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Green InterTraffic

AIR QUALITY REPORT

AIR QUALITY SURVEY OF THE ROAD E18 BETWEEN HELSINKI AND SAINT PETERSBURG

The Project funded by the European Union, the Russian Federation and the Republic of Finland

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CONTENTS

PART I

1 INTRODUCTION

In this study the current and future air quality situation on the road E18 is being examined. This report describes the emission calculation of the road traffic on the road E18 from Saint Petersburg to Helsinki and the highest concentrations caused by these emissions were analysed with dispersion modelling. The current situation is based on year 2018 traffic and emission data and future estimate represents the year 2035. A mathematical atmospheric dispersion model used in calculations is called the Contaminants in the Air from a Road of the Finnish Meteorological Institute (CAR-FMI). The current air quality situation is analysed based on novel air quality sensor measurements from January to July 2020. Typically, road traffic emissions increase the nitrogen dioxide and particulate matter concentrations in traffic environments and that is why these compounds are being considered in this study. This air quality assessment is done within the framework of the Cross-border co-operation (CBC) project Green InterTraffic that aims to diminish the environmental impact of the road traffic.

The emission calculation method applied in this report is called a Common Method for Emission calculation. Method was developed as common approach for this study and it is based on the tier 3 method in the European Emission inventory guidebook for road transport. Calculations are based on the assumption that the road traffic on both sides of the road consists of the most common vehicle types (passenger cars, light commercial vehicles, busses, trucks with and without a trailer). The driving speed is assumed to be constant.

The dispersion model CAR-FMI has been developed in the Finnish Meteorological Institute. This local-scale air pollution dispersion model is designed for assessing the dispersion of atmospheric emissions from the road traffic. The CAR-FMI model has been widely applied in many countries and projects. The dispersion modelling calculations were carried out to assess the concentrations of nitrogen dioxide (NO_2) and fine particulate matter ($PM_{2.5}$) in ambient air. The computed concentrations were compared against the WHO (World Health Organization) health-based air quality standards.

The road traffic flow data used in the study is based on the open data (https://kartta.paikkatietoikkuna.fi/) in Finnish side and the data regarding Russian side was provided by the project partner Traffic Integration Ltd and GIBDD MVD RF (State Inspectorate for Traffic Safety of the Russian Ministry of Interior). The emission calculations and dispersion simulations were performed by the Expert Services of Finnish Meteorological Institute.

2 INPUT DATA FOR DISPERSION MODELLING

2.1 Location of the research area

The European road E18 is in total almost 2 000 km long road from Northern Ireland to Saint Petersburg, Russia. In this project the study area focuses on the route between Helsinki and Saint Petersburg (Figure 1). This route is approximately 350 km long. The border crossing point in Finland is called Vaalimaa and in Russia Torfjanovka.

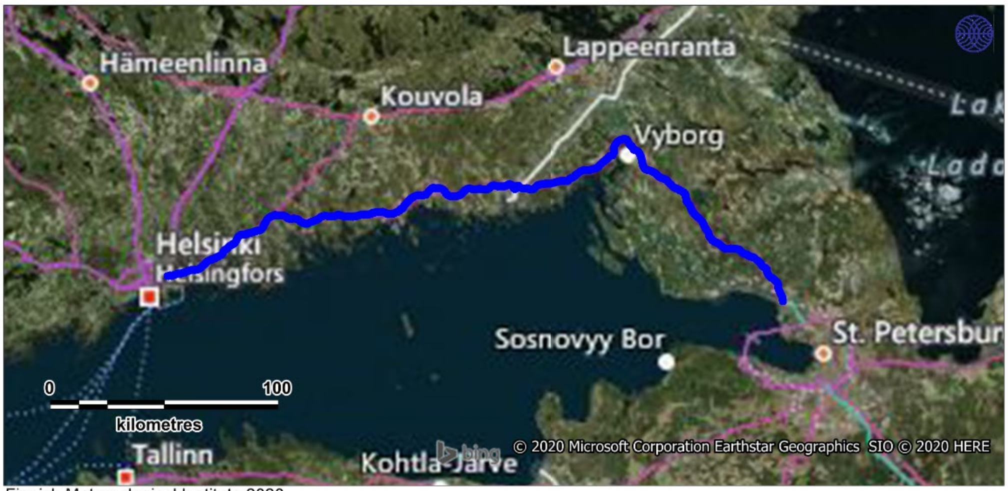

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Figure 1. The road E18 from Helsinki to Saint Petersburg via Vyborg. The road is highlighted with the blue line.

2.2 Traffic flow and emission calculations

The road traffic emission calculations were done for present and future situations both in Finland and in Russia. The present scenario (S0) is based on the traffic flow and traffic composition of the year 2018 and the future scenario (S4) on the estimation for the year 2035.

The emission calculations for road traffic exhaust gases were calculated by using the emission factors defined by the European Environmental Agency (*EEA, 2018*). The emission factors depend on vehicle type, fuel type, EURO-emission standard class and driving speed.

In Finland, the future scenario is based on the VTT's (Technical Research Centre of Finland Ltd) estimate of the traffic distribution development for passenger cars, light commercial vehicles, busses and trucks with and without trailer as well as distribution of the EURO emission standards in each category (lipasto.vtt.fi, ALIISA vehicle fleet model, 2019). The target year was 2035. The future estimation of the traffic distribution is called a baseline scenario since it is based only on those actions that have already been decided. The average daily traffic flow were available in https://kartta.paikkatietoikkuna.fi/. In the future scenario of this air quality assessment the number of heavy-duty vehicles were assumed to stay in the same level as in present situation. The number of passenger cars increases approximately 10 % compared to the present situation. (*Lapp et al. 2018*)

The Russian company Traffic Integration Ltd has done prognosis on the future traffic fleet and flow developments for the road E18 in Green InterTraffic research project. The results are published in the report called "*The Green Roadmap and the road map for the creation of an intelligent transport system for unmanned vehicles of the E18 (SPb-Helsinki)*" (*Vorontsova et al. 2020*). The report includes three different kind of development stages (S1, S2 and S3) and the fourth scenario is a combination of all the actions in previous stages (such as improving road conditions to enable higher speed limits and renewal of the car fleet step by step) (S4). In this air quality study the impact of all these scenarios has been assessed. However, the aim is to develop the traffic fleet and road and complete all stages (S1, S2 and S3) to reach the scenario S4. The assumptions behind the future scenarios in Russian side are described in detail in the Green Road Map report. In this report the present situation (S0) and the future scenario S4 are described in more detail and the scenarios S1, S2 and S3 are shown in Appendix.

The study area is the road E18 from Helsinki to Saint Petersburg. The road traffic emissions were calculated for the road E18 and for the most important roads within 3 kilometres from the road E18. In the dispersion model the roads are described as short line sources, that release emissions to their surroundings. The emissions are calculated for each line source separately based on the traffic flow, fleet and speed. The weekly and diurnal variation of the traffic is considered according to the Finnish automatic traffic measurement station in Porvoo along the road E18 (Figure 2). The total traffic flow, number of heavy-duty vehicles and the calculated emissions in present (S0) and future scenarios (S1–S4) are presented in Figure 3 – Figure 10 and in appendixes (Figure 24 – Figure 35). The emissions decrease from present situation to future scenario S4. Only in scenario S3 the emission levels increase because this scenario suggests that the driving speed on the road would increase and the traffic fleet would stay approximately the same as in present situation (Figure 32 and Figure 35). In other scenarios the emissions decrease, and the decline is the largest in the scenario S4.

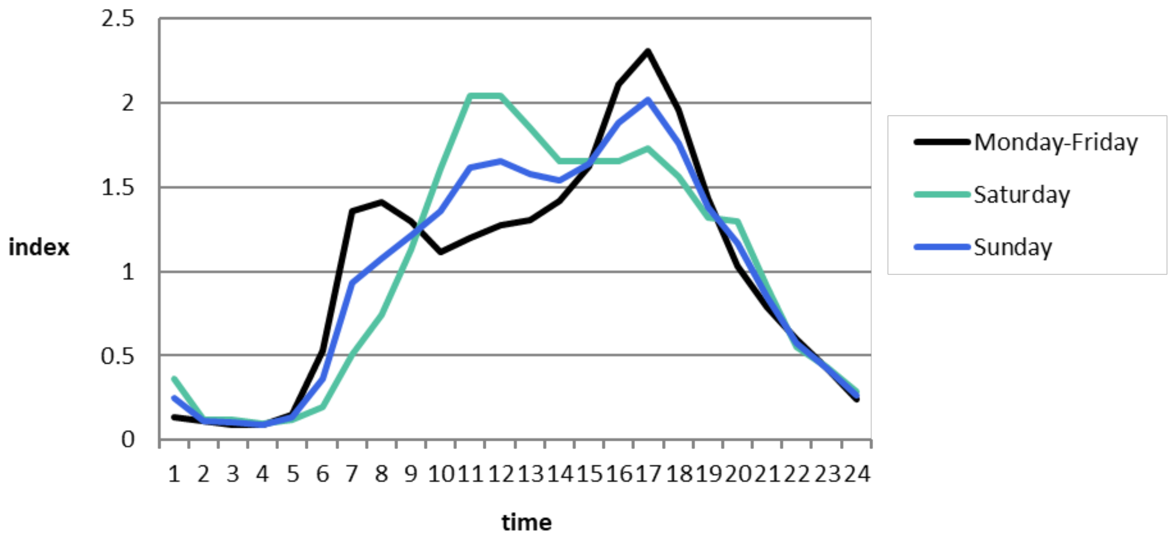


Figure 2. Hourly variation of the traffic flow indexes along the road E18 in Porvoo automatic traffic measurement point.

Figure 3. **Average daily traffic** on the road E18 from Helsinki to Saint Petersburg in **present situation (S0)**.

Figure 4. **Average daily traffic** on the road E18 from Helsinki to Saint Petersburg **in future situation (S4)**.

Figure 5. **Average daily heavy-duty traffic** on the road E18 from Helsinki to Saint Petersburg in present situation **(S0)**.

Figure 6. **Average daily heavy-duty traffic** on the road E18 from Helsinki to Saint Petersburg in future situation **(S4)**.

