LIFEINDEXAIR

Technical report on the implementation of the management tool

Deliverables B6.1 & B6.2

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<u>This document contains:</u>

Deliverable B6.1 – Technical report on the implementation of the management tool in Lisbon

Deliverable B6.2 – Technical report on the implementation of the management tool in Athens, Kuopio, Oporto and Treviso

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EXECUTIVE SUMMARY

The technical report on the implementation of the management tool is a document of the LIFE Index-Air project, delivered in the context of the Action B6 – Implementation of the Management Tool, more specifically in Action B6.1 – Initial application and testing of the Management Tool in Lisbon and Action B6.2 – Application of Management Tool in Athens, Kuopio, Oporto and Treviso.

1. INTRODUCTION

The LIFE Index-Air tool is a user-friendly tool designed to provide an integrated procedure to estimate the impact of the particles on the citizens living in European cities and support the policy makers to identify measures to improve air quality.

The LIFE Index-Air tool is based on an integrated exposure-dose-burden of disease assessment, and provides:

- Modelling of ambient concentrations based on PM emissions;
- Exposure modelling for the assessment of population exposure;
- Dosimetry modelling for the assessment of respiratory deposition and internal doses;
- Burden of disease (BoD) methodology for estimating the health impacts;
- Built-up of policy making scenarios.

This report presents the tool implemented in the five cities: Lisbon and Porto (Portugal), Athens (Greece), Kuopio (Finland) and Treviso (Italy).

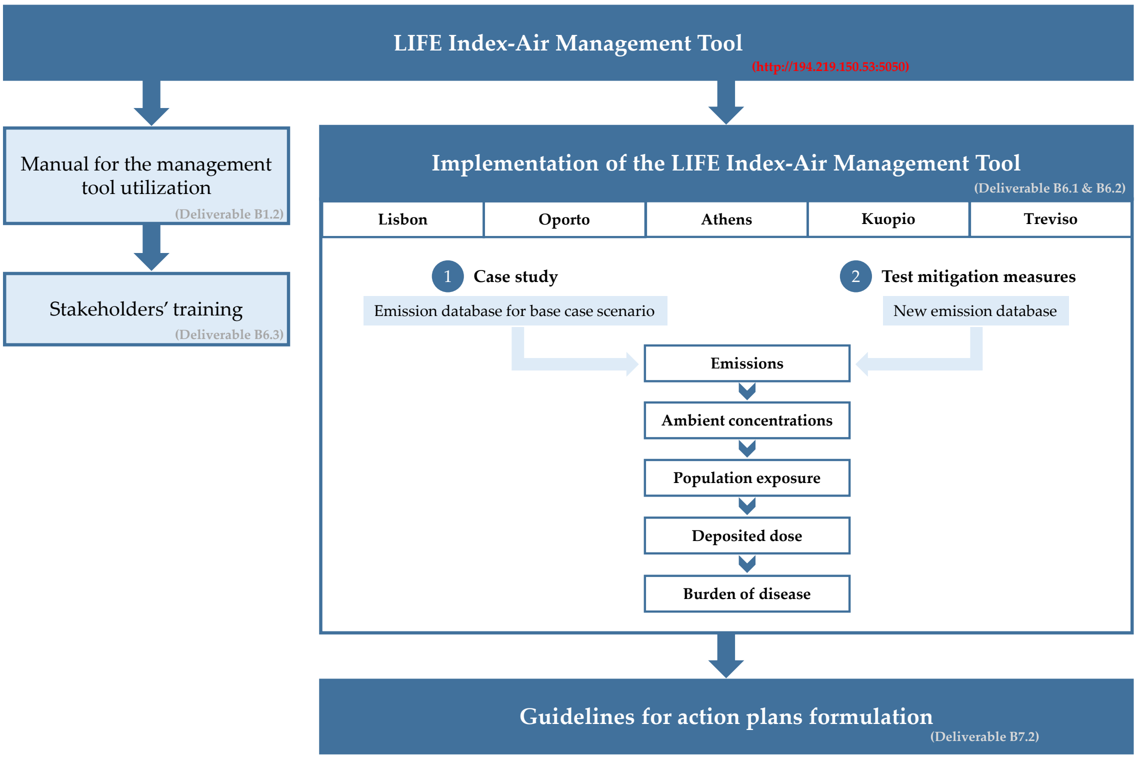


Figure 1.1 – Implementation of the LIFE Index-Air Management Tool.

2. METHODOLOGY

Firstly, the tool is run for the base case scenario to identify the major source emissions and to estimate the PM ambient concentrations, population exposure, deposited dose and BoD based on current conditions. The base year for which all calculations are performed is 2015.

Then, several modified scenarios are evaluated based on changes in the road vehicles fleet, residential heating and cruise shipping. The tool allows to assess the impact of these new scenarios on ambient air quality, population exposure and related health effects. The new traffic scenarios can be set changing the number of vehicles (passenger cars and buses), the fuel type (petrol, dieses, natural gas and electric) and European emission standards (from EURO I and VI). The residential heating scenarios may be tested modifying the amount of wood consumed and the type of wood burning devices (fireplace, more efficient fireplaces, woodstove, wood burning furnace, salamander stove, boiler, oven, wood burning water heater and furnace). In the case of the cruise shipping scenario it is possible to change the number of cruises. The base case inputs for each emission source (Traffic, Residential heating and Cruise shipping) can be found in Annex 1 of the "Manual for the management tool utilization" available on Deliverable B1.2.

The modified scenarios/mitigation measures implemented in the tool are indicated in Table 2.1. The cruise shipping scenarios can only be applied for Athens, Lisbon and Porto. The other two cities (Kuopio and Treviso) are not expected to be significantly affected by cruise shipping emissions.

Table 2.1 – Modified scenarios/mitigation measures tested in the LIFE Index-Air tool.

Sector		Scenario no.	Scenario code	Measure
Road traffic	Passenger cars fleet	Scenario 1	S1	Diesel cars replaced by electric cars
		Scenario 2	S2	100% electric cars
		Scenario 3	S3	-50% no. of cars
		Scenario 4	S4	No cars EURO I, II, III and IV -> 50% cars EURO V and 50% cars EURO VI
	Buses fleet	Scenario 5	S5	No buses EURO I, II, III and IV -> 50% cars EURO V and 50% cars EURO VI
		Scenario 6	S6	100% electric buses
Residential heating		Scenario 7	S7	More efficient fireplaces (No fireplaces, woodstove and salamander stove)
		Scenario 8	S8	-20% of wood consumed
Cruise ships		Scenario 9	S9	+20% no. of cruises
		Scenario 10	S10	No cruises

3. IMPLEMENTATION OF THE MANAGEMENT TOOL IN LISBON

CHARACTERISATION OF LISBON

PHYSICAL GEOGRAPHY

Lisbon is the largest city of Portugal and the continental Europe's westernmost capital city. It is set on seven hills and located at the point where the River Tagus flows into the Atlantic Ocean. The western side of the city is manly occupied by the Monsanto Forest Park, one of the largest urban parks in Europe, with an area close to 10 km^2. The Lisbon municipality covers an area of 100.05 km^2 and together with 17 other municipalities composes the Lisbon metropolitan area with about 3015 km^2.

DEMOGRAPHY

According to the 2011 census, Lisbon's metropolitan area is the most populous area of Portugal with a population of around 2.7 million inhabitants, representing Lisbon municipality approximately 20% of this total population. Lisbon's metropolitan area is the 11th-most populous urban area in the European Union (Demographia, 2021). Lisbon municipality's population can increase up to more than 1 million people per day as a consequence of commuting movements plus tourist visitors.

CLIMATE

Lisbon has a Mediterranean climate influenced by the warm Gulf Stream current that crosses the Atlantic from North America and by the presence of the semi-permanent Azores high-pressure and the Icelandic low-pressure systems over the North Atlantic Ocean.

In winter the daytime temperatures are generally mild, around 15 °C. The westerly winds prevail, bringing quite frequent rains, sometimes abundant, and windy conditions. However, when the Azores Anticyclone move over Portugal there are periods of good weather in winter. During these periods, fog can form at night and in the early morning. Very cold days are not frequent. Summers are warm, sunny and dry with average daytime temperatures of 26-29 °C, falling to 16–18°C at night. The breeze blows from the ocean, tempering the heat. However, there can even be hot periods due to African air masses: in these days, the temperature can reach 40 °C. Spring and autumn are generally mild, with some periods of bad weather (World climate guide).

The city is sunny throughout the year, with an annual average of 2800 hours of sunshine. Average annual rainfall is 710 mm, more abundant in winter and autumn, moderate and less frequent in spring, and extremely uncommon in summer (World climate guide).

TRANSPORT

Road

According to the annual report "Traffic Index 2019", Lisbon ranked as the most congested city in the Iberian Peninsula (based on TomTom navigation data). In 2017, the transport fleet in the city included 366,671 vehicles; of which 80% were passenger cars, 6% motorcycles, 0.4% buses, and 14% other types (ASF, 2018).

Rail

Lisbon has a dense rail transport network that spans the entire metropolitan area, comprising railway and metro systems. "Comboios de Portugal" company operates passenger trains in Portugal, connecting major cities from north to south. Fertagus connects Lisbon to suburbs on the Setúbal Peninsula, located to the south across the Tagus River. In 2019, Lisbon Metro carried 183.1 million passengers, with an 8.2% increase. The Metro Sul do Tejo light railway system carried 15.6 million passengers (+26.4%) (INE, 2020).

Maritime

Lisbon cruise port is located on the North bank of River Tagus, surrounded by the historical cultural centre of Lisbon. It is one of the most active port on the European Atlantic Coast, serving over 570,000 travellers and with 338 cruise ship calls in 2018 (Lisbon Cruise Port, 2021). Moreover, public ferries connect Lisbon to its Southern suburbs.

Air

Lisbon airport also known as Humberto Delgado Airport, is the country's main domestic and international gateway. It is one of the largest airports in Europe in terms of passenger volume, having served more than 30 million people in 2019. The airport is located 7 km north of the city centre.

INDUSTRY

The south bank of the Tagus River is heavily industrialised. The industries include textile, footwear, leather, furniture, ceramics, cork, oil refineries, petrochemicals, cement, automotives, shipping industry, electrical and electronics goods, machinery and paper industries.

