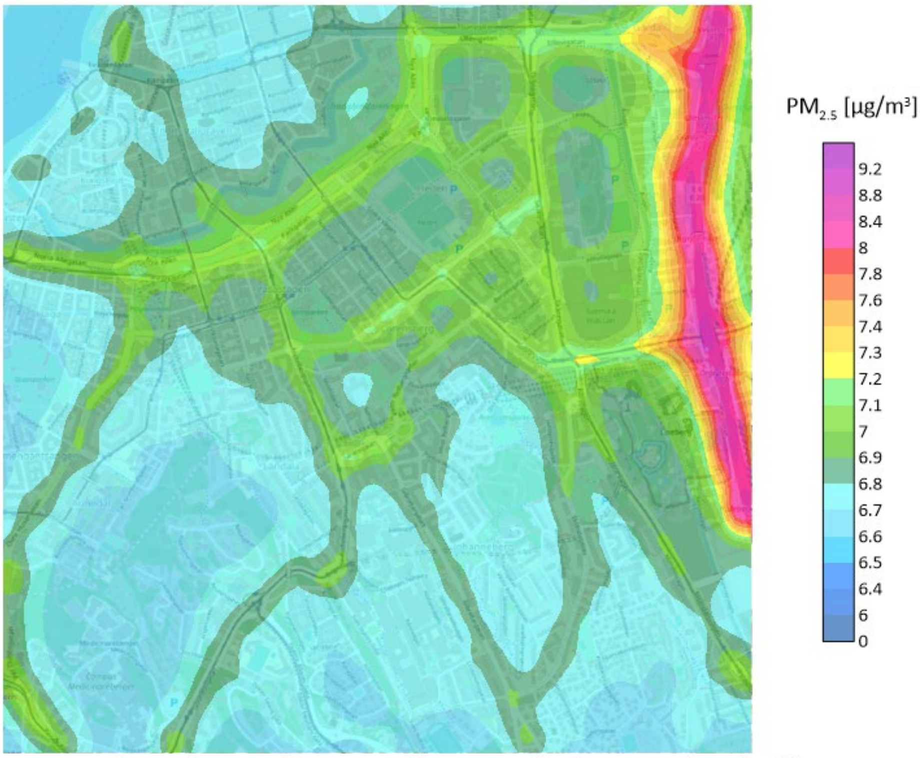


Figure 53. NO_2 concentration in the most-likely scenario 2019 (top) and 2030 (bottom) in the city of Gothenburg.

Concentration of $PM_{2.5}$ in scenario most-likely 2019 [µg/m³]



Concentration of $PM_{2.5}$ in scenario most-likely 2030 [µg/m³]