Figure 7. Road traffic **emissions of nitrogen oxides (NO_x)** on the road E18 from Helsinki to Saint Petersburg in present situation **(S0)**.

Figure 8. Road traffic **emissions of nitrogen oxides (NO_x)** on the road E18 from Helsinki to Saint Petersburg in future situation **(S4)**.

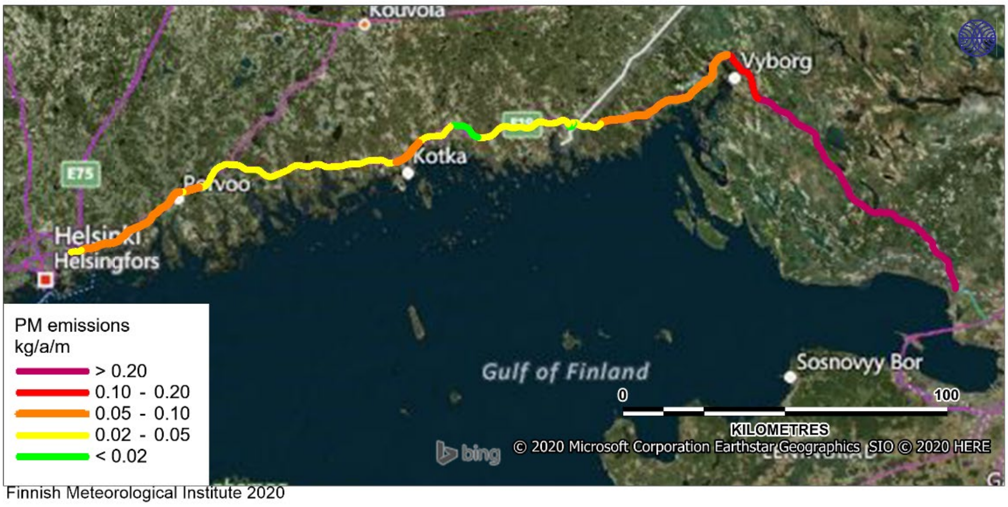


Figure 9. Road traffic **emissions of particulate matter (PM)** on the road E18 from Helsinki to Saint Petersburg in present situation **(S0)**.

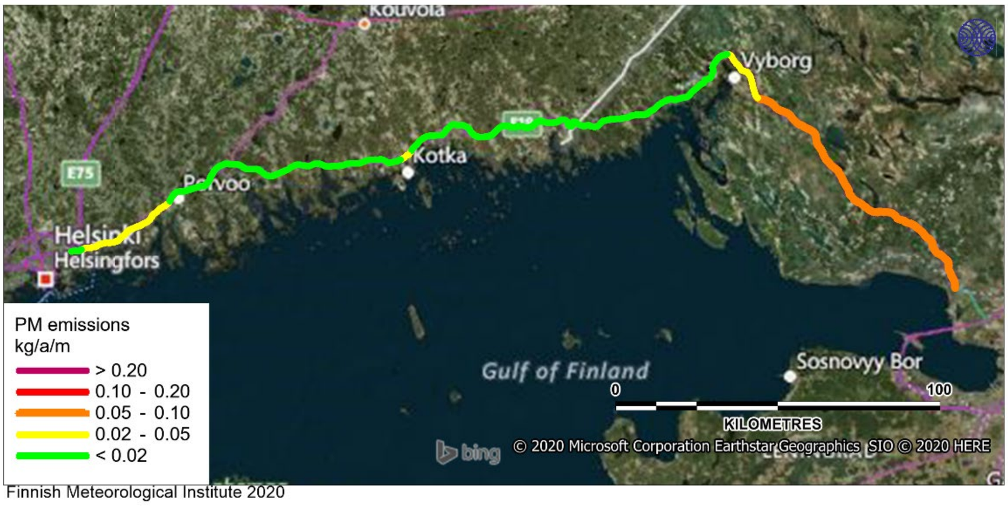


Figure 10. Road traffic **emissions of particulate matter (PM)** on the road E18 from Helsinki to Saint Petersburg in future situation **(S4)**.

2.3 Meteorological data and background concentrations

Two meteorological data sets were formed to represent the meteorological conditions on the road E18 from Helsinki to Saint Petersburg. Both sets are based on the weather observations of the year 2018. The data was extracted from the database of the Finnish Meteorological Institute which includes international weather observations shared via World Meteorological Organization's Global Telecommunication System. A one-year-long time series of observations is generated with the meteorological data pre-processing model that is based on the atmospheric boundary layer parameterization method (*Karppinen, 2001*).

The method can be used to estimate the variables affecting the state of the boundary layer that are needed in the emission dispersion model calculations, using routine meteorological observations and basic physics equations. The method takes local factors in the study area, such as the roughness of the terrain around the weather stations and the seasonal albedo values (the ability of the soil surface to reflect solar radiation) for different soil qualities into account. Meteorological data representing the weather conditions of the study area for one year was used in the calculations. The most representative weather stations in the study area, which measure all the weather variables required by the model, were selected. The weather observation and sounding data meet the quality requirements of WMO (World Meteorological Organization) and ICAO (International Civil Aviation Organization). Wind direction and speed data were generated as a distance-weighted statistical combination of observations from two or three weather stations. The result was hourly time series of meteorological data required in the dispersion models.

The meteorological time series representing the climatic conditions at the Finnish side of the road E18 between Helsinki and Vaalimaa was formed from the observation data of the weather stations at Porvoo Harabacka, Virolahti Koivuniemi and Helsinki Kumpula from the year 2018. Sounding observations from Jokioinen were used to determine the mixing height. The wind direction and wind speed distribution in the study area is shown in Figure 11. Southwest winds are predominant in the study area, while there are fewer winds from east.

The meteorological time series representing the climatic conditions at the Russian side of the road E18 between Vaalimaa (Torfjanovka) and Saint Petersburg were formed from the observation data of the weather stations at Vyborg and Ozerki. The wind direction and wind speed distribution in the study area is shown in Figure 12. Southwest winds are predominant in the data set, while there are fewer winds from north.

The background concentration data used in the calculations was derived from a air quality monitoring station in Virolahti, Finland. The site is classified as a background station and it is located approximately 14 km from the border crossing point Vaalimaa. Ozone, fine particulate matter and nitrogen oxide measurement data was collected from the year 2018. The annual mean concentration for nitrogen dioxide was 4.2 $\mu g/m^3$ and for fine particulate matter 6.5 $\mu g/m^3$ (*Finnish meteorological Institute, 2019*). Nitrogen oxide emissions are transformed into more harmful nitrogen dioxide with the help of ozone and sun light in the ambient air. Thus, ozone concentration data is also needed in the model calculations. It is assumed that 20 % of direct NOx emissions from road traffic is nitrogen dioxide (NO_2) before the chemical transformation of nitrogen monoxide to nitrogen dioxide (*Anttila et al., 2011*).

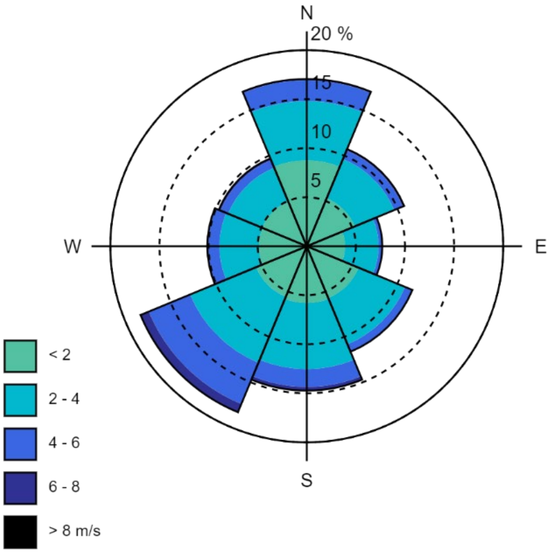


Figure 11. Wind speed and direction of the meteorological data set used at the Finnish side of the study area.

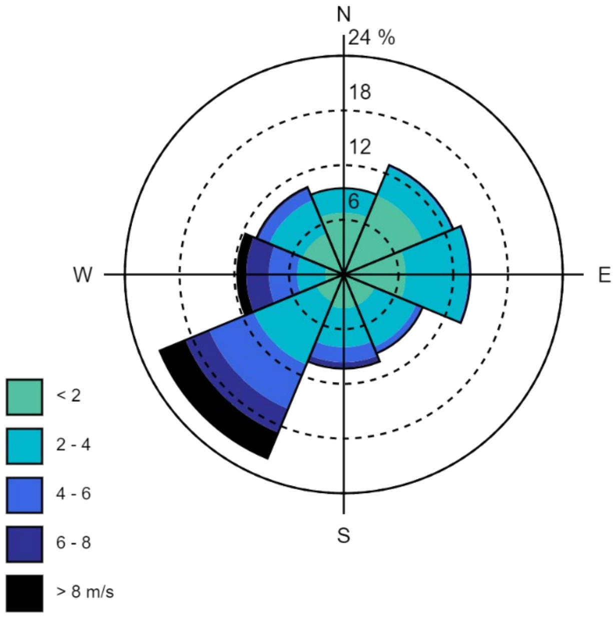


Figure 12. Wind speed and direction of the meteorological data set used at the Russian side of the study area.

3 RESULTS OF THE DISPERSION MODELLING STUDIES

Nitrogen dioxide (NO_2) and fine particulate matter ($PM_{2.5}$) concentrations were computed by using a dispersion model CAR-FMI. The calculation height is the breathing level (2 m above ground). Based on hourly values the mean concentrations comparable to WHO guideline values were defined. The concentrations were calculated on short road sections and they represent the situation in average throughout the year on the road. This type of assessment gives the maximum concentrations that the road traffic causes on the road. If the calculations had been made in larger area it would be quite clear that the emissions dilute and disperse quite rapidly and that the modelled concentrations are lower as the distance from the main road grows. The background concentrations have been included to the calculations.