ATMOSPHERIC POLLUTION

The natural typology of the city with several hills, together with the predominance of narrow streets and a scarce green areas, promotes the accumulation of pollutants. The dominant source of air pollutants in the city is road traffic emissions (Almeida et al., 2009a, 2009b). There is a high diurnal variability in PM10, PM2.5 and NO_2 concentrations due to the road traffic conditions. Moreover, it has a significant contribution of marine aerosol due to the geographic position and the dominant western wind regime (Almeida et al., 2013). In addition to the nearby airport with several continental and transatlantic flights, there is also an important port of call for cruises, receiving a high number of ships, which engines could be very polluting. These constitute additional sources of air pollutants that are transported across the city. The city is also frequently affected by North African air mass transport, which contributes significantly to the atmospheric mineral dust load (Almeida et al., 2008). This phenomenon registers a significant PM10 annual average weight between 5 and 10% (EGCA, 2018). More precisely, the main PM10 emission sectors are: road transport (62%), industry (26%), electric production (9%) and maritime transport (2%) (Ferreira et al., 2017). For PM2.5, the largest contributors to its total mass are secondary aerosol and vehicle exhaust. Under adverse meteorological conditions, low dispersion conditions and thermal inversions, particularly in winter, high concentrations of air pollutants can be registered (Alves et al., 2010).

Base Case

The base case scenario corresponds to the air quality condition verified over the city of Lisbon in the year 2015. The base case is based on the CAMx model integrated with the data obtained in the air monitoring stations.

Emissions

<u>Lisbon municipality</u>

- Figure 3.1 shows the Lisbon municipality emissions in 2015, for the main gas pollutants (NH_3, NOx, SO_2 and VOC), particulate matter (PM10 and PM2.5) and heavy metals (As, Cd, Ni and Pb), per activity sector.
- The "road transport" sector was the largest source of NH_3 (55%), NOx (62%) and Ni (89%) emissions.
- The "other mobile sources and machinery" sector, associated to the maritime, rail and air transport, was the largest source of SO_2 (84%), PM10 (51%), PM2.5 (56%), As (96%), Cd (63%) and Pb (96%).
- "Solvent and other product use" sector was the largest source of VOC (53%).

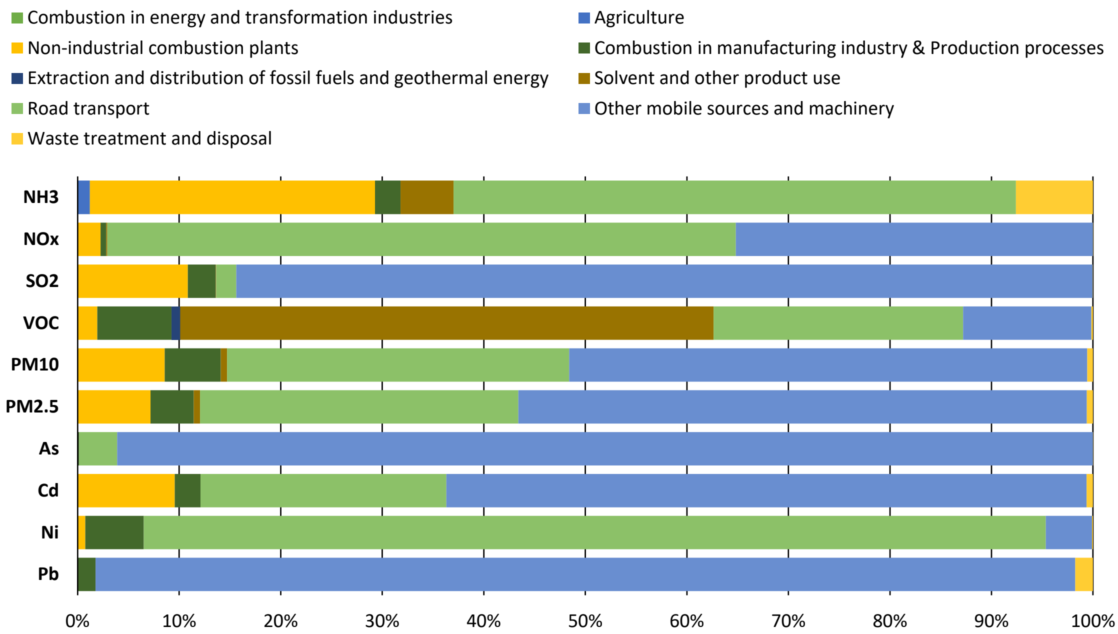


Figure 3.1 – Share of Lisbon municipality emissions (in %) of the main pollutants, by sector group in 2015.

<u>Other municipalities of the metropolitan area of Lisbon</u>

- Figure 3.2 shows the Lisbon metropolitan area (excluding the Lisbon municipality) emissions in 2015, for the main gas pollutants (NH_3, NOx, SO_2 and VOC), particulate matter (PM10 and PM2.5) and heavy metals (As, Cd, Ni and Pb), per activity sector.
- The "combustion in manufacturing industry & production processes" sector group was the largest contributor to total emissions of SO_2 (66%) and heavy metals (76% for As, 97% for Cd, 80% for Ni and 54% for Pb).

- Road transport was the largest source of NO_X (63%).
- Solvent and other product use was the largest source of VOC (50%).
- The sector that presented the highest contribution for PM (38% for PM10 and 37% for PM2.5) was the "Non-industrial combustion plants", followed by "Combustion in manufacturing industry & Production processes" and "road transport", both with a contribution around 26% for PM10 and PM2.5. The "Non-industrial combustion plants" sector includes the residential, institutional and commercial plants.
- The "Agriculture" sector contributed to 32% of NH_3 emissions.
- Most of the pollutant emissions from combustion processes, which includes "combustion in manufacturing industry & production processes" and "non-industrial combustion plants" sectors, come from the other municipalities of the metropolitan area of Lisbon.

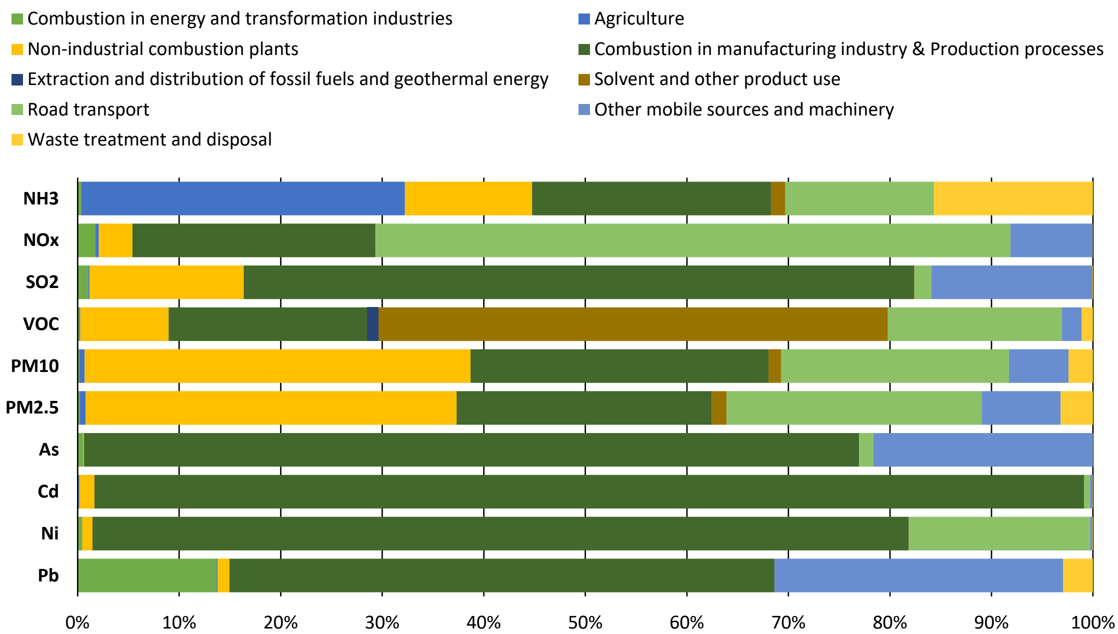


Figure 3.2 – Share of Lisbon metropolitan area (excluding the Lisbon municipality) emissions (in %) of the main pollutants, by sector group in 2015.

- In the other municipalities of the metropolitan area of Lisbon are observed higher pollutant emissions (Table 3.1) than in the municipality of Lisbon.
- In Lisbon municipality, the VOC showed the highest total emission of 2015 (15043 t/year) followed by NOx (7108 t/year).
- Similarly, in the other municipalities of the metropolitan area of Lisbon, the VOC had the highest total emission (81703 t/year) followed by NOx (27193 t/year).
- Regarding the heavy metals, in the Lisbon municipality the highest emissions were registered for As (801 kg/year) whereas in the other municipalities of the metropolitan area of Lisbon the emissions of As and Ni were very similar, with a total value of 7860 and 7837 kg/year, respectively.

Table 3.1 – Total emissions of the main pollutants in 2015 for the Lisbon municipality and the other municipalities of the metropolitan area of Lisbon.