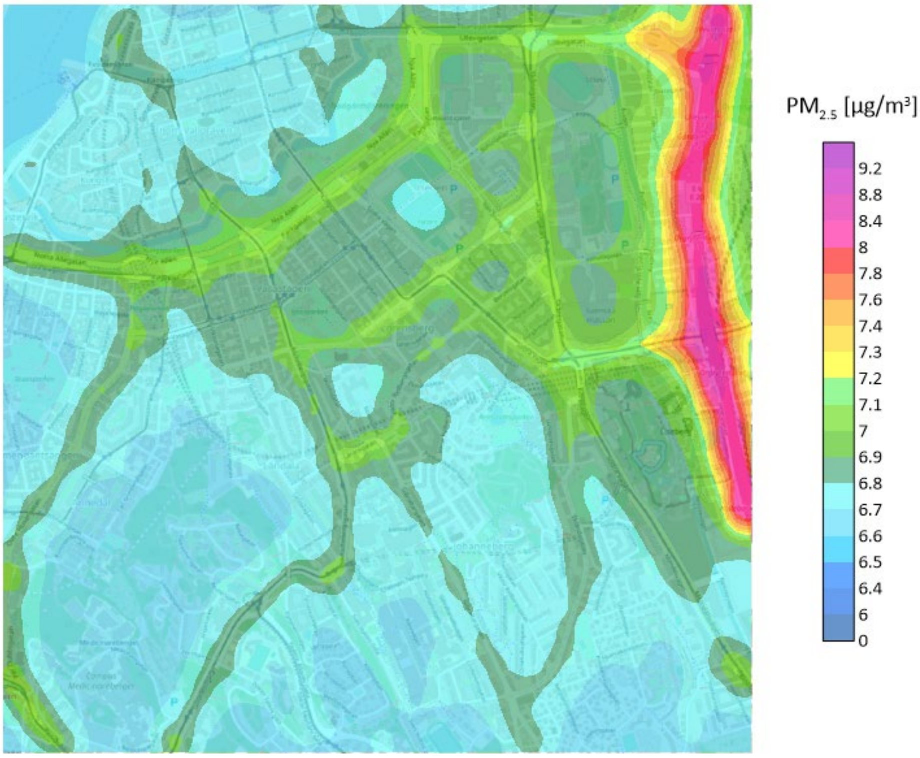


Figure 54. $PM_{2.5}$ concentration in the most-likely scenario 2019 (top) and 2030 (bottom) in the city of Gothenburg.