The calculation results for present situation (S0) and future scenario (S4) are presented in chapters 3.1 Nitrogen dioxide (NO_2) and 3.2 Fine Particulate matter ($PM_{2.5}$). The results for future scenarios S1, S2 and S3 are presented in appendix Figure 36–Figure 41.

3.1 Nitrogen dioxide (NO_2)

The calculation results for annual nitrogen dioxide concentrations are presented in Figure 13 and Figure 14. In present situation, the highest concentrations occur on the busy roads of Saint Petersburg where WHO guideline might exceed. The number of vehicles and heavy-duty vehicles is estimated to be quite large and it causes high emissions and thus high NO_2 concentrations in breathing level. The concentrations are significantly lower in future scenario S4. The WHO guideline values are not exceeded according to the future scenario calculations.

Figure 13. The annual mean **concentration (µg/m³) of nitrogen dioxide (NO_2)** in ambient air in breathing level in present situation **(S0)**.

Figure 14. The annual mean **concentration (µg/m³) of nitrogen dioxide (NO_2)** in ambient air in breathing level in future situation **(S4)**.

The highest nitrogen dioxide concentrations along the route from Helsinki to Saint Petersburg are presented in the Table 1 and in appendix Table 8. From the tables can be seen, that in future situation the concentrations drop quite significantly, and the highest values do not exceed the WHO guideline values. In present situation, the annual guideline value is exceeded on a road section that is 2 km long and the highest hourly mean value is exceeded in a 84 km long road section near Saint Petersburg (Table 2 and in appendix Table 9).

Table 1. The highest nitrogen dioxide concentrations along the E18 road from Helsinki to Saint Petersburg compared to the WHO guideline values (WHO, 2006) in present situation (S0) and in future scenario (S4).

Nitrogen dioxide (NO_2)	Guideline value µg/m³	Present situation S0	Future scenario S4
annual mean	40	41	20
1-hour mean	200	418	168

Table 2. Length of the road where WHO guideline values for nitrogen dioxide (*WHO, 2006*) are exceeded on the road E18 in present situation (S0) and in future scenario (S4).

Road length, km	Present situation S0	Future scenario S4
annual mean	2	0
1-hour mean	84	0

3.2 Fine Particulate Matter ($PM_{2,5}$)

The calculation results for fine particulate matter concentrations are presented in Figure 15 and Figure 16. The highest concentrations occur in present situation on the busy roads of Saint Petersburg. The number of vehicles and heavy-duty vehicles are estimated to be quite large and it causes high emissions and thus high concentrations in breathing level. The WHO guideline values are exceeded according to the calculations near Saint Petersburg in current situation. The concentrations are significantly lower in future scenario S4.

Figure 15. The annual mean **concentration (µg/m³) of fine particulate matter ($PM_{2.5}$)** in ambient air in breathing level in present situation **(S0)**.

Figure 16. The annual mean **concentration (µg/m³) of fine particulate matter ($PM_{2.5}$)** in ambient air in breathing level in future situation **(S4)**.

The highest fine particulate matter concentrations along the route from Helsinki to Saint Petersburg are presented in the Table 3 and in appendix Table 10. It can be seen from the tables, that in future situation the concentrations drop quite significantly, and the highest values are clearly lower than the WHO guideline values. In present situation the annual guideline value is exceeded on a road section that is 7 km long and the highest hourly mean value is exceeded in a 10 km long road section (Table 4 and in appendix Table 11).

Table 3. The highest nitrogen dioxide concentrations along the E18 road from Helsinki to Saint Petersburg compared to the WHO guideline values (WHO, 2006) in present situation (S0) and in future scenario (S4).

Fine particulate matter ($PM_{2.5}$)	Guideline value µg/m³	Present situation S0	Future scenario S4
annual mean	10	10.5	7.0
24-hour mean	25	28	13

Table 4. Length of the road where WHO guideline values for nitrogen dioxide (*WHO, 2006*) are exceeded on the road E18 in present situation (S0) and in future scenario (S4).

Road length, km	Present situation S0	Future scenario S4
annual mean	7	0
24-hour mean	10	0

Background concentrations have strong impact on the fine particulate matter concentrations in the study area. In Finland the highest concentrations usually occur during the long-range transport episodes (e.g. forest fires). During these kind of episodes, the fine particulate matter concentrations exceed the WHO guideline values quite easily even on background measurement stations.

In this modelling study, only fine particulate matter concentrations ($PM_{2.5}$) were considered. It is possible that the concentration of inhalable particles (PM_{10}, larger than $PM_{2.5}$) in adverse meteorological condition may exceed the WHO guideline values set for PM_{10}. The concentrations for inhalable particles increase in the vicinity of busy roads during the street dust seasons. Street dust is present typically in the spring in March-April and in late autumn after the onset of the winter tires. Also small particle concentrations can become high during these street dust episodes. Street dust and high particulate matter can be significantly affected by winter maintenance of the streets as well as street cleaning and dust binding.

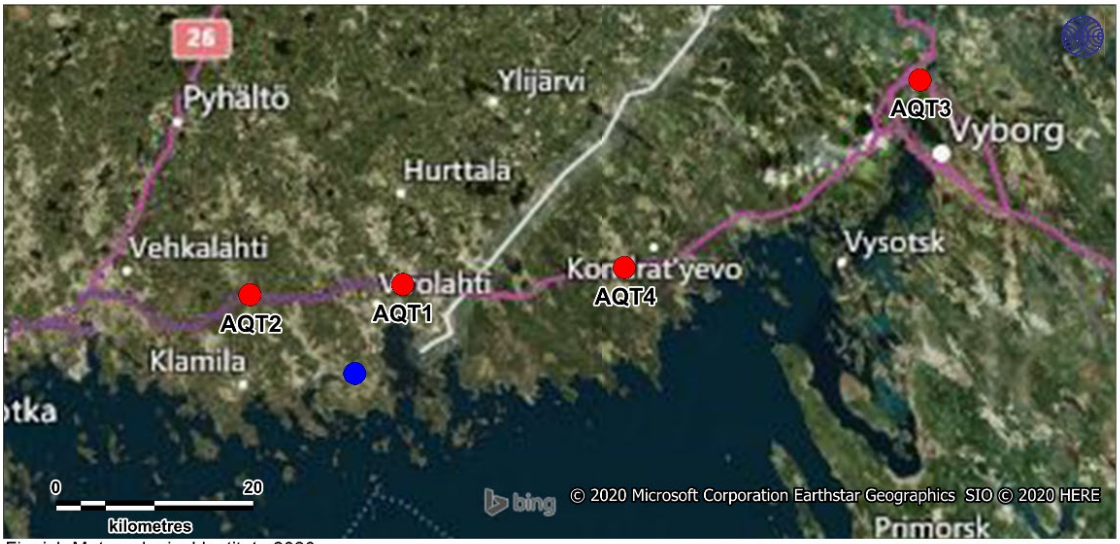
4 AIR QUALITY SENSOR MEASUREMENTS ALONG THE ROAD E18

In this air quality survey, the current air quality situation was assessed also with measurements. The concentrations were estimated with Vaisala AQT420 air quality sensors in four locations (Figure 17) along via E 18 Route. The sensor measurement data can be considered as indicative results of the pollution concentrations due to the accuracy of the measurement technology. Therefore, the exact concentration values provided by these instruments should not be considered but instead concentration levels and the changes in the concentration levels are more important and useful. One feature of the sensors is that they cannot be calibrated in the same way as the conventional monitoring devices are calibrated. Each sensor should be compared against the reference or equivalent monitoring methods before and after the measurement campaign to evaluate and understand their performance level

Before the measurement campaign the devices were tested against the reference or equivalent methods in Kumpula, Helsinki during July 2019. In these comparison measurements simple correction coefficients were defined for AQT sensors and they were applied in data analysis. Unreasonably high measurement values were discarded from the data set as incorrect values.

The sensor measurements started in Russian side 10.10.2019 and lasted until 17.8.2020. In Finnish side the measurements started 13.11.2019 and they will last until December 2020. During the measurements real-time data was available at the project website http://en.greenintertraffic.ru/meteo/vaisala-aqt420-air-quality/.

Finnish Meteorological Institute has an air quality background measurement station Virolahti that locates quite near to the road E18. In Virolahti measurement station several compounds are being monitored with reference or equivalent methods, for example fine particulate matter, nitrogen oxides and ozone. The air quality data is openly available in https://en.ilmatieteenlaitos.fi/air-quality. The distance between Virolahti and sensors in Finland was approximately 14 km (Figure 17).



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● = Background measurement station of Virolahti

● = AQT measurement sites

Figure 17. The locations of four Vaisala AQT sensors (AQT1–AQT4) shown as red dots on the map and the Virolahti background measurement station with blue dot.

The concentrations from the November 2019 to July in 2020 observed by AQT sensors are presented in Figure 18 - Figure 21. The observations from Virolahti background measurement station are also included for November 2019 – April 2020.

The averages of monthly and highest hourly mean concentrations of sensor measurements seem to be in line with nitrogen dioxide (NO_2) background measurements. The concentrations in background stations should be in general much lower than along the roadsides near the direct emission sources (road traffic). The measured nitrogen dioxide concentrations are well below the WHO guideline values in all sites. The concentration values seem to increase towards the end of the measurement campaign, and this can be a sign of sensor aging.