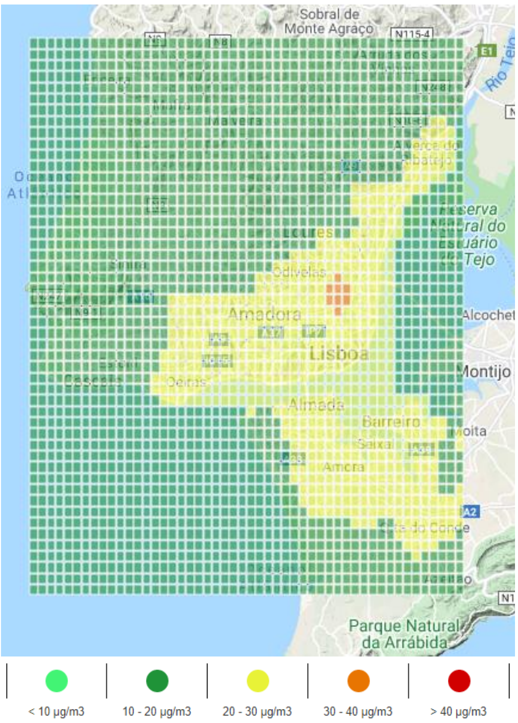
	NH_3	NOx	SO_2	VOC	PM10	PM2.5	As	Cd	Ni	Pb
	Total									
	t/year						kg/year			
Lisbon Municipality	132	7108	332	15043	980	893	801	16	417	11
Other municipalities of the metropolitan area of Lisbon	1914	27193	1514	81703	5790	4378	7860	2565	7837	95

AMBIENT CONCENTRATIONS

- PM10 annual average concentration in Lisbon Municipality was 25 µg/m^3. The worst annual average concentration was 39 µg/m^3, which did not exceed the annual limit value of 40 µg/m^3 defined by the EU Directive. However, both average and maximum values were higher than the guideline defined by the WHO (20 µg/m^3).
- PM10 annual average concentration in the other municipalities of the metropolitan area of Lisbon was 18 µg/m^3 and the highest average concentration was 33 µg/m^3. This maximum value exceeded the annual guideline defined by the WHO.
- PM2.5 annual average concentration in Lisbon Municipality was 14 µg/m^3. The worst annual average concentration was 21 µg/m^3, which did not exceed the annual limit value of 25 µg/m^3 defined by the EU Directive. However, both average and maximum values were higher than the guideline defined by the WHO (10 µg/m^3).
- PM2.5 annual average concentration in the other municipalities of the metropolitan area of Lisbon was 10 µg/m^3 and the highest average concentration was 18 µg/m^3. This maximum value exceeded the annual guideline defined by the WHO.
- Observing the PM10 and PM2.5 maps in Figure 3.3, it is shown that the highest concentrations were observed at Lisbon airport and its surroundings.
- In Lisbon municipality the annual mean concentrations of As (0.06 ng/m^3), Cd (0.05 ng/m^3) and Ni (0.84 ng/m^3) did not exceeded neither the target values established by the EU Directive (6, 5 and 20 ng/m^3 for As, Cd and Ni, respectively) nor the WHO estimated reference levels for As (6.6 ng/m^3) and Ni (25 ng/m^3) and the WHO air quality guideline for Cd (5 ng/m^3). The annual mean Pb concentration (0.34 ng/m^3) was much lower than the EU Directive limit value and WHO air quality guideline of 0.5 µg/m^3.
- In the other municipalities of the metropolitan area of Lisbon the annual mean concentrations of As (0.05 ng/m^3), Ni (0.66 ng/m^3) and Pb (0.27 ng/m^3) were lower than those obtained in Lisbon municipality. Conversely, the annual Cd mean concentration (0.07 ng/m^3) in the other municipalities of the metropolitan area of Lisbon was slightly higher than in the Lisbon municipality, but still without exceeding neither the EU Directive target values nor the WHO air quality guideline.
- On average, for Lisbon municipality, the ambient mean concentrations of both PM10 and PM2.5 in winter were 61% higher than in summer. For heavy metals, the mean concentrations in winter were between 34% (for Pb) and 80% (for As) higher than in summer. The high concentrations in winter can be attributed not only to additional emission sources, such as domestic wood combustion for residential heating, but also to natural phenomenon of thermal inversion that limits the pollutants dispersion.

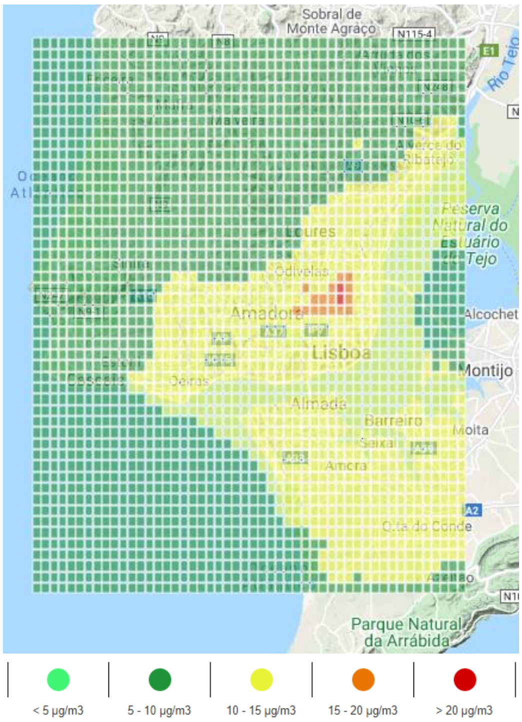
- For the other municipalities of the metropolitan area of Lisbon, the PM10 and PM2.5 ambient mean concentrations in winter were 72% higher than in summer. For heavy metals, the mean concentrations in winter were between 48% (for Ni) and 70% (for As) higher than in summer.

PM10



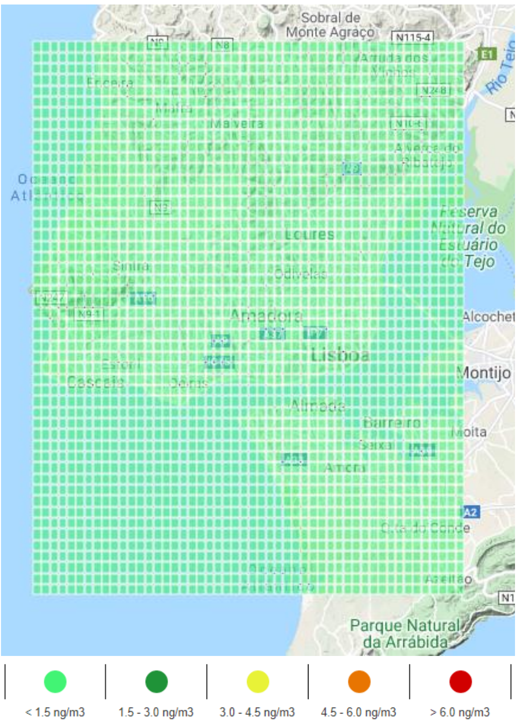
	Average	Minimum	Maximum
Lisbon Municipality	25.43	21.11	38.73
Municipalities of the metropolitan area of Lisbon	18.08	11.53	32.77

PM2.5

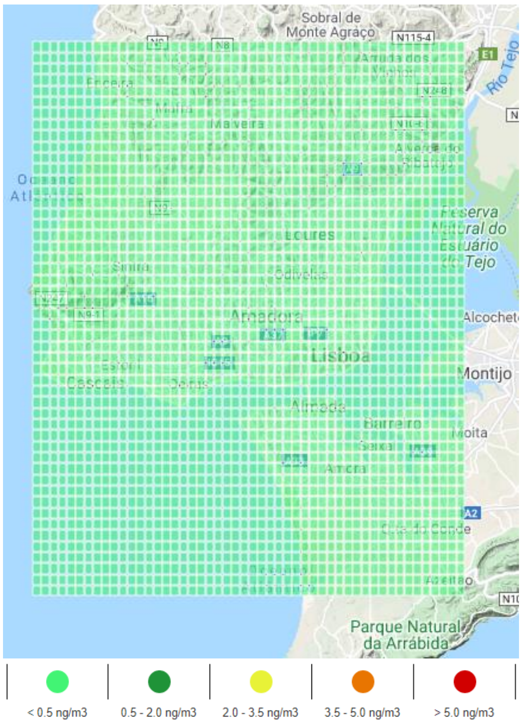


	Average	Minimum	Maximum
Lisbon Municipality	13.78	11.43	21.32
Municipalities of the metropolitan area of Lisbon	9.65	5.98	17.90

As



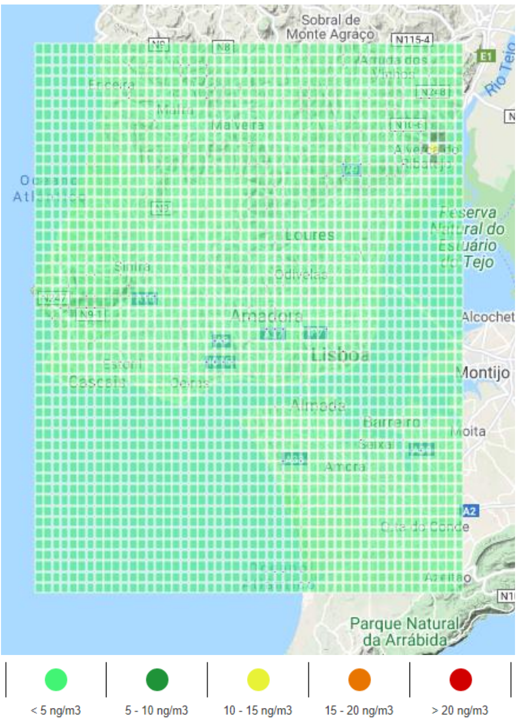
Cd



	Average	Minimum	Maximum
Lisbon Municipality	0.06	0.04	0.17
Municipalities of the metropolitan area of Lisbon	0.05	0.01	0.27

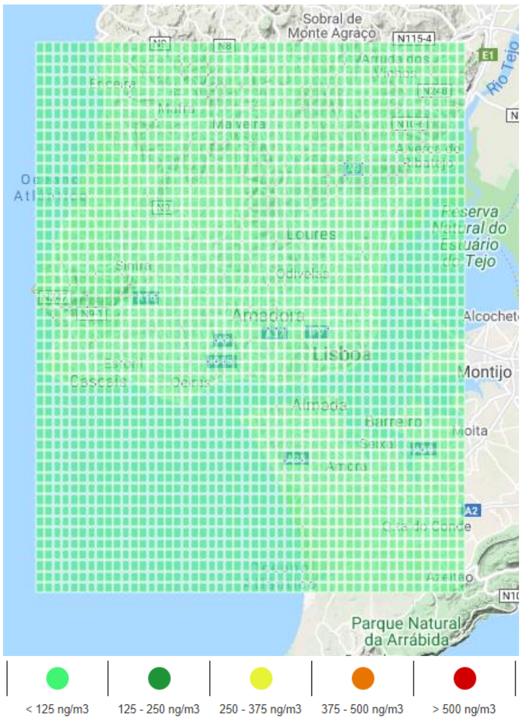
	Average	Minimum	Maximum
Lisbon Municipality	0.05	0.04	0.07
Municipalities of the metropolitan area of Lisbon	0.07	0.01	1.61

Ni



	Average	Minimum	Maximum
Lisbon Municipality	0.84	0.47	3.04
Municipalities of the metropolitan area of Lisbon	0.66	0.09	10.16

Pb



	Average	Minimum	Maximum
Lisbon Municipality	0.34	0.23	0.67
Municipalities of the metropolitan area of Lisbon	0.27	0.07	2.08

Figure 3.3 – Annual average ambient concentrations of PM (in µg/m^3) and heavy metals (in ng/m^3) in Lisbon.