8.3 Amsterdam

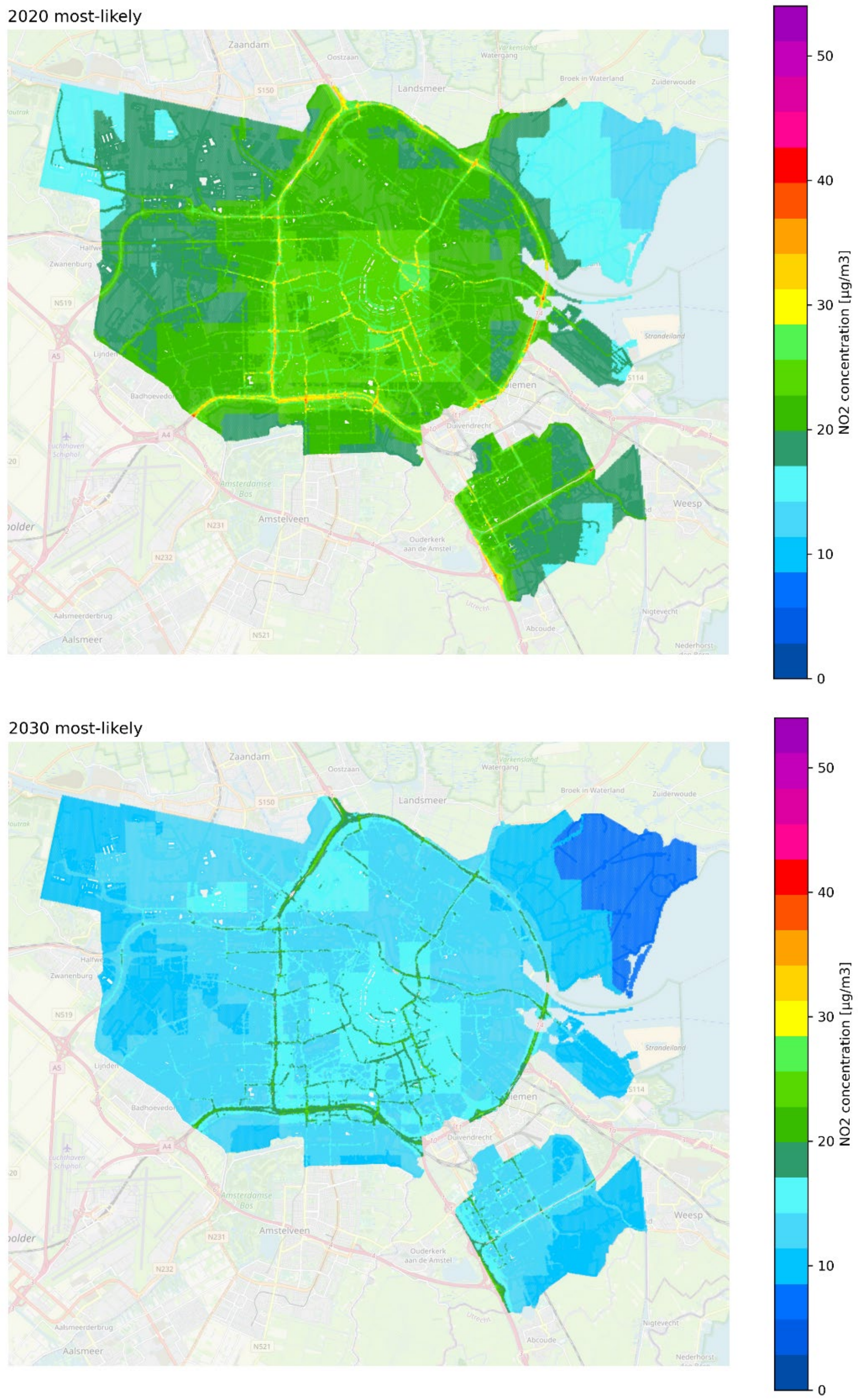


Figure 55. NO_2 concentration in the most-likely scenario 2020 (top) and 2030 (bottom) in the city of Amsterdam.