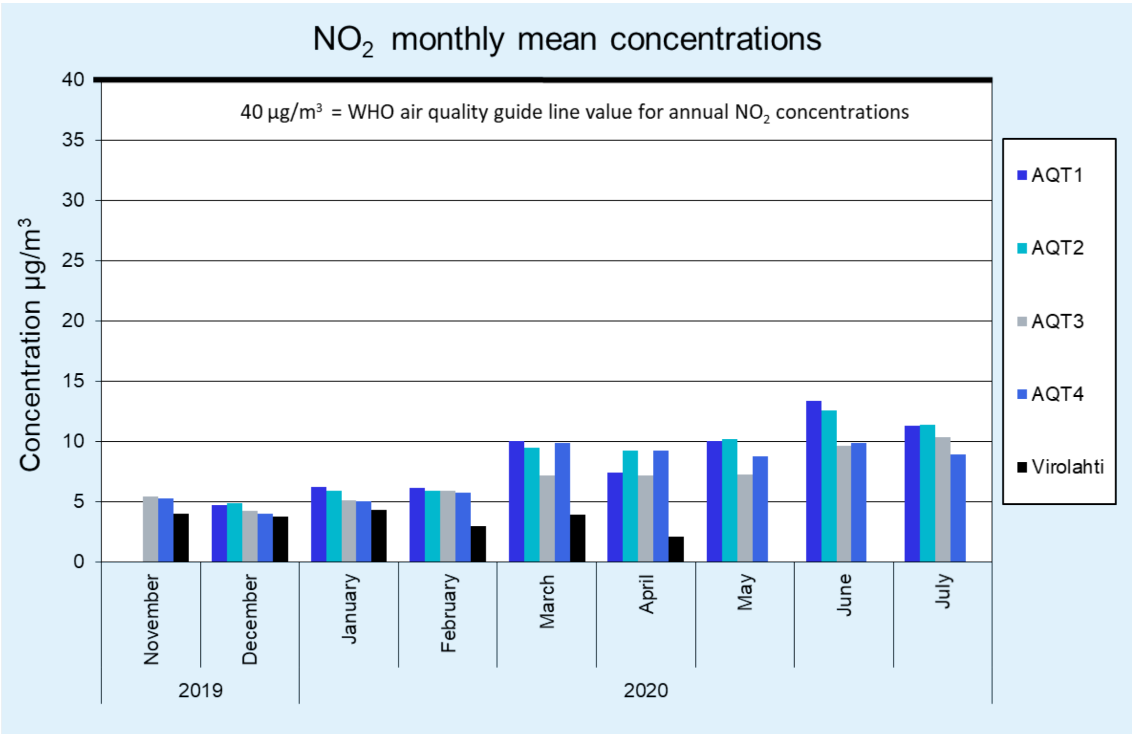

Figure 18. The monthly mean concentrations of **nitrogen dioxide** from period November 2020 until July 2020. Calibrated NO_2 values from Virolahti are available until April 2020.

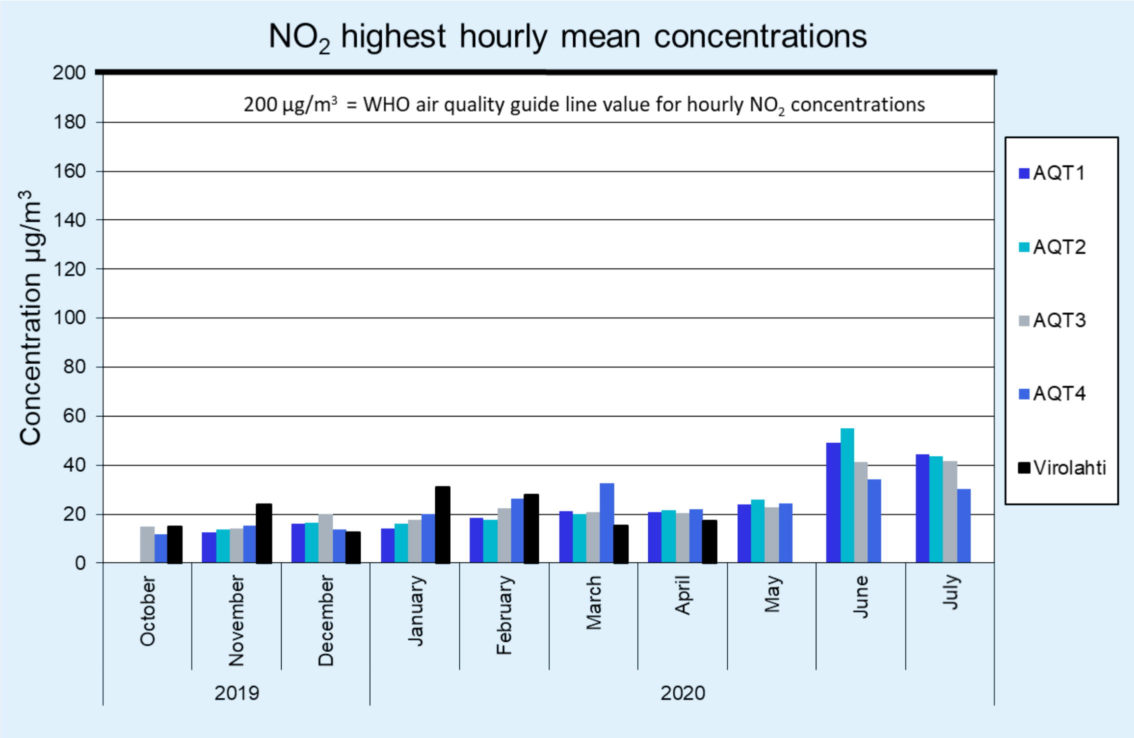

Figure 19. The highest hourly mean concentrations of **nitrogen dioxide** from period October 2020 until July 2020. Calibrated NO_2 values from Virolahti are available until April 2020.

Based on the measurement data comparison, it seems that the concentration level of fine particulate matter does not quite reach the detection limit of AQT sensors and on the other hand some of the detected concentrations are quite high. The fine particulate matter data quality seems to be somewhat more unstable in comparison to NO_2 measurements. The monthly averages of fine particulate matter ($PM_{2.5}$) measured by sensors seem to be an underestimation because the background concentrations in monthly level are somewhat higher. The concentrations in background stations should be lower than along the roadsides near the emission source. The unreasonably high concentrations of AQT3 and AQT4 sensors were removed from the chart. The concentration values seem to increase towards the end of the measurement campaign (especially seen on sensor AQT4) and this can be a sign of sensor aging.

However, according to the measurements of AQT sensors it is likely that the WHO guideline value for annual concentrations is not exceeded at the sites. The highest daily concentrations exceed the WHO guideline values with AQT2, AQT3 and AQT4 during some months (Figure 21) which can be partly explained with the unstable data and possible overestimation of the concentrations by the sensors. During the months when the daily average values are not exceeded the concentrations are quite moderate and reasonable.

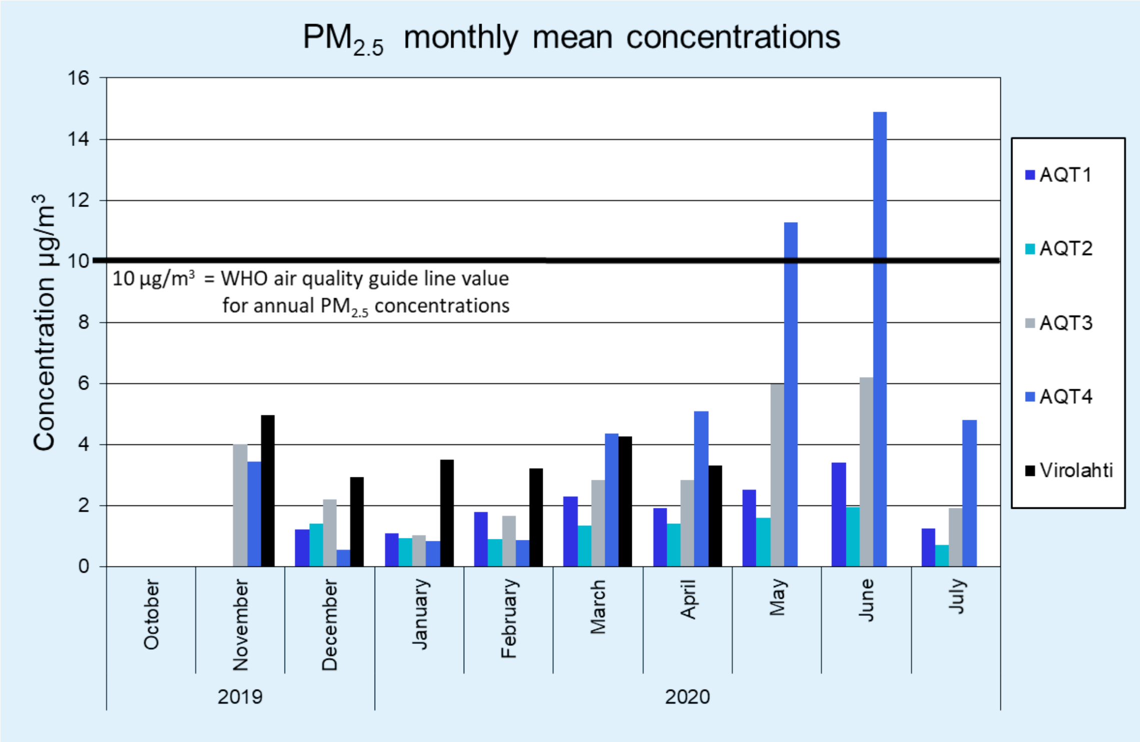

Figure 20. The monthly mean concentrations of **fine particulate matter** from period November 2020 until July 2020. Calibrated NO_2 values from Virolahti are available until April 2020.