PM10 exceedances

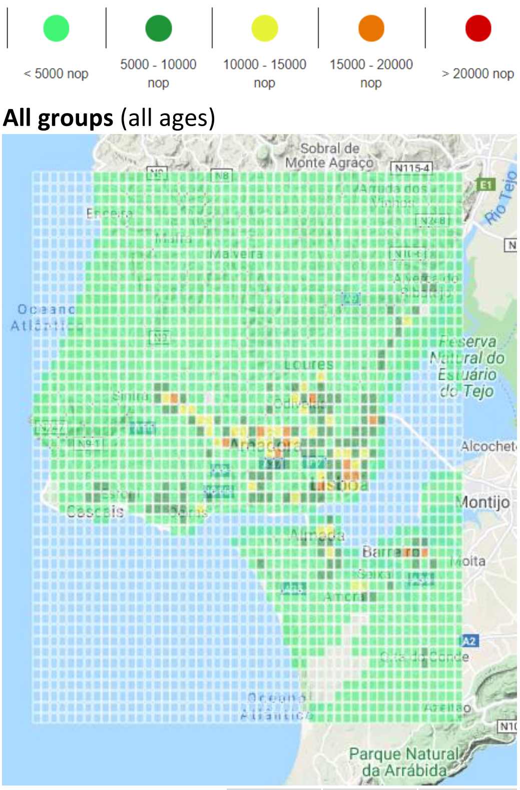
- For PM10, the current EU legislation defined in the Directive 2008/50/EC, with the objective of protecting human health and the environment, presents a daily limit value of 50 µg/m^3, which should not be exceeded more than 35 times a year.
- In Lisbon Municipality this EU air quality standard was exceeded in some cells, being the worst condition registered in a cell where a maximum of 83 days showed a daily average value higher than 50 µg/m^3 (Table 3.2).
- In the other municipalities of the metropolitan area of Lisbon this indicator was also not fulfilled in some cells, occurring a maximum of 66 exceedance days during the year in the worst cell (Table 3.2).

Table 3.2 – Number of PM10 exceedance days in 2015 for Lisbon.

	Minimum	Maximum
Lisbon Municipality	5	83
Other municipalities of the metropolitan area of Lisbon	2	66

Population Groups

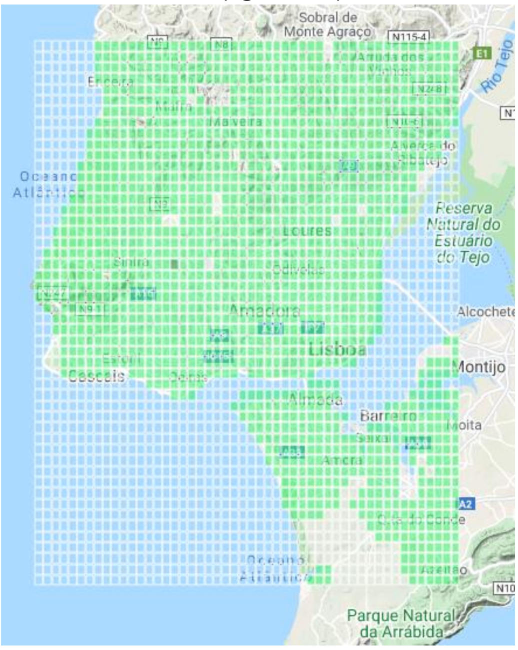
- The population in the study area was divided into 5 age groups characterised by different inhalation rates, activities and responses to the air pollution.
- Mean population density in Lisbon Municipality is 5505 inhabitants per km^2 (Figure 3.4).
- In Lisbon Municipality the largest fraction (54%) of the population is in the range 26-65 years old (working adults), 24% are elderly people and the remaining population are children and adolescents under 26. The latter are divided into students (14%, 11-25 years old), elementary school children (4%, 5-10 years old) and pre-school children (4%, <5 years old).
- The other municipalities of the metropolitan area of Lisbon have a mean population density of 1238 inhabitants per km^2, with a population distribution similar to that in the Lisbon Municipality for working adults (56%), students (16%), pre-school (5%) and elementary school (5%) children. The elderly people are slightly smaller (17%).



	Average	Minimum	Maximum
Lisbon Municipality	5505	0	16871
Municipalities of the metropolitan area of Lisbon	1238	0	16899

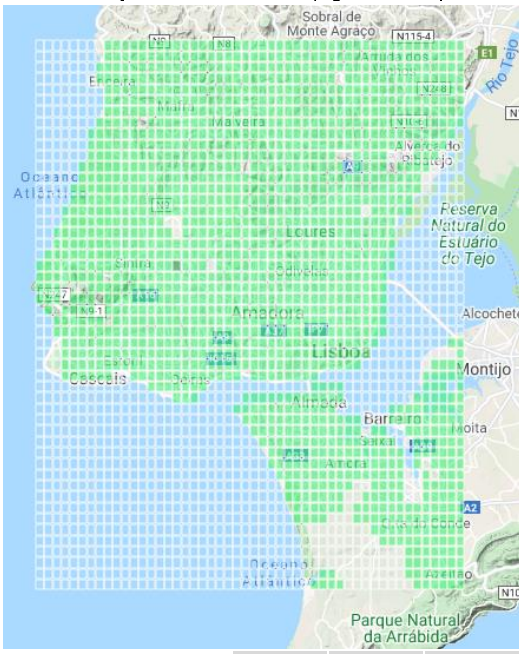
Figure 3.4 – Map with spatial distribution (1 km x 1 km) of all population across Lisbon, expressed in number of people (nop). The average, minimum and maximum population densities are expressed in nop/km^2.

Pre-school children (ages 0 – 4)



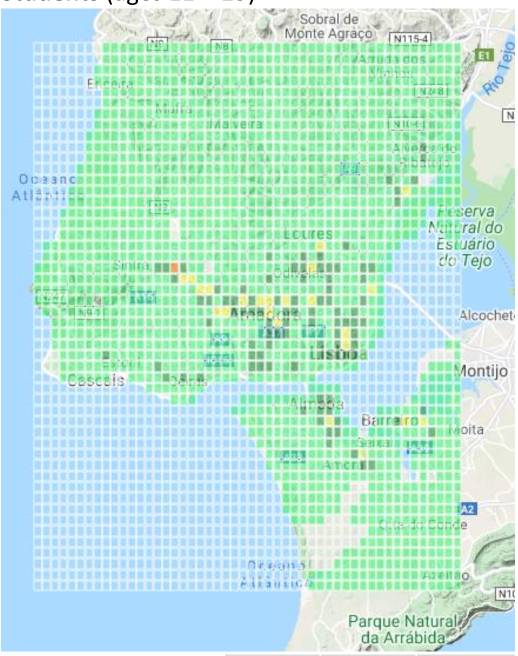
	Average	Minimum	Maximum
Lisbon Municipality	237	0	861
Municipalities of the metropolitan area of Lisbon	65	0	1029

Elementary school children (ages 5 – 10)



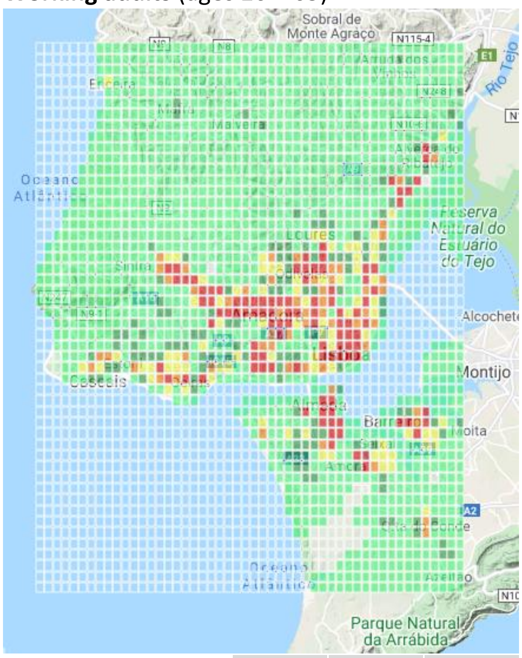
	Average	Minimum	Maximum
Lisbon Municipality	234	0	730
Municipalities of the metropolitan area of Lisbon	67	0	1037

Students (ages 11 – 25)



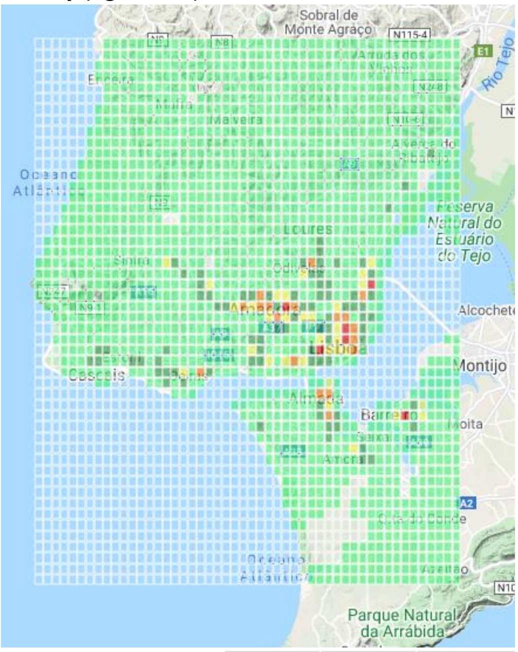
	Average	Minimum	Maximum
Lisbon Municipality	766	0	2126
Municipalities of the metropolitan area of Lisbon	200	0	3042

Working adults (ages 26 – 65)



	Average	Minimum	Maximum
Lisbon Municipality	2947	0	9052
Municipalities of the metropolitan area of Lisbon	698	0	9508

Elderly (ages > 65)



	Average	Minimum	Maximum
Lisbon Municipality	1321	0	4743
Municipalities of the metropolitan area of Lisbon	209	0	4554

Figure 3.5 – Maps with spatial distribution (1 km x 1 km) of population across Lisbon for each population group, expressed in number of people (nop). The average, minimum and maximum population densities are expressed in nop/km^2.