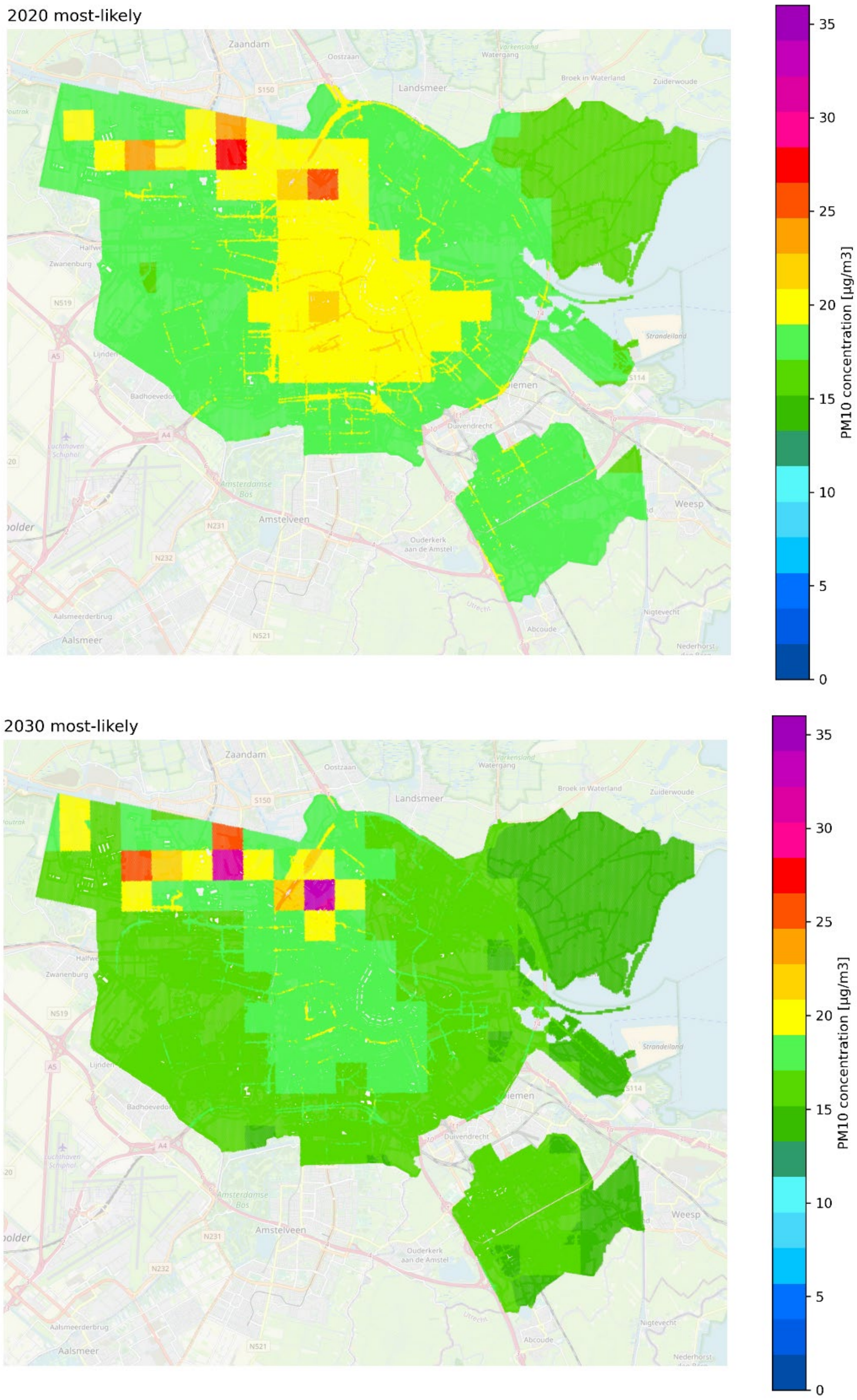


Figure 56. PM$_{10}$ concentration in the most-likely scenario 2020 (top) and 2030 (bottom) in the city of Amsterdam.

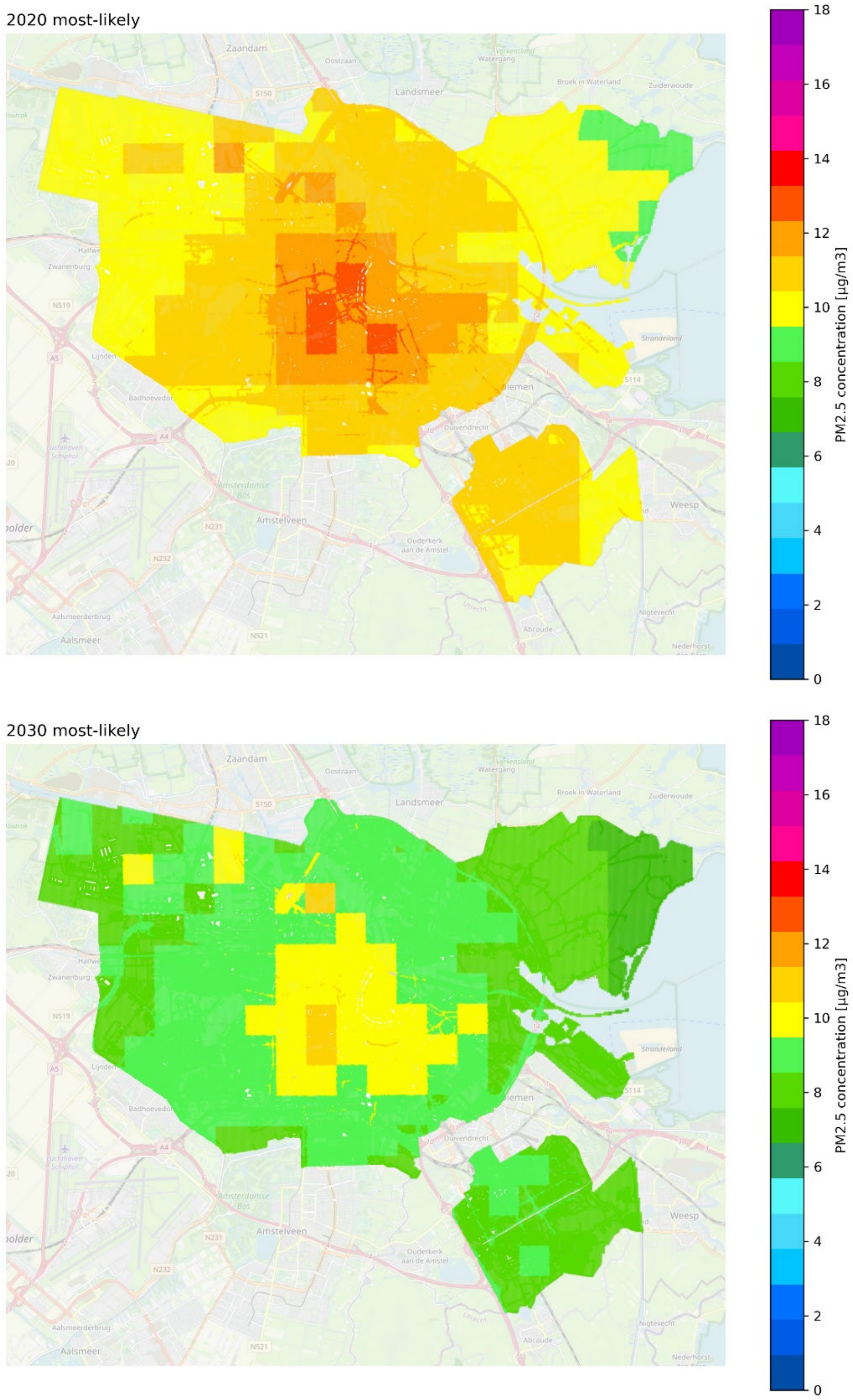


Figure 57. $PM_{2.5}$ concentration in the most-likely scenario 2020 (top) and 2030 (bottom) in the city of Amsterdam.