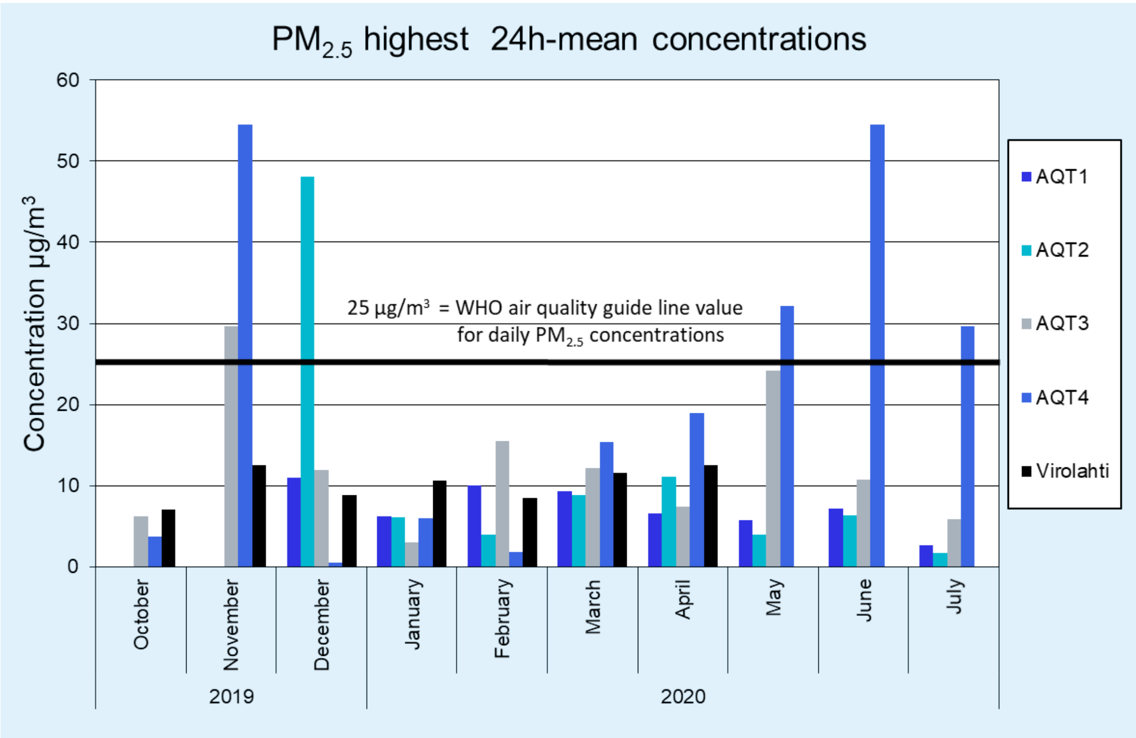

Figure 21. The highest daily mean concentrations of **fine particulate matter** from period November 2020 until July 2020. Calibrated NO_2 values from Virolahti are available until April 2020.

4.1 Dispersion modelling study results in sensor measurement locations

The air quality dispersion modelling study was based on the traffic and emission data of the year 2018. The dispersion modelling calculation results were compared with the sensor measurement data by using dispersion modelling tool to calculate the concentration values to the four air quality sensor locations. The calculated concentrations are presented in the Table 5 and the measurement results in the Table 6. However, as the air quality sensor measurement period was November 2019 – July 2020 the dispersion modelling results are not fully comparable with the sensor measurement results as they represent different time periods. In general, it seems that the measured and modelled nitrogen dioxide concentrations are approximately in the same level in Finnish side, but modelled concentrations in sensor locations in Russian side (AQT3 and AQT 4) are clearly higher than sensor measurements indicate. Measured fine particulate matter concentrations are in most of the sensor locations (AQT1, AQT2 and AQT3) clearly lower than modelled concentrations which may be due to the sensitivity and high detection limits of the sensors. When comparing the modelled concentration values with the sensor measurements it is important to consider that there are most likely high uncertainties in the sensor measurement data in the study environments. Nevertheless, different air quality assessment tools such as different type of measurements and dispersion modelling calculations can be used to supplement each other. It is an advantage to have more than one source of information that supports the air quality assessment. In this study, the emission inventories, dispersion modelling calculations and sensor measurements have been used in order to assess the air quality impact of the E18 road.

Table 5. The modelled nitrogen dioxide and fine particulate matter concentrations in sensor measurement locations along the E18 road. The emission dispersion modelling study is done for the year 2018.

	AQT1	AQT2	AQT3	AQT4
Nitrogen dioxide (NO_2) annual mean	7	7	22	12
Fine particulate matter ($PM_{2.5}$) annual mean	7	7	8	7

Table 6. The average concentrations of nitrogen dioxide and fine particulate matter measured by air quality sensors along the E18 road over the measurement period November 2019 – July 2020.

	AQT1	AQT2	AQT3	AQT4
Nitrogen dioxide (NO_2) annual mean	8	9	7	8
Fine particulate matter ($PM_{2.5}$) annual mean	2	1	3	5

5 CONCLUSIONS

In this air quality study, the current and future air quality situation of the road E18 from Helsinki to Saint Petersburg was analysed with a dispersion model and innovative air quality sensor measurements. The nitrogen dioxide and fine particulate matter concentrations were compared to WHO´s air quality guideline values. This study was done to analyse the environmental impact of the road traffic in the project Green InterTraffic financed by South-East Finland-Russia CBC Programme 2014-2020. The project aims to improve the environmental burden caused by road traffic and the test calculations were done for the road E18 from Helsinki to Saint Petersburg.

The emission calculation is based on Common method developed for cross-border co-operation project Green InterTraffic. The Common method is based on the method described in the emission inventory guidebook published by European Environmental Agency. The dispersion modelling calculations were done with the dispersion model CAR-FMI which is developed at the Finnish Meteorological Institute to examine the dispersion of road traffic emissions. The starting point of the survey was to study the present air quality situation (year 2018) and future scenarios (target year 2035). Calculations took the future development of the traffic fleet, traffic flow and changes in driving speed into account. The country-specific features of the road traffic were considered in the emission calculations as detailed as possible. The emission factors from European emission inventory guidebook are dependent on traffic fleet and driving speeds. Also, the differences of the meteorological conditions on both sides of the cross border were considered in dispersion modelling. The meteorological observations required to form the meteorological time series for Finnish and for Russian sides of the road sections covered the year 2018. The background concentrations for dispersion modelling were based on the observations from Finnish Meteorological Institute´s Virolahti background air quality measurement station from year 2018.

The World Health Organization (WHO) has given guideline values for pollutants in ambient air. The meaning of the guideline values is that should not be exceeded in areas where people live and spend time. The air quality guideline values should be considered, for example in traffic planning, land use planning or city planning in order to prevent human exposure to harmfully high levels of air pollution in advance.

In this study, the concentrations were calculated only on the road E18 to assess the maximum pollution concentrations. The concentrations of air pollutants typically disperse and dilute quite fast as the distance grows from the road. The highest concentrations of nitrogen dioxide and fine particulate matter are typically observed along the road and at the crossroads. The highest nitrogen dioxide and fine particulate matter concentrations on the road E18 formed to the eastern end of the road. Based on calculations the concentrations may exceed the WHO air quality guideline values in present situation in relatively short road sections but in future scenarios in year 2035 the concentrations seem to be significantly lower. It is noticeable that the single development stage (S1, S2 or S3) alone does not improve the air quality situation as much as all of them together (combination scenario S4).

There are many uncertainties in future estimations. However, it is very likely that the emissions are lower in future than in present situation because of the traffic fleet development by the wider use of new technologies and tightening emission limits. The modelled concentration levels are quite moderate and common for traffic surroundings.

The novel type of sensor measurements conducted in four locations along the road E18 from Helsinki to Saint Petersburg showed that the measured concentration levels are also quite moderate. It is likely that the concentration levels of nitrogen dioxide do not exceed the WHO guideline values. The fine particulate matter concentration levels are most of the time below the detection limit of the sensor devices and some of the measured concentrations are likely to be overestimations, thus it seems that the particulate matter data is more unstable than the nitrogen dioxide data. However, according to the fine particulate measurements it is likely that the WHO guideline value for annual concentrations is not exceeded in the sensor locations. The preliminary results indicate that it is possible that the WHO guideline value for fine particulate matter is exceeded in the current state, but it should be studied more carefully after the final sensor comparison campaign is completed in Helsinki.

Assessing the air quality of the road E18 based on the air quality sensor measurements and air quality dispersion modelling it can be concluded that the current air quality situation in the study area is moderate and can be considered typical for this type of traffic environments. It is very likely that the future traffic fleet development will improve the air quality situation along the E18 road. However, in case the number of vehicles and heavy-duty vehicles in E18 road will increase more in future than estimated in the scenarios, the air quality situation might not improve as estimated in this study.

PART II

6 BACKGROUND INFORMATION ON AIR QUALITY

6.1 Factors affecting air quality

The main emission sources that have an impact on ambient air quality are transport, energy production, industry and wood burning. Pollutants are also transported to Finland through long-range transport. Most of the emissions are released in the lower part of the atmosphere that is called a boundary layer. In the boundary layer the emissions are mixed with the surrounding air and the concentrations dilute. The emissions can spread over large areas with moving air masses. During this transport air pollutants can react with each other and with other compounds in the air to form new compounds. Air pollutants are removed from the air as wet deposition, as dry deposition on various surfaces or though chemical transformation.

The spread of air pollution mainly takes place in the lower part of the atmosphere, the boundary layer. Its height in Finland is typically less than a kilometre, but especially in summer it can rise to more than two kilometres. The lowest boundary layer heights are usually observed in winter in severe frosts. The height of the boundary layer determines the volume of air into which the emissions can immediately mix. The wind conditions in the boundary layer roughly determine the direction of airborne transport, but the turbulence of the airflows in the boundary layer and the height of the bed significantly affect the mixing of air pollutants and the dilution of concentrations during transport. Key meteorological factors for spreading include wind direction and speed, atmospheric stability, and mixing height. Atmospheric stability refers to the sensitivity of the atmosphere to vertical mixing. Stability is determined by the vertical temperature structure of the atmosphere and mechanical turbulence, i.e. the turbulence of the air generated by the friction of the substrate.

Inversion refers to a situation where the temperature of the atmosphere rises as it goes up. Especially during the surface inversion, air quality can rapidly deteriorate locally. In the surface inversion, the ground surface and the air layer near it cools down so that the colder air remains under the warmer air mass above it. Cold surface air, when heavier, cannot rise through the warm layer above, and vertical movement of the atmosphere is prevented. In the inversion layer, the wind is very weak, and the air-stirring turbulence is low, resulting poor dilution of air pollutants. In inversion situations, pollutant concentrations increase in agglomerations, especially during traffic congestion, as air pollutants accumulate in the low air layer near emission sources.

6.2 Particulate matter

Particulate matter ($PM_{2,5}$) pose the greatest health risk to people compared to other pollutants in ambient air. A threshold for PM concentrations below which no damage to health is observed has not been identified. The main components of PM are sulphate, nitrates, ammonia, sodium chloride, carbon (elementary and organic), organic matter, mineral dust and water. The particles are identified according to their aerodynamic diameter, as either PM_{10} (particles with an aerodynamic diameter smaller than 10 µm) or

$PM_{2.5}$ (aerodynamic diameter smaller than 2.5 μm). The fine particulates ($PM_{2.5}$) are more dangerous since, when inhaled, they may reach the peripheral regions of the bronchioles, and interfere with gas exchange inside the lungs. The sources of different sizes of particulate matter are presented in Figure 22.