Population Exposure

- The population exposure (the product of the pollutant and population exposed to it) was categorised into 5 subgroups in addition to the overall group ("all groups") for the Lisbon Municipality and the other municipalities of the metropolitan area of Lisbon. This exposure is estimated considering the time-activity patterns.
- Table 3.3 shows the annual average exposure to PM and heavy metals weighted by the number of people present in the Lisbon study case domain.
- In Lisbon Municipality, in 2015 the population exposure was 120000 µg/m^3.nop for PM10 and 77000 µg/m^3.nop for PM2.5. Regarding the heavy metals, the highest population exposure was obtained for Ni (3700 ng/m^3.nop), followed by Pb (1600 ng/m^3.nop), Cd (250 ng/m^3.nop) and As (250 ng/m^3.nop).
- For the other municipalities of the metropolitan area of Lisbon, all the population was exposed to 24000 µg/m^3.nop for PM10 and 15000 µg/m^3.nop for PM2.5. For the heavy metals the highest population exposure was obtained for Ni (990 ng/m^3.nop) followed by Pb (420 ng/m^3.nop) and the lowest was for As (64 ng/m^3.nop).
- Population exposure was higher in Lisbon municipality not only because of the difference in the pollutant concentrations (Figure 3.3), but also because the population exposed is higher in Lisbon municipality (Figure 3.4).

Table 3.3 – PM and heavy metals exposure for each population sub-group in Lisbon.

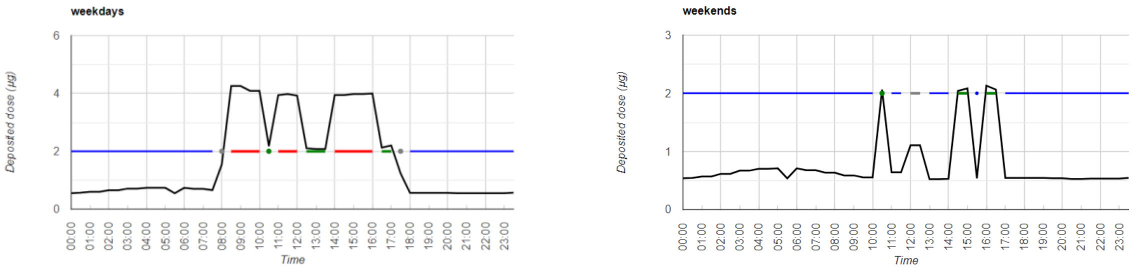
		PM10	PM2.5	As	Cd	Ni	Pb
		µg/m³.nop		ng/m³.nop			
Lisbon Municipality	All groups	120000	77000	250	250	3700	1600
	Pre-school children	6000	3600	11	11	160	72
	Elementary school children	5700	3400	11	11	160	70
	Students	19000	11000	35	37	510	230
	Working adults	60000	38000	130	130	1900	840
	Elderly	25000	17000	57	57	860	370
Other municipalities of the metropolitan area of Lisbon	All groups	24000	15000	64	88	990	420
	Pre-school children	1400	850	3.4	4.9	52	23
	Elementary school children	1400	840	3.4	4.9	52	23
	Students	4200	2500	10	14	160	70
	Working adults	12000	7700	35	48	540	230
	Elderly	3400	2400	11	14	170	70

Deposited Dose

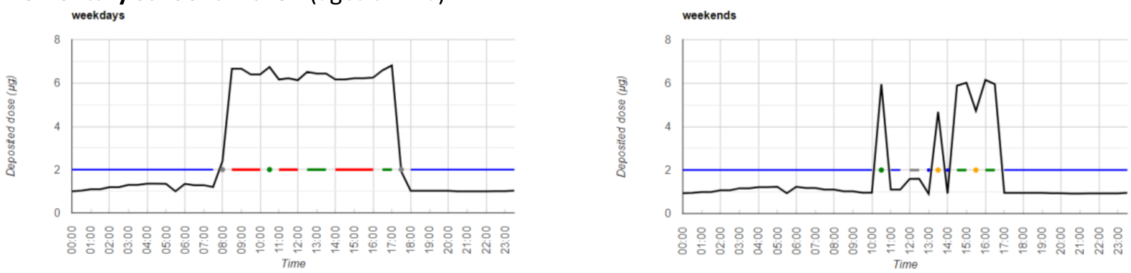
- The deposited dose of PM10 and PM2.5 was divided into 5 population sub-groups: pre-school children, elementary school children, students, working adults and elderly. The deposited dose is estimated through the individual exposure, the inhalation rate and other standardize anatomical characteristics of the individual sub-groups.
- In Figure 3.6 and Figure 3.8 is represented the daily variability of the deposited dose of PM10 and PM2.5, respectively. By observing the graphs, it is possible to identify which microenvironment or activity is contributing most to the daily deposited dose.
- For pre-school children the highest PM10 and PM2.5 deposited doses were obtained when the children were at school during the weekdays and outdoors on the weekend. The lowest PM10 and PM2.5 deposited doses were observed at home on both weekdays and weekends.
- For elementary school children and students, on weekdays the highest PM10 and PM2.5 deposited doses were observed outdoors followed by school microenvironment, and the lowest values were at home. On the weekends, the highest PM10 and PM2.5 deposited doses were observed outdoors followed by indoors-other, and the lowest doses occurred at home. The difference of the PM deposited doses between these two population groups and the first one (pre-school children) may be due to the age difference, i.e. younger children have lower ventilation rates and also lower physical activity intensity.
- For working adults and elderly, both on weekdays and weekends the highest deposited doses of PM10 and PM2.5 occurred outdoors and the lowest were at home. In general, the working adults with office work had PM deposited doses very similar to those observed at home.
- PM10 and PM2.5 deposited doses showed to be higher on weekdays than weekends for all population sub-groups, except for working adults. For elderly this difference was almost negligible.

PM10

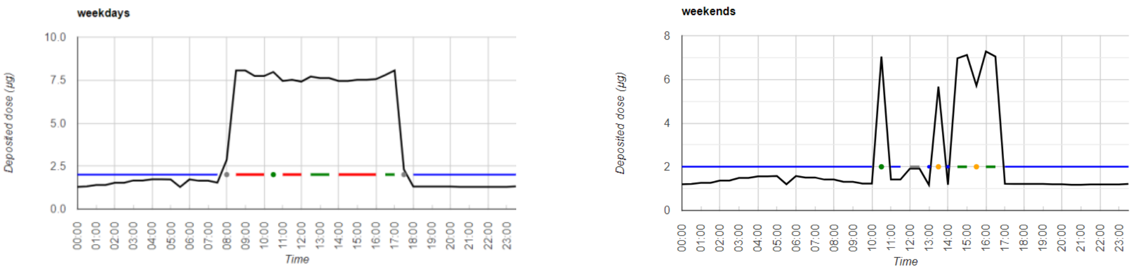
Pre-school children (ages 0 – 4)



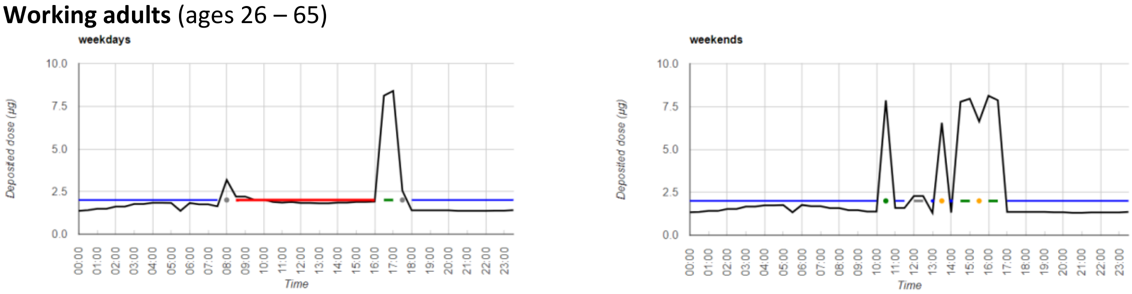
Elementary school children (ages 5 – 10)



Students (ages 11 – 25)



Working adults (ages 26 – 65)



Elderly (ages > 65)

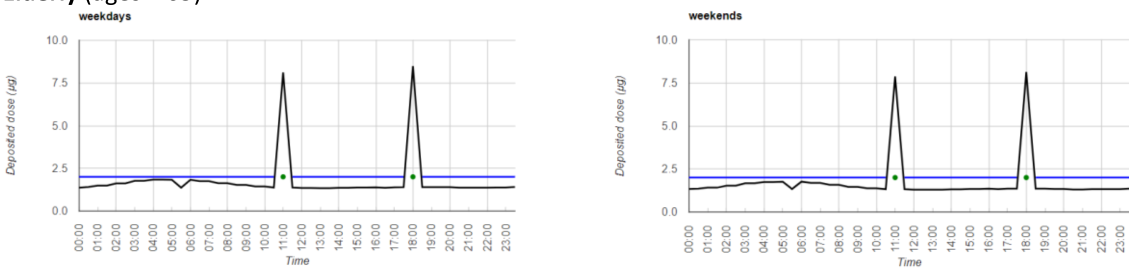


Figure 3.6 – PM10 dose (in all regions) throughout the day for each population group in Lisbon metropolitan area.

- The distribution of the PM10 deposited dose in the different regions of the human respiratory tract (HRT) is represented in Figure 3.7.
- For all population sub-groups the highest amount of PM10 deposited on the upper airways (anterior nasal passages – ET1) and the lowest values were obtained in the BB region, which is composed by trachea and bronchi.
- Due to the highest PM10 deposited dose during the weekdays, the students presented the highest PM10 deposited dose along one year, followed by elementary school children, working adults, elderly and pre-school children.