9 Annex C: Translation table HBEFA to SRM / VERSIT+

Table 23 Translation HBEFA traffic situation to SRM and speed category

Dutch calc. method (SRM)	Speed category*	HBEFA traffic situation	Road type for subsegment (fuel*euro standard) weighting	Road type for emission factors
1	0 - 15	URB/Access/30/Freeflow	WT1	WS1
1	15 - 30	URB/Access/30/Freeflow	WT1	WM1
1	30 - 50	URB/Local/50/Freeflow	WT1	WF1
1	50 - 70	URB/Distr/70/Freeflow	WT2	WT2
1	70 - 80	URB/Trunk-City/80/Freeflow	WT2	WT2
2	30	RUR/Access/30/Freeflow	WT1	WM1
2	50	RUR/Local/50/Freeflow	WT1	WF1
2	70	RUR/Distr/70/Freeflow	WT2	WT2
2	80	RUR/Trunk/80/Freeflow	WT2	WT2
2	90	RUR/Trunk/90/Freeflow	WT2	W93
2	100	RUR/MW/100/Freeflow	WT3	W03
2	110	RUR/MW/110/Freeflow	WT3	W13
2	120	RUR/MW/120/Freeflow	WT3	W23
2	130	RUR/MW/130/Freeflow	WT3	W33
2	30C	RUR/Access/30/St+Go	WT1	WS1
2	50C	RUR/Local/50/St+Go	WT1	WS1
2	70C	RUR/Distr/70/St+Go	WT3	WS3
2	80C	RUR/Trunk/80/St+Go	WT3	WS3
2	90C	RUR/Trunk/90/St+Go	WT3	WS3
2	100C	RUR/MW/100/St+Go	WT3	WS3
2	110C	RUR/MW/110/St+Go	WT3	WS3
2	120C	RUR/MW/120/St+Go	WT3	WS3
2	130C	RUR/MW/130/St+Go	WT3	WS3

*) speed category should not be confused with speed limit. It is an indication of the average speed driven on a road in case of no congestion. C indicates congestion.

Table 24 Translation of HBEFA subsegment to VERSIT+ class

Subsegment	VERSIT+ class
PC petrol <ECE	(group of 36 older petrol emission factors 1982-1992)
PC petrol ECE-15'00	
PC petrol ECE-15'01/02	
PC petrol ECE-15'03	
PC petrol ECE-15'04	
PC petrol AGV82 (CH)	
PC petrol conv other concepts	
PC petrol Ucat	
PC petrol Euro-1	LPABEUR1
PC petrol PreEuro 3WCat <1987	(group of 36 older petrol emission factors 1982-1992)
PC petrol PreEuro 3WCat 1987-90	LPABR3WC