The effects of PM on health occur at levels of exposure currently being experienced by most urban and rural populations in both developed and developing countries. Chronic exposure to particles contributes to the risk of developing cardiovascular and respiratory diseases, as well as of lung cancer. The mortality in cities with high levels of pollution exceeds that observed in relatively cleaner cities by 15–20%. Even in the EU, average life expectancy is estimated to be 8.6 months shorter due to exposure to $PM_{2.5}$ produced by human activities (*WHO, 2016*).

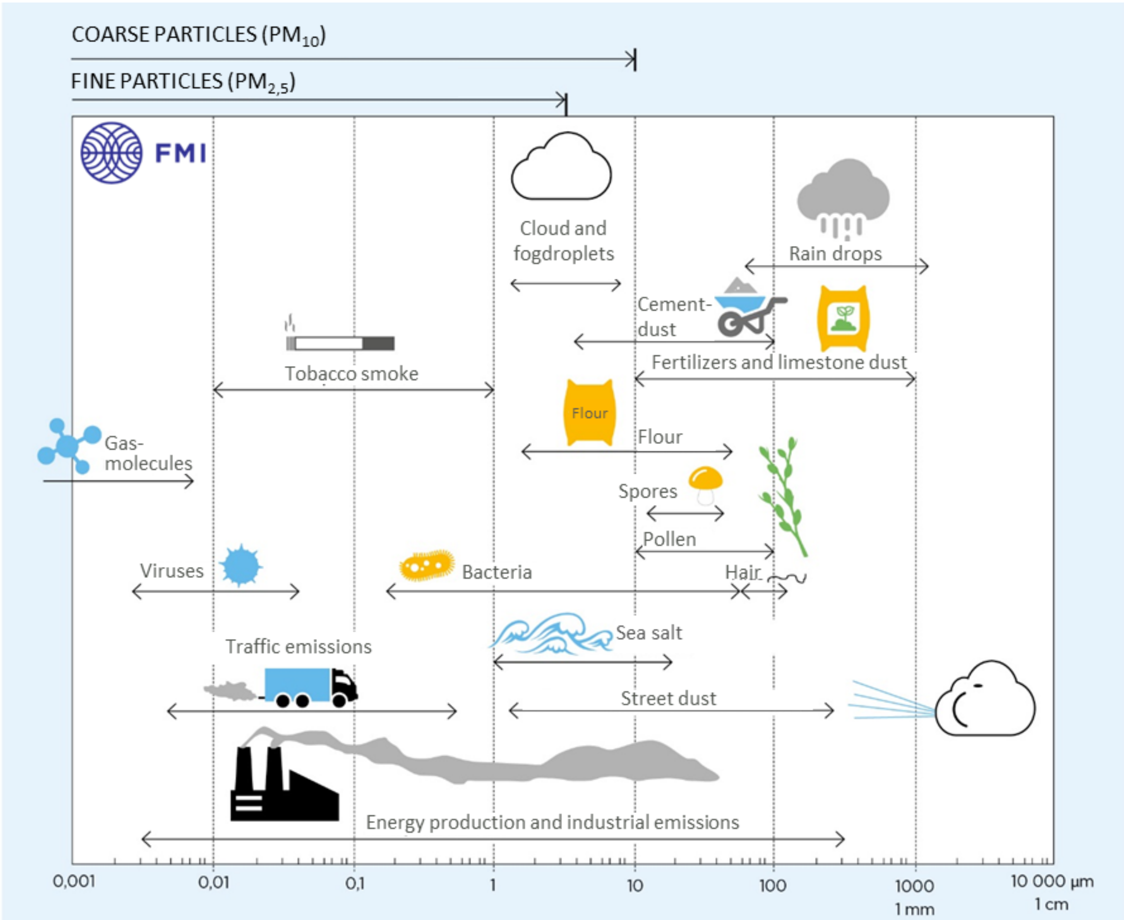

Figure 22. Sources of particulate matter of different particle sizes.

6.3 Nitrogen dioxide

As an air pollutant, nitrogen dioxide (NO_2) has several correlated activities. In short-term concentrations exceeding 200 μg/m^3 it is a toxic gas that causes significant inflammation of the airways. Nitrogen dioxide is the main source of nitrate aerosols, which form an important fraction of fine particulate matter ($PM_{2.5}$) and, in the presence of ultraviolet light, of ozone. The major sources of anthropogenic emissions of NO_2 are combustion processes (heating, power generation and engines in vehicles and ships). Epidemiological studies have shown that the symptoms of bronchitis in asthmatic children increase in association with long-term exposure to NO_2. Reduced lung function growth is also linked to NO_2 at concentrations currently measured (or observed) in cities of Europe and North America (*WHO, 2016*).

7 AIR QUALITY STANDARDS

Different countries typically have their local air quality legislation. This is also the case in Finland and Russia. Finland, as part of European Union is following the EU Air Quality directives and has implemented them to the Finnish national legislation. Limit values defined in EU Air Quality directives are binding in all European Union member countries. In addition to these, Finland has also set some additional air quality guideline values that are valid only in Finland.

Russian has also air quality legislation in federal and regional (oblast) level. The air quality limit values (Maximum permissible pollution concentrations) are defined on the Federal legislation.

In this study, as the aim is to use common approach to study the air quality impact of the E18 road, the international reference values are used for that. World Health Organisation (WHO) is the leading and coordinating authority for health within the United Nations. The concentrations retrieved with measurements or air quality dispersion modelling tools can be compared to health-based guideline values set by the WHO. The aim is that the guideline values are not exceeded and thus preserve good air quality and protect public from health effects of the air pollutants.

Table 7. The guideline values for nitrogen dioxide and particulate matter in ambient air (WHO, 2006).

Component	Guideline value µg/m³	Statistical determination
Fine particulate matter ($PM_{2.5}$)	10	annual mean
	25	24-hour mean
Nitrogen dioxide (NO_2)	40	annual mean
	200	1-hour mean

8 LOCAL SCALE DISPERSION MODEL

Air pollution dispersion models can be used to study the dilution and dispersion of various air pollutants in the atmosphere and the formation of air pollutant concentrations in the study area. Models often also include calculation methods that, in addition to transport, can be used to assess the transformation of air pollutants and chemical reactions in the atmosphere, as well as the exit from the atmosphere as a deposit. In this study, the dispersion models developed by the Finnish Meteorological Institute were used to describe the spread of road traffic emissions and to assess air quality impacts.

The Finnish Meteorological Institute's dispersion models have been developed on a long-term basis for more than forty years with the aim of producing reliable information on air quality, especially in Finnish conditions, e.g. to support urban and transport planning and the design of air protection measures, and to assess concentrations and exposure of the population. The operation of the models has been developed in numerous research projects, and according to verification studies, the results of the modelling have been found to be very compatible with the air quality measurement results of Finnish agglomerations and industrial environments. The models include a calculation method for the chemical transformation of nitrogen oxides.

The dispersion model used in this study can be used to estimate air pollutant concentrations and deposition in the vicinity of road traffic emission sources. Road traffic emission model CAR-FMI (Contaminants in the Air from a Road - Finnish Meteorological Institute, *Karppinen, 2001 & Härkönen et al. 2001*) is a Gaussian finite line source dispersion model i.e., a plume model for an open road network where there are not too many buildings or obstacles. In the model, roads are treated as straight line segments. The properties of traffic and emissions, as well as meteorological variables, are assumed to be constant during each hour. The model computes hourly time-series of pollutant concentrations originated from vehicular exhausts. There is an option with $PM_{2.5}$ concentrations that re-suspended particles from road surface can be considered in the modelling.

CAR-FMI uses the general analytical solution of Luhar and Patil (1989) for the dispersion of gaseous compounds. The dispersion parameters are modelled as function of the Monin-Obukhov length, the friction velocity and the mixing height. Traffic-originated turbulence is modelled with a semi-empirical treatment. The model includes a treatment for the basic reactions of nitrogen oxides, oxygen and ozone, using a receptor-oriented discrete parcel method, and the dry deposition of the fine particles. More detailed description of the model physics can be found from articles: *Härkönen et al., 2001; Härkönen, 2002*. An evaluation of the model against the measurements is described by *Kukkonen et al. 2001*

Data on emissions and their sources, measured and modelled information on the state of the atmosphere, as well as information on the background concentration of air pollutants in the study area, are needed as input data for the dispersion models. In addition, various spatial data are needed as input data, such as information on topography and surface quality, as well as information on the location of emission sources. The calculation of traffic emissions takes into account traffic volumes and their hourly variation, the shares of different types of vehicles in traffic volumes, driving speed and vehicle-specific speed-dependent emission factors.

Emission calculations should be performed using as detailed information as possible. Depending on the traffic data available, the emission coefficients can be applied using one of the three alternatives that European Environmental Agency EEA suggests in the emission inventory guidebook (*EEA, 2017*).

In this study the impact of the road traffic on ambient air quality and the pollution levels of nitrogen oxides (NO_x) and fine particulate matter ($PM_{2.5}$) were simulated with the CAR-FMI -model. A simplified illustration of operating the dispersion model is in Figure 23.