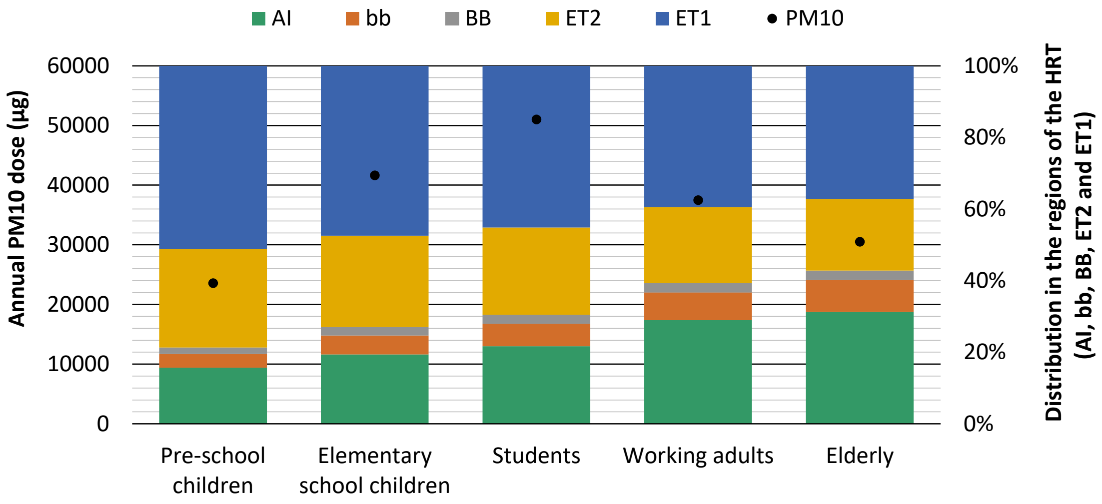


Figure 3.7 – Annual cumulative dose for PM10 (µg) and its distribution in the different regions of the HRT for each population group in Lisbon metropolitan area.

PM2.5

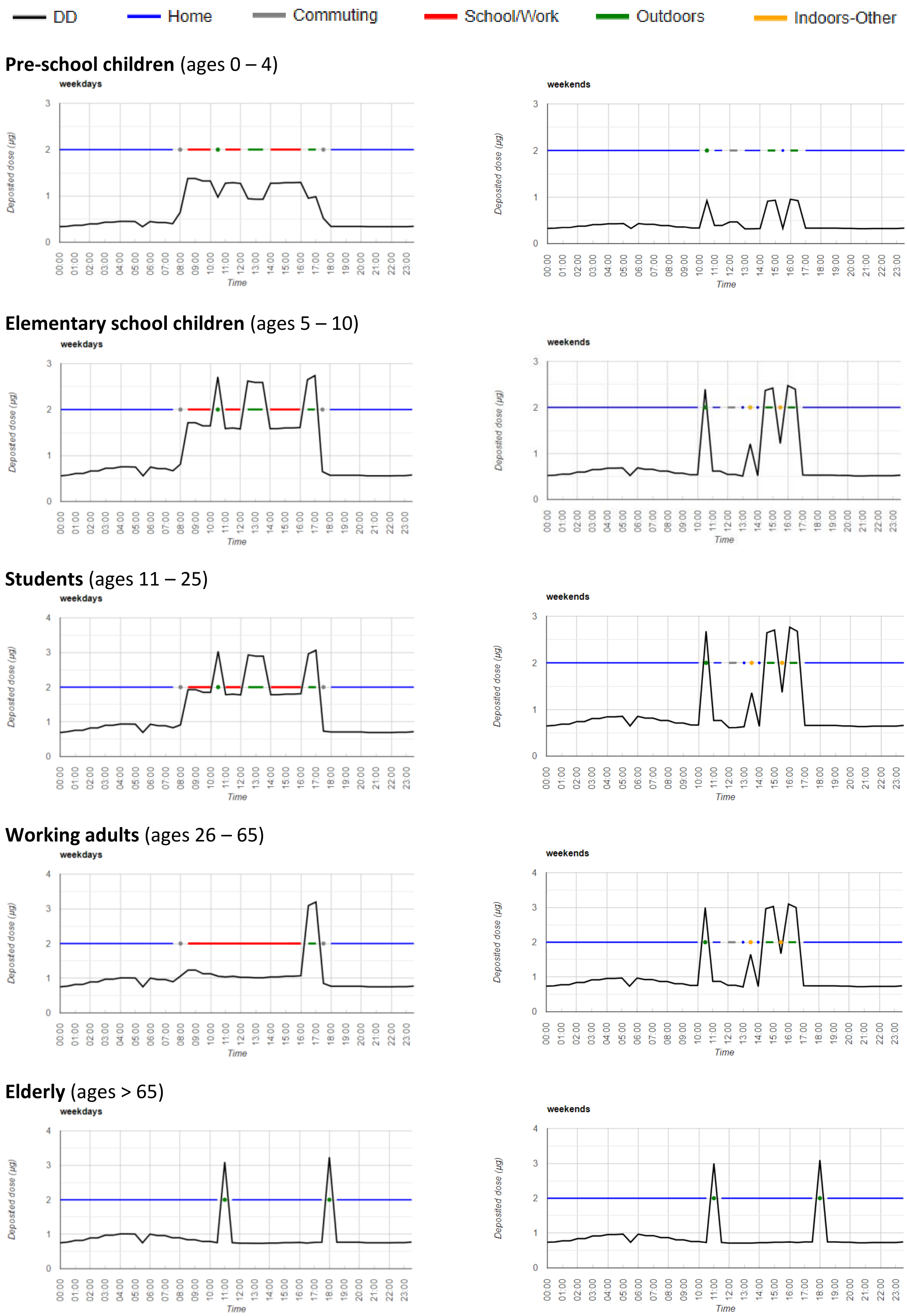


Figure 3.8 – PM2.5 dose (in all regions) throughout the day for each population group in Lisbon metropolitan area.

- The distribution of the PM2.5 deposited dose in the different regions of the human respiratory tract (HRT) is represented in Figure 3.9.
- For pre-school children the highest amount of PM2.5 deposited on the upper airways (anterior nasal passages – ET1), while for the remaining population sub-groups was on the lower airways (terminal bronchiole), which consists of respiratory bronchioles, alveolar ducts, alveolar sacs, and alveoli.
- The lowest PM2.5 deposited doses were obtained in the BB region for all population sub-groups.
- Due to the highest PM2.5 deposited dose during the weekdays, the students presented the highest PM2.5 deposited dose along one year, followed by working adults, elementary school children, elderly and pre-school children.

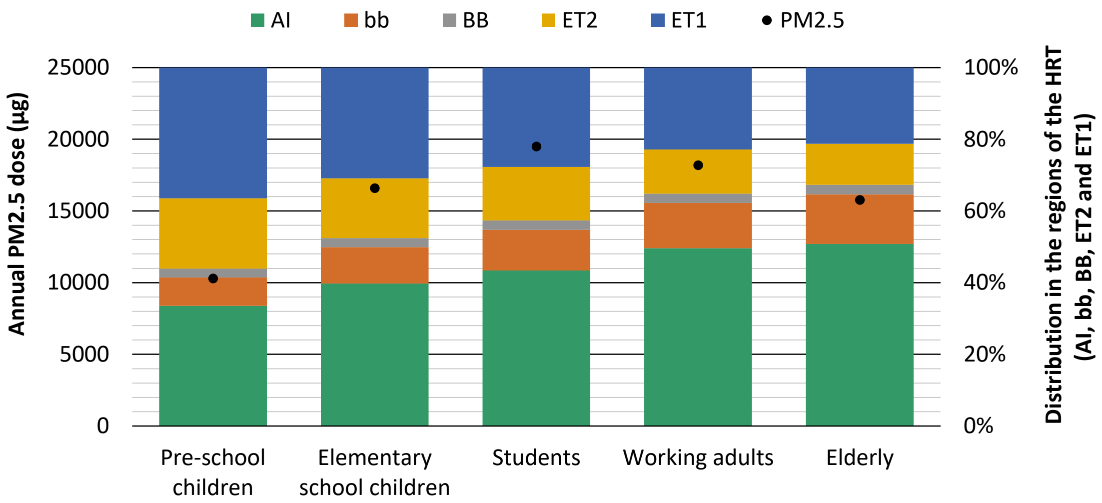


Figure 3.9 – Annual cumulative dose for PM2.5 (µg) and its distribution in the different regions of the HRT for each population group in Lisbon metropolitan area.

- The comparison of the PM10 and PM2.5 deposited dose highlights the low penetration of the coarser particles through the lower respiratory regions. In fact, most of the particles larger than 2.5 µm deposited in the extra-thoracic regions, ET1 and ET2.

Burden of Disease

- The health impacts associated with exposure to PM2.5 concentration levels in 2015 were estimated using Burden of Disease (BoD) methods.
- BoD is a comparable metric to measure health losses, including both premature mortality and morbidity. In addition, estimates for sick days and school absenteeism are provided for elementary school children.
- BoD parameters are provided as a total for the whole city, as well as spatially distributed across the city.

- As shown in Table 3.4, BoD is quantified based on Upper Respiratory Infections in the case of the children population groups (pre-school children and elementary school children) and on Natural Mortality in the case of adults over 25 years old (working adults and elderly).
- BoD is measured in disability adjusted life years (DALY), which is calculated as the sum of years of life lost due to premature mortality (YLL) and disability weighted years lived with disabilities (YLD), and may be expressed in YLL, YLD, DALY, or in number of deaths.
- In metropolitan area of Lisbon, for children and adults was estimated 1.30 and 51000 DALY attributed to PM2.5 exposure.
- The YLL and YLD estimations for adults over 25 years old were 32000 and 19000, respectively, whereas for children were overlooked.
- In total, 2000 premature deaths were attributed to PM2.5 exposure in 2015.

Table 3.4 – Upper respiratory infections and natural mortality per population sub-group in Lisbon metropolitan area.

	Upper Respiratory Infections			Natural Mortality		
	Pre-school children	Elementary school children	All groups	Working adults	Elderly	All groups
DALY	0.61	0.69	1.30	23000	28000	51000
YLL	0.00	0.02	0.02	11000	21000	32000
YLD	0.61	0.67	1.30	11000	7200	19000
Deaths	0.00	0.00	0.00	320	1700	2000
Sick days (mild)	–	6400.00	–	–	–	–
Sick days (moderate)	–	4000.00	–	–	–	–
Sick days (severe)	–	80.00	–	–	–	–
Days of school absenteeism	–	2000.00	–	–	–	–
Total sick days	–	11000.00	–	–	–	–

BUILT-UP OF POLICY MAKING SCENARIOS

The builder scenarios are based on ANN algorithms. This is an approximation that causes a bias error on the result. The results of base case from CAMx model is not exactly equal to the ones obtained with ANN. For this reason, the modified scenarios outputs are compared with the base outputs obtained with the ANN algorithms.