Subsegment	VERSIT+ class
PC petrol Euro-2	LPABEUR2
PC petrol Euro-3	LPABEUR3
PC petrol Euro-4	LPABEUR4
PC petrol Euro-5	LPABEUR5
PC petrol Euro-6ab	LPABEUR6
PC petrol Euro-6c	LPABEUR6
PC petrol Euro-6d-temp	LPABEUR6
PC petrol Euro-6d	LPABEUR6
PC petrol Euro-7	No emission standard proposed yet
PC diesel conv PC diesel 1986-1988	(group of 36 older diesel emission factors 1982-1992)
PC diesel Euro-1	LPADEUR1
PC diesel Euro-2	LPADEUR2
PC diesel Euro-2 (DPF)	LPADEUR3HOF
PC diesel Euro-3	LPADEUR3
PC diesel Euro-3 (DPF)	LPADEUR3HOF
PC diesel Euro-4	LPADEUR4
PC diesel Euro-4 (DPF)	Mix of LPADEUR4DPF and LPADEUR4HOF
PC diesel Euro-5	LPADEUR5
PC diesel Euro-5 other SU before software update	LPADEUR5
PC diesel Euro-5 EA189 before software update	LPADEUR5
PC diesel Euro-5 EA189 after software update	LPADEUR5
PC diesel Euro-5 other SU after software update	LPADEUR5
PC diesel Euro-6ab	LPADEUA6
PC diesel Euro-6ab SU before software update	LPADEUA6
PC diesel Euro-6ab SU after software update	LPADEUA6
PC diesel Euro-6c	LPADEUA6
PC diesel Euro-6d-temp	LPADEDT6
PC diesel Euro-6d	LPADEUD6
PC diesel Euro-7	No emission standard proposed yet
PC CNG/petrol Euro-2_(CNG)	LPACEUR2
PC CNG/petrol Euro-2_(P)	(avoid double counting)
PC CNG/petrol Euro-3_(CNG)	LPACEUR3
PC CNG/petrol Euro-3_(P)	(avoid double counting)
PC CNG/petrol Euro-4_(CNG)	LPACEUR4
PC CNG/petrol Euro-4_(P)	(avoid double counting)
PC CNG/petrol Euro-5_(CNG)	LPACEUR5
PC CNG/petrol Euro-5_(P)	(avoid double counting)
PC CNG/petrol Euro-6_(CNG)	LPACEUR6
PC CNG/petrol Euro-6_(P)	(avoid double counting)
PC FFV Euro-3 _(E85)	(is already included in petrol euro 3 in terms of vkm)
PC FFV Euro-3 _(P)	(avoid double counting)
PC FFV Euro-4 _(E85)	(is already included in petrol euro 4 in terms of vkm)

Subsegment	VERSIT+ class
PC FFV Euro-4 _(P)	(avoid double counting)
PC FFV Euro-5 _(E85)	(is already included in petrol euro 5 in terms of vkm)
PC FFV Euro-5 _(P)	(avoid double counting)
PC FFV Euro-6 _(E85)	(is already included in petrol euro 6 in terms of vkm)
PC FFV Euro-6 _(P)	(avoid double counting)
PC BEV	LPAEZEEV
PC PHEV petrol Euro-4_(El)	N/A (none on the market)
PC PHEV petrol Euro-4_(P)	N/A
PC PHEV petrol Euro-5_(El)	LPEBEUR5
PC PHEV petrol Euro-5_(P)	(avoid double counting)
PC PHEV petrol Euro-6d_(El)	LPEBEUR6
PC PHEV petrol Euro-6d_(P)	(avoid double counting)
PC PHEV petrol Euro-6ab_(El)	LPEBEUR6
PC PHEV petrol Euro-6ab_(P)	(avoid double counting)
PC PHEV diesel Euro-4_(El)	N/A
PC PHEV diesel Euro-4_(D)	N/A
PC PHEV diesel Euro-5_(El)	LPEDEUR5
PC PHEV diesel Euro-5_(D)	(avoid double counting)
PC PHEV diesel Euro-6d_(El)	LPEDEUD6
PC PHEV diesel Euro-6d_(D)	(avoid double counting)
PC PHEV diesel Euro-6ab_(El)	LPEDEUA6
PC PHEV diesel Euro-6ab_(D)	(avoid double counting)
PC LPG/petrol Euro-2_(LPG)	LPALEUR2
PC LPG/petrol Euro-2_(P)	(avoid double counting)
PC LPG/petrol Euro-3_(LPG)	LPALEUR3
PC LPG/petrol Euro-3_(P)	(avoid double counting)
PC LPG/petrol Euro-4_(LPG)	LPALEUR4
PC LPG/petrol Euro-4_(P)	(avoid double counting)
PC LPG/petrol Euro-5_(LPG)	LPALEUR5
PC LPG/petrol Euro-5_(P)	(avoid double counting)
PC LPG/petrol Euro-6_(LPG)	LPALEUR6
PC LPG/petrol Euro-6_(P)	(avoid double counting)
PC FuelCell	LPAHZEEV
PC 2S EE	-
PC 4S EE	-