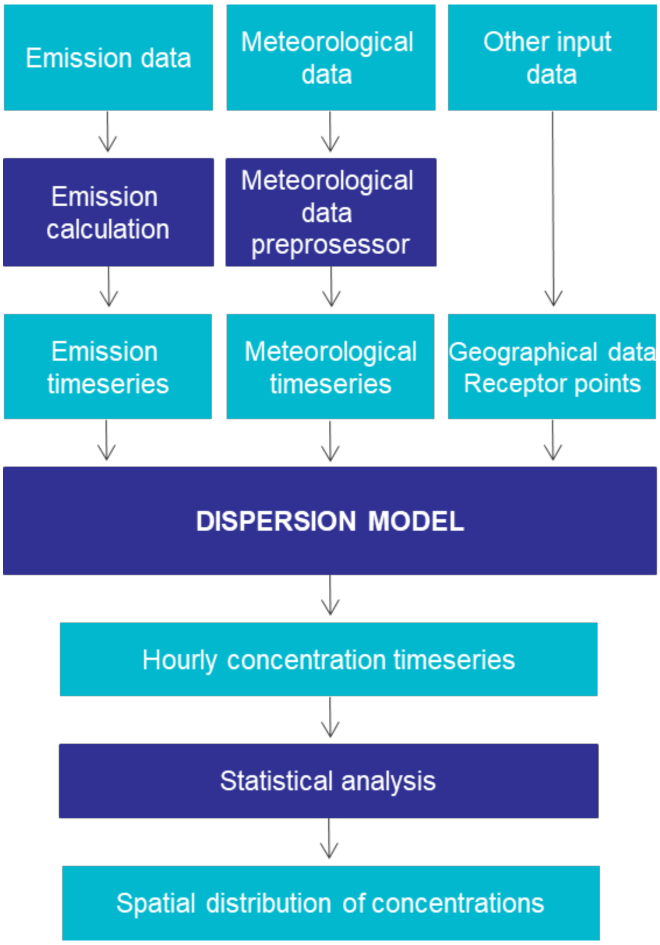

Figure 23. A simplified general principal diagram of the dispersion model CAR-FMI. The model is developed by Finnish Meteorological Institute.

The chemical transformation for NO oxidation to NO_2 is considered in the model to evaluate the actual NO_2 concentrations in ambient air. Nitrogen oxides (NO_x) emitted in burning of fossil fuels consists mainly of nitric oxide (NO, 90–95 %) and to a lesser extent of nitrogen dioxide (NO_2, 5–10 %). After exhaust from flue the percentage of NO_2 in air starts to increase through oxidation of NO mainly by atmospheric ozone (O_3).

8.1 A Common Method for Emission calculations

In this project a Common Method for emission calculations is applied. The method is based on the tier 3 method described in the emission inventory guidebook of the European Environmental Agency (*EEA, 2017*).

In general, the emission calculation is done separately for each road section and it is based on the traffic flow of each vehicle type on the section, the driving speed on the road, and the vehicle types on the road. Emission factors (*EEA, 2017*) are calculated separately for each different vehicle type and their EURO emission standards. In the Common method for Emission calculation all the vehicles are assumed to belong to the same, the most common EURO class of each vehicle category. The Common method also takes the cross-border traffic into account. In border crossing area the traffic is estimated to consist of 70 % of Russian vehicles and 30 % of Finnish vehicles. The numbers are based on the statistics from the Russian Customs. A detailed description of the common method emission calculation method is given in the report of Estimating Exhaust Gas Emission of the Road Traffic (*Lähdeaho et al 2019*).

8.2 Meteorological methods

The basic meteorological parameters relevant for dispersion simulations are wind (speed and direction), ambient air temperature, boundary layer stability and mixing height. Wind determines the speed and direction of dispersion. Stability gives indication of the turbulent mixing rate inside the boundary layer. Turbulent mixing is the most important factor for pollutant dilution during transport. Mixing height describes the vertical extent of the plume.

Turbulence data and boundary layer height are not available from any routine base measurements. Indirect methods have therefore been introduced to calculate these parameters. The meteorological pre-processing model MPP-FMI developed in the Finnish Meteorological Institute (*Karppinen et al., 1997 & 2000*) has been utilised in this study. This pre-processing model is based on a slightly modified version of the energy budget method of van Ulden and Holtslag (1985). This method evaluates the turbulent heat and momentum fluxes in the atmospheric boundary layer by utilising the routinely available weather observations. The output of the pre-processor consists of estimates of the hourly time series of the relevant atmospheric parameters (the Monin-Obukhov length scale, the friction velocity and the convective velocity scale) as well as the boundary layer height.

Meteorological time series for dispersion simulations are compiled by interpolating the weather data to the site of application (area, city or factory location) with a straightforward distance-weighted interpolation. Several weather stations can be included in the interpolation. Time series normally cover from 1 to 3 years of data, depending on application.

REFERENCES

Karppinen, A., Kukkonen, J., Nordlund, G., Rantakrans, E. ja Valkama, I., 1998. A dispersion modelling system for urban air pollution. Ilmansuojelun julkaisuja no. 28. Ilmatieteen laitos, Helsinki.

Karppinen, A., 2001, Meteorological pre-processing and atmospheric dispersion modeling of urban air quality and applications in the Helsinki metropolitan area, Academic dissertation, Finnish Meteorological Institute, Contributions No, 33, Helsinki.

Lapp, T., Tikkanen, P., Ristikartano, J., Niinikoski, M., Rinta-Piirto, J., Moilanen, P., 2018. Valtakunnalliset liikenne-ennusteet. Liikenneviraston tutkimuksia ja selvityksiä 57/2018. Liikennevirasto. Helsinki. ISBN 978-952-317-633-1

Lähdeaho, O., Hilmola, O.-P., Laukkanen, E., Rasila, T., Salmi, J., Wemberg, A., Hannuniemi, H., Komppula, B., Kauhaniemi, M., Kangas, L., Lovén, K., Pietarila, H., Vorontsova, S., Vorontsov, A., Karelina, L., Pavlov, V. 2019. The Manual of the estimating greenhouse gas and other air emissions of the road traffic. available: http://en.greenintertraffic.ru/

Olesen, H.R., 1995. Datasets and protocol for model validation. Internal Journal of Environmental and Pollution, Vol. 5, Nos. 4-6, pp. 693-701.

Ulden, A.P. Van & Holtslag, A.A.M., 1985. Estimation of Atmospheric Boundary Layer Parameters for Diffusion Applications. J. Clim. Appl. Meteor., 24, 1196–1207.

Vorontsova, S., Popov, Y., Pavlov, V., Lähdeaho, O., Laukkanen, E., 2020. The Green Roadmap and the road map for the creation of an intelligent transport system for unmanned vehicles of the E18 (SPb-Helsinki). Green InterTraffic. available at http://en.greenintertraffic.ru/greenintertraffic/materials/documents-of-the-project.html

VTT, 2017. LIPASTO traffic emissions. Available at URL: http://lipasto.vtt.fi/en/index.htm Retrieved: 25.June.2019.

WHO, 2016. http://www.who.int/mediacentre/factsheets/fs313/en/index.html (accessed 10.6.2016).

Härkönen, J., Nikmo, J., Karppinen, A., and Kukkonen, J., 2001. A refined modelling system for estimating the emissions, dispersion, chemical transformation and dry deposition of traffic-originated pollution from a road. In: Cuvelier, C. et al., Seventh International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, Joint Research Centre, European Commission, Ispra, Italy, pp. 311-313.

Härkönen, J.,2002: Regulatory dispersion modelling of traffic-originated pollution, Ph.D. thesis, Finnish Meteorological Institute Contributions 38, University Press, Helsinki, Finland, 103 pp., available at: http://ethesis.helsinki.fi/julkaisut/mat/fysik/vk/harkonen/regulato.pdf

Kukkonen, J., Härkönen, J., Walden, J., Karppinen, A., Lusa, K., 2001. Evaluation of the CAR-FMI model against measurements near a major road. Atmospheric Environment 35 p. 949-960.

APPENDIX

Number of vehicles, scenarios S1–S3

Figure 24. **Average daily traffic** on the road E18 from Helsinki to Saint Petersburg in future situation **(S1)**.

Figure 25. **Average daily traffic** on the road E18 from Helsinki to Saint Petersburg in future situation **(S2)**.

Finnish Meteorological Institute 2020

Figure 26. **Average daily traffic** on the road E18 from Helsinki to Saint Petersburg in future situation **(S3)**.

Number of heavy-duty vehicles, scenarios S1–S3

Finnish Meteorological Institute 2020

Figure 27. **Average daily heavy-duty traffic** on the road E18 from Helsinki to Saint Petersburg in future situation **(S1)**.

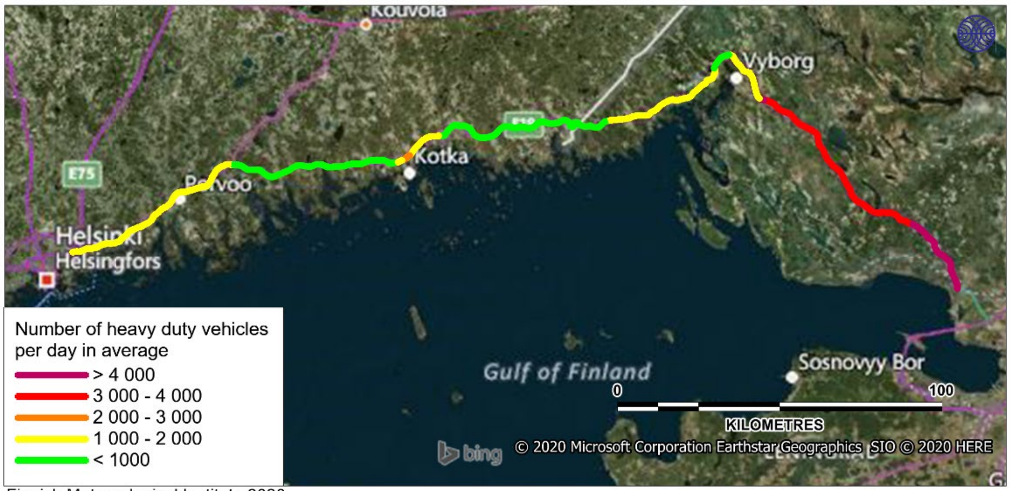

Figure 28. **Average daily heavy-duty traffic** on the road E18 from Helsinki to Saint Petersburg in future situation **(S2)**.

Figure 29. **Average daily heavy-duty traffic** on the road E18 from Helsinki to Saint Petersburg in future situation **(S3)**.