The assessment of the modified scenarios/mitigation measures is performed by comparing the modified outputs for air quality, population exposure, deposited dose and burden of disease with the respective outputs for the base case. The mitigation measures tested in the tool are indicated in Table 2.1.

PM AMBIENT CONCENTRATIONS

- Relative changes (%) in PM10 and PM2.5 concentrations between the reference case and the modified scenarios (S1 – S10) are indicated in Table 3.5. The base case values are in $\mu g/m^3$.
- The PM10 and PM2.5 concentrations are different among modified scenarios.
- In Lisbon municipality, the highest relative changes for PM10 concentrations were observed for scenario S4, where the apportionment (%) of passenger cars in terms of European emission standards was changed. Considering that 50% of cars are EURO V and 50% are EURO VI the average PM10 concentrations may have reductions from 3 to 8 $\mu g/m^3$ comparing with the reference case.
- The total electrification of the passenger cars (scenario S2) had the highest impact in the average PM2.5 concentrations in both Lisbon municipality (up to 3 $\mu g/m^3$ of reduction) and the other municipalities of the metropolitan area of Lisbon (up to 1 $\mu g/m^3$), as well as in the average PM10 concentrations in the other municipalities of the metropolitan area of Lisbon (up to 3 $\mu g/m^3$).
- The PM concentration reductions obtained for cars fleet scenarios were more relevant during the winter period and less during the summer.
- The modified scenarios applied to buses fleet (S5 and S6) and cruise ships (S9 and S10) did not seem affect the average PM concentrations in both Lisbon municipality and other municipalities of the metropolitan area of Lisbon. The impact of these scenarios may be detected mainly on local area. Thus, the spatial resolution of 1 x 1 km^2 used in the tool may not be sensible to these local variations. Future work should focus on this issue.
- Changes in the cars fleet (S1-S4) seem to have higher impact on PM concentrations in Lisbon municipality than in the other municipalities of the metropolitan area of Lisbon, while for residential heating scenarios (S7 and S8) happens the opposite. These results were expected because traffic is more intense in Lisbon city centre and the residential heating is more common in rural areas.

Table 3.5 – Relative changes (%) in PM10 and PM2.5 concentrations between the reference case and the modified scenarios (S1 – S10) in Lisbon.

		Base	Road traffic						Residential heating		Cruise ships	
		Reference	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
		µg/m³	Relative changes (%) in PM concentrations									
LISBON MUNICIPALITY												
PM10	Annual	25	-17.4	-18.2	-7.7	-18.8	*	*	-4.6	*	*	*
	Winter	41	-18.0	-18.8	-8.2	-19.3	*	*	-4.7	*	*	*
	Summer	16	-16.7	-17.2	-7.2	-17.9	*	*	-4.5	*	*	*
	Spring	25	-17.5	-18.1	-7.8	-18.7	*	*	-4.6	*	*	*
	Autumn	24	-17.6	-18.4	-7.9	-18.9	*	*	-4.7	*	*	*
PM2.5	Annual	14	-13.5	-13.9	-6.3	-12.9	*	*	-2.5	*	*	*
	Winter	23	-13.9	-14.2	-6.6	-13.2	*	*	-2.6	*	*	*
	Summer	9	-12.9	-13.4	-6.0	-12.3	*	*	-2.4	*	*	*
	Spring	14	-13.5	-13.9	-6.4	-12.9	*	*	-2.5	*	*	*
	Autumn	13	-13.7	-14.1	-6.5	-13.1	*	*	-2.6	*	*	*
OTHER MUNICIPALITIES OF THE METROPOLITAN AREA OF LISBON												
PM10	Annual	18	-7.1	-7.7	-3.4	-6.3	*	*	-7.7	-2.9	*	*
	Winter	35	-7.1	-7.7	-3.5	-6.3	*	*	-7.7	-2.9	*	*
	Summer	9	-7.0	-7.6	-3.3	-6.2	*	*	-7.7	-2.9	*	*
	Spring	18	-7.0	-7.6	-3.4	-6.3	*	*	-7.7	-2.9	*	*
	Autumn	17	-7.1	-7.7	-3.4	-6.3	*	*	-7.6	-2.9	*	*
PM2.5	Annual	10	-5.7	-5.9	-3.0	-5.3	*	*	-4.4	*	*	*
	Winter	19	-5.5	-5.8	-2.9	-5.2	*	*	-4.4	*	*	*
	Summer	5	-5.8	-6.0	-2.9	-5.4	*	*	-4.3	*	*	*
	Spring	10	-5.6	-5.9	-2.9	-5.2	*	*	-4.3	*	*	*
	Autumn	9	-5.8	-6.0	-2.9	-5.4	*	*	-4.3	*	*	*

∗ Value is within the range of uncertainty of the Tool (± 2%).

POPULATION EXPOSURE

- Relative changes (%) in PM10 and PM2.5 population exposure between the reference case and the modified scenarios (S1 – S10) are indicated in Table 3.6. The base case values are in µg/m³ · nop.
- According to the PM ambient concentrations, the PM10 and PM2.5 population exposure are also different among modified scenarios.
- The total electrification of the passenger cars (scenario S2) had the highest impact in the average PM10 and PM2.5 population exposure in both Lisbon municipality and the other municipalities of the metropolitan area of Lisbon (up to 20000 µg/m³ · nop of reduction).
- In Lisbon municipality, the highest relative changes for PM10 and PM2.5 population exposure were observed for working adults mainly for cars fleet scenarios (S1 – S4).
- In general, the differences in PM2.5 exposure between the reference case and the modified scenarios were lower for elderly sub-group than for the remaining sub-groups in both Lisbon municipality and other municipalities of the metropolitan area of Lisbon. The differences in PM10 exposure for elderly were among the highest.

- As observed for PM ambient concentrations, changes in the cars fleet (S1-S4) seem to have higher impact on PM population exposure in Lisbon municipality than in the other municipalities of the metropolitan area of Lisbon, while for residential heating scenarios (S7 and S8) happens the opposite.

Table 3.6 – Relative changes (%) in PM10 and PM2.5 population exposure between the reference case and the modified scenarios (S1 – S10) in Lisbon.

		Base	Road traffic						Residential heating		Cruise ships	
		Reference	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
		µg/m³ · nop	**Relative changes (%) in PM population exposure**									
LISBON MUNICIPALITY												
PM10	All groups	120000	-16.7	-16.7	-8.3	-16.7	*	*	*	*	*	*
	Pre-school children	5933	-11.9	-15.3	-6.8	-13.6	*	*	*	*	*	*
	Elementary school children	5633	-12.5	-16.1	-7.1	-14.3	*	*	*	*	*	*
	Students	18333	-11.1	-11.1	-5.6	-11.1	5.6	*	*	*	*	*
	Working adults	59667	-13.6	-16.9	-6.8	-16.9	*	*	-3.3	*	*	*
	Elderly	24667	-12.5	-12.5	-4.2	-12.5	4.2	*	-4.0	-4.0	*	-4.0
PM2.5	All groups	77333	-10.3	-10.3	-5.1	-9.0	*	*	*	*	*	*
	Pre-school children	3600	-11.1	-11.1	-5.6	-8.3	*	*	-2.8	*	*	-2.8
	Elementary school children	3433	-11.4	-11.4	-5.7	-11.4	*	*	*	*	*	*
	Students	11000	-9.1	-9.1	*	-9.1	*	*	*	*	*	*
	Working adults	38333	-12.8	-12.8	-7.7	-10.3	*	-2.6	*	*	*	*
	Elderly	17000	-5.9	-5.9	-5.9	-5.9	*	*	*	*	*	*
OTHER MUNICIPALITIES OF THE METROPOLITAN AREA OF LISBON												
PM10	All groups	30000	-10.0	-10.0	-3.3	-6.7	*	*	-6.7	-3.3	*	*
	Pre-school children	1800	-11.1	-11.1	-5.6	-5.6	*	*	-5.6	-5.6	*	*
	Elementary school children	1733	-5.9	-5.9	*	-5.9	*	*	-5.9	*	*	*
	Students	5233	-7.7	-7.7	*	-5.8	*	*	-3.8	*	*	*
	Working adults	15000	-6.7	-6.7	-6.7	-6.7	*	*	-6.7	*	*	*
	Elderly	4267	-11.6	-11.6	-4.7	-9.3	-2.3	*	-4.8	-2.4	*	*
PM2.5	All groups	19000	-5.3	-5.3	*	-5.3	*	*	*	*	*	*
	Pre-school children	1100	-9.1	-9.1	-9.1	-9.1	*	*	-9.1	*	*	*
	Elementary school children	1100	-9.1	-9.1	-9.1	-9.1	*	*	-9.1	-9.1	*	*
	Students	3200	-3.1	-6.3	-3.1	-3.1	*	*	-3.1	*	*	*
	Working adults	9833	-7.1	-7.1	-3.0	-6.1	*	*	-4.1	*	*	*
	Elderly	3000	-3.3	-3.3	*	-3.3	*	*	-3.3	*	*	*

* Value is within the range of uncertainty of the Tool (± 2%).

Deposited Dose

- Relative changes (%) in PM10 and PM2.5 deposited dose between the reference case and the modified scenarios (S1 – S10) are indicated in Table 3.7. The base case values are in µg.
- Reduction in the PM10 and PM2.5 deposited dose were observed for the scenarios applied to the cars fleet (S1 – S4) and to the first scenario related to the residential heating (S7),

which considers the total replacement of conventional residential fireplaces (open fireplaces), woodstoves, and salamander stoves by more efficient fireplaces.

- The highest relative changes for PM10 and PM2.5 deposited dose were observed for working adults, while the lowest reductions were for pre-school children.

Table 3.7 – Relative changes (%) in PM10 and PM2.5 deposited dose between the reference case and the modified scenarios (S1 – S10) in Lisbon.