Nitrogen oxide emissions, scenarios S1–S3

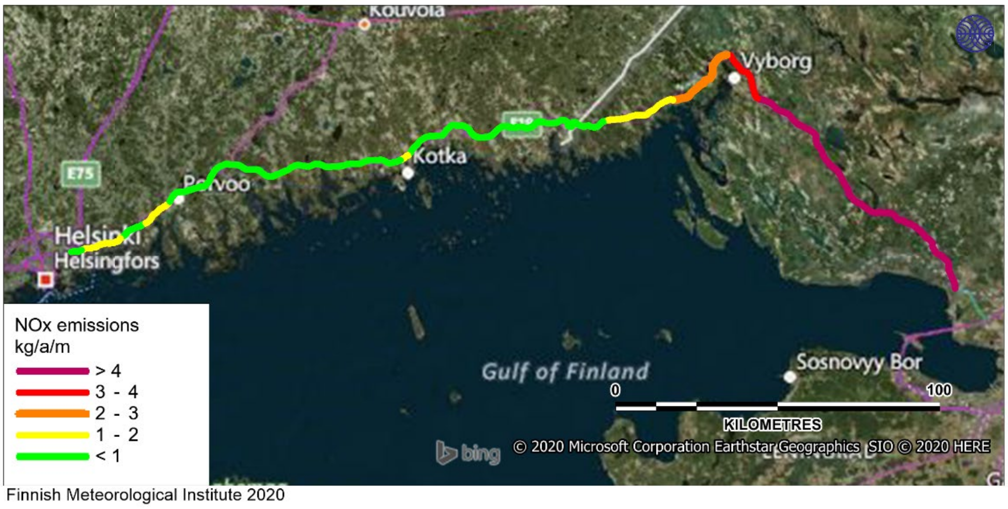

Figure 30. Road traffic **emissions of nitrogen oxides (NOx)** on the road E18 from Helsinki to Saint Petersburg in future situation **(S1)**.

Figure 31. Road traffic **emissions of nitrogen oxides (NOx)** on the road E18 from Helsinki to Saint Petersburg in future situation **(S2)**.

Figure 32. Road traffic **emissions of nitrogen oxides (NOx)** on the road E18 from Helsinki to Saint Petersburg in future situation **(S3)**.

Particulate matter emissions, scenarios S1–S3

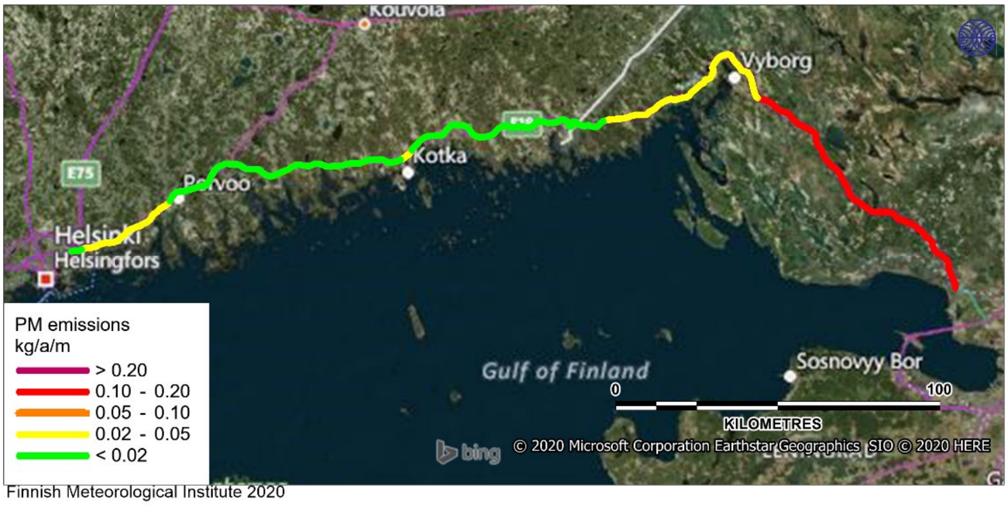

Figure 33. Road traffic **emissions of particulate matter (PM)** on the road E18 from Helsinki to Saint Petersburg in future situation **(S1)**.

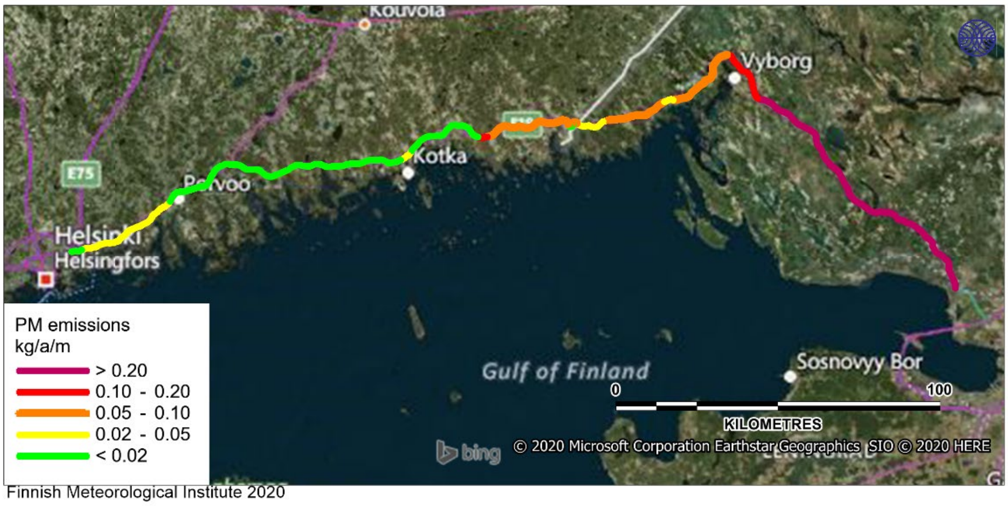

Figure 34. Road traffic **emissions of particulate matter (PM)** on the road E18 from Helsinki to Saint Petersburg in future situation **(S2)**.

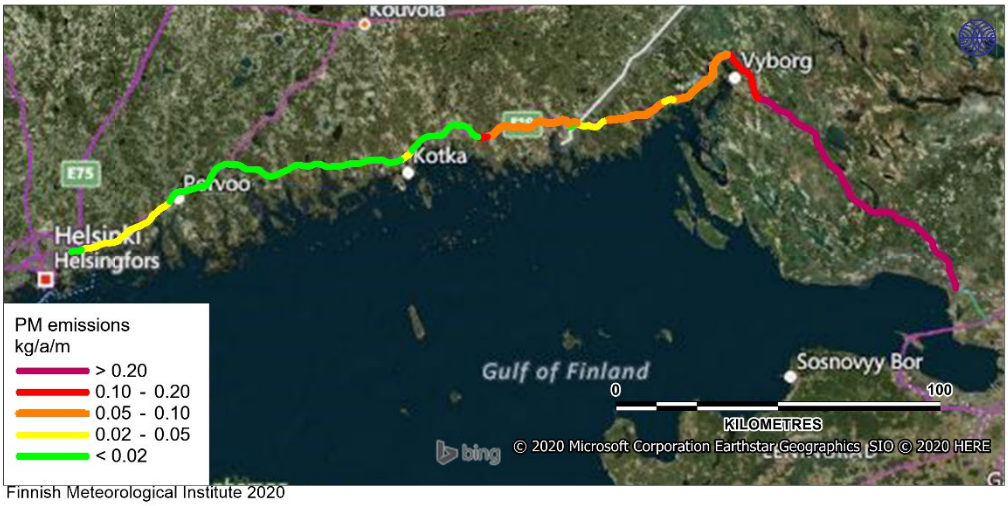

Figure 35. Road traffic **emissions of particulate matter (PM)** on the road E18 from Helsinki to Saint Petersburg in future situation **(S3)**.

Nitrogen dioxide concentrations, scenarios S1–S3

Figure 36. The annual **concentration (µg/m³) of nitrogen dioxide (NO_2)** in ambient air in breathing level in future situation **(S1)**.

Figure 37. The annual **concentration (µg/m³) of nitrogen dioxide (NO_2)** in ambient air in breathing level in future situation **(S2)**.

Figure 38. The annual **concentration (µg/m³) of nitrogen dioxide (NO_2)** in ambient air in breathing level in future situation **(S3)**.

Table 8. The highest nitrogen dioxide (NO_2) concentrations along the E18 road from Helsinki to Saint Petersburg compared to the WHO guideline values in future scenarios S1, S2 and S3 (WHO, 2006).

Nitrogen dioxide (NO_2)	Guideline value µg/m³	Future scenario S1	Future scenario S2	Future scenario S3
annual mean	40	34	39	44
1-hour mean	200	279	362	414

Table 9. Length of the track where WHO guideline values for nitrogen dioxide (NO_2) (*WHO, 2006*) are exceeded on the road E18 in present situation (S0) and in future scenario (S4).

Track length, km	Future scenario S1	Future scenario S2	Future scenario S3
annual mean	0	0	4
1-hour mean	10	50	76

Fine particulate matter concentrations, scenarios S1–S3

Figure 39. The annual **concentration (µg/m³) of fine particulate matter ($PM_{2.5}$)** in ambient air in breathing level in future situation **(S1)**.

Figure 40. The annual **concentration (µg/m³) of fine particulate matter ($PM_{2.5}$)** in ambient air in breathing level in future situation **(S2)**.

Figure 41. The annual **concentration (µg/m³) of fine particulate matter ($PM_{2.5}$)** in ambient air in breathing level in future situation **(S3)**.

Table 10. The highest fine particulate matter ($PM_{2.5}$) concentrations along the E18 road from Helsinki to Saint Petersburg compared to the WHO guideline values in future scenarios S1, S2 and S3 (WHO, 2006).

Fine particulate matter ($PM_{2.5}$)	Guideline value µg/m³	Future scenario S1	Future scenario S2	Future scenario S3
annual mean	10	8	10	11
24-hour mean	25	16	25	28

Table 11. Length of the track where WHO guideline values for fine particulate matter ($PM_{2.5}$) (*WHO, 2006*) are exceeded on the road E18 in future scenarios S1, S2 and S3 (WHO, 2006).

Track length, km	Future scenario S1	Future scenario S2	Future scenario S3
annual mean	0	0	13
24-hour mean	0	0	5