		LISBON METROPOLITAN AREA										
		Base	Road traffic						Residential heating		Cruise ships	
		Reference	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
		µg	Relative changes (%) in PM deposited dose									
PM10	Pre-school children	23681	-4.4	-4.7	-2.1	-4.1	*	*	-3.9	*	*	*
	Elementary school children	41879	-4.9	-5.2	-2.3	-4.5	*	*	-4.3	*	*	*
	Students	51292	-4.8	-5.2	-2.3	-4.5	*	*	-4.3	*	*	*
	Working adults	37770	-5.7	-6.1	-2.7	-5.3	*	*	-5.1	*	*	*
	Elderly	30711	-5.2	-5.6	-2.4	-4.8	*	*	-4.6	*	*	*
PM2.5	Pre-school children	10356	-4.7	-5.0	-2.2	-4.3	*	*	-4.1	*	*	*
	Elementary school children	16691	-5.1	-5.5	-2.4	-4.7	*	*	-4.5	*	*	*
	Students	19615	-5.1	-5.4	-2.4	-4.7	*	*	-4.5	*	*	*
	Working adults	18324	-5.7	-6.1	-2.7	-5.3	*	*	-5.1	*	*	*
	Elderly	15874	-5.1	-5.4	-2.4	-4.7	*	*	-4.5	*	*	*

∗ Value is within the range of uncertainty of the Tool (± 2%).

BURDEN OF DISEASE

- Relative changes (%) in health impacts due to exposure to PM2.5 between the reference case and the modified scenarios (S1 – S10) are indicated in Table 3.8. The base case values are in number.
- Changes in the buses fleet (S5 and S6) and cruise ships (S9 and S10) have negligible effects on health impacts (most of the values are within the range of uncertainty of the Tool).
- Among the modified scenarios applied to cars fleet (S1 – S4) and residential heating (S7 and S8), the elementary school children can have a reduction of the number of sick days and days of school absenteeism of up to 1000 (S1 and S2) and 200 (S1, S2 and S4), respectively.
- The population of the Lisbon metropolitan area can have reductions of up to:
  - 200 deaths (S1, S2 and S4);
  - 6000 disability adjusted life years (S2);
  - 3000 years of life lost due to premature mortality (S1, S2 and S4);
  - 2000 disability weighted years lived with disabilities (S1, S2 and S4);

Table 3.8 – Relative changes (%) in health impacts due to exposure to PM2.5 between the reference case and the modified scenarios (S1 – S10) in Lisbon.

		LISBON METROPOLITAN AREA										
		Base	Road traffic						Residential heating		Cruise ships	
		Reference	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
		no.	Relative changes (%) in health impacts due to exposure to PM2.5									
Upper respiratory infections - Elementary school children	Sick days (mild)	6100	-9.8	-9.8	-4.9	-8.2	*	*	-6.6	-3.3	*	*
	Sick days (moderate)	3800	-10.5	-10.5	-5.3	-7.9	*	*	-5.3	-2.6	*	*
	Sick days (severe)	76	-9.2	-10.5	-3.9	-9.2	*	*	-5.3	-2.6	*	*
	Days of school absenteeism	1900	-10.5	-10.5	-5.3	-10.5	*	*	-5.3	*	*	*
	Total sick days	9933	-10.0	-10.0	-5.0	-9.0	*	*	-5.1	-2.0	*	*
Natural Mortality - all groups	DALY	49000	-10.2	-12.2	-6.1	-10.2	*	*	-6.1	-2.0	*	-2.0
	YLL	31000	-9.7	-9.7	-6.5	-9.7	*	*	-6.5	-3.2	*	*
	YLD	18000	-11.1	-11.1	-5.6	-11.1	*	*	-5.6	-5.6	*	*
	Deaths	1900	-10.5	-10.5	-5.3	-10.5	*	*	-5.3	*	*	*

* Value is within the range of uncertainty of the Tool (± 2%).

4. IMPLEMENTATION OF THE MANAGEMENT TOOL IN PORTO

CHARACTERISATION OF PORTO

PHYSICAL GEOGRAPHY

The Metropolitan Area of Porto is the second largest metropolitan area of Portugal, it is located at a latitude of 41°10′N and a longitude of 8°40′E (Pereira et al., 2007). It is located on the North Coast of Portugal and has a geographical area of 2041 Km^2 which includes 17 municipalities. The municipality of Porto has an area of 41.4 km^2.The region is limited on the west by the Atlantic Ocean with 50 km of coastline, and is crossed by the Douro River. Topographically the zone is rather uneven, with a maximum altitude of about 300 m that decreases with proximity to the coast (Pereira et al., 2007).

DEMOGRAPHY

Porto Metropolitan Area is the second most populous Portuguese region, with about 1.72 million inhabitants and a population density of 842 inhabitants/km^2. Approximately 237,591 people are resident in Porto municipality (based on AMPorto navigation data).

CLIMATE

The proximity of this area to the Azores Anticyclone and the rapidly advancing depressions associated with movements of the Polar Front affect the weather. It is influenced by the two different types of air masses, warm and humid, from the subtropics and polar zone (Pereira et al., 2007). The mean temperature in Porto ranges from 9ºC to 19ºC (in 2019) (based on Tempo.net navigation data), the annual air humidity is between 75% and 80% (in 2003), and the total annual mean precipitation varies from 1000 mm to 1200 mm (in 2003). The winds are predominantly from the west and northwest (Pereira et al., 2007).

TRANSPORT

Road

In 2017, from a total of 3.426 million travels per day, about 1.738 million were carried out by car and 232,647 thousand were travelling by bus. The congestion level, in 2019, was 31%, 3% higher since 2018, for which 21% are in highways and 36% are in other roads. According to the statistics, the worst time to travel in Porto is on weekdays between 8 AM and 9 AM from 5 PM to 7 PM with numbers between 50% and 76% (based on TomTom navigation data).

Rail

The rail public transports used by the population of Porto are subway and train, which accounted for 67 707 and 27 173 thousand travels in 2017, respectively.

Maritime

Port of Leixões is located at 3 km from the city of Porto on north of the mouth of the Douro River. It receives around 80 000 passengers annually in cruise ships.

Air

Porto airport also known as Francisco Sá Carneiro Airport, is currently the second-busiest airport in the country. It is surrounded by the municipalities of Matosinhos (to the south and west), Vila do Conde (to the north) and Maia (to the east). In 2019, 13.1 million passengers have been welcomed at Porto airport (VINCI Airports statistics, 2021).

INDUSTRY

Porto is at the forefront of the Portuguese creative industries, especially in design-based consumer goods for the textile, clothing, footwear, cork, accessories, furniture, wine and jewellery sectors, metallurgy, and also medium- and high-tech sectors, particularly automotive and machinery. Moreover, in Porto there is a high industrial density composed of an oil refinery, a petrochemical plant, a thermoelectric plant with natural gas and an incineration unit (Pereira et al., 2007).

ATMOSPHERIC POLLUTION

The air pollution problems in Porto result from emission sources located in the central area of the city and in the industrial belt in the north. The industrial belt in the North, spread over the municipalities of Matosinhos and Maia, that includes an important industrial source of SO_2 which is the oil refinery near the port of Leixões (Pinho, 1997).

The concentration of pollutants is usually lower compared to the high levels of emission, this effect is due to the characteristics of the city such as its location on the map, in which its good exposure to moderate marine winds pollutants are dispersed, only on days where the winds are weak is when the concentration of pollutants are higher such as SO2 (from factories) or NOx or CO (from the car flow) and the particles tend to stay in the more compact areas of the city centre of Porto (Pinho, 1997).

According to a source apportionment study conducted at a traffic site in Porto (Figure 4.1), the major contributor to PM10 and PM2.5 concentrations is vehicular traffic (23% for PM10 and 32% for PM2.5). A significant contribution from biomass burning (12% for PM10 and 17% for PM2.5), mineral (18% for PM10 and 15% for PM2.5) and heavy oil and secondary (10% for PM10 and 13% for PM2.5) was also identified. Additionally, the contribution from fresh sea salt was also very significant for PM10 (16%).

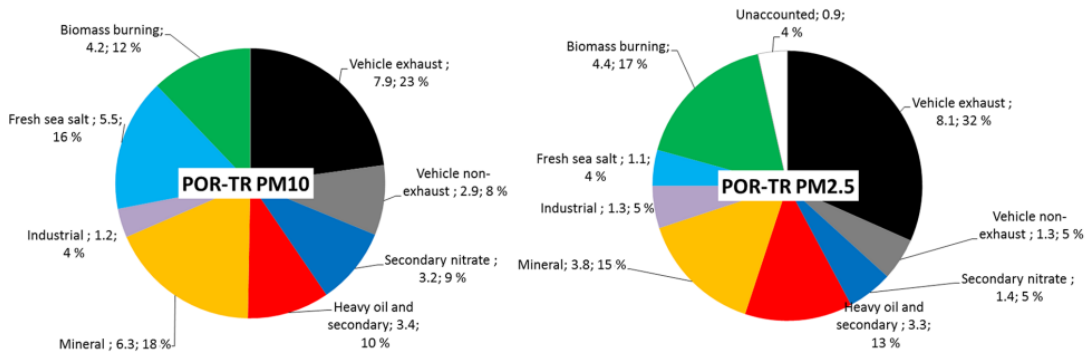


Figure 4.1 – Contribution (in μg/m^3 and as % of total) of major sources to PM10 and PM2.5 concentrations measured at a suburban site in Porto, Portugal (Amato et al., 2016).

Base case

The base case scenario corresponds to the air quality condition verified over the city of Porto in the year 2015. The base case is based on the CAMx model integrated with the data obtained in the air monitoring stations.

Emissions

Porto municipality

- Figure 4.2 shows the Porto municipality emissions in 2015, for the main gas pollutants (NH_3, NOx, SO_2 and VOC), particulate matter (PM10 and PM2.5) and heavy metals (As, Cd, Ni and Pb), per activity sector.
- The "road transport" sector was the largest source of NH_3 (55%), NOx (93%), PM10 (58%), PM2.5 (60%), As (95%), Cd (57%) and Ni (98%) emissions.
- "Solvent and other product use" sector was the largest source of VOC (52%).
- Both "Combustion in manufacturing industry & Production processes" and "Waste treatment and disposal" sector contributed to 50% of Pb emissions.
- Non-industrial combustion plants sector was the largest source of SO_2 (54%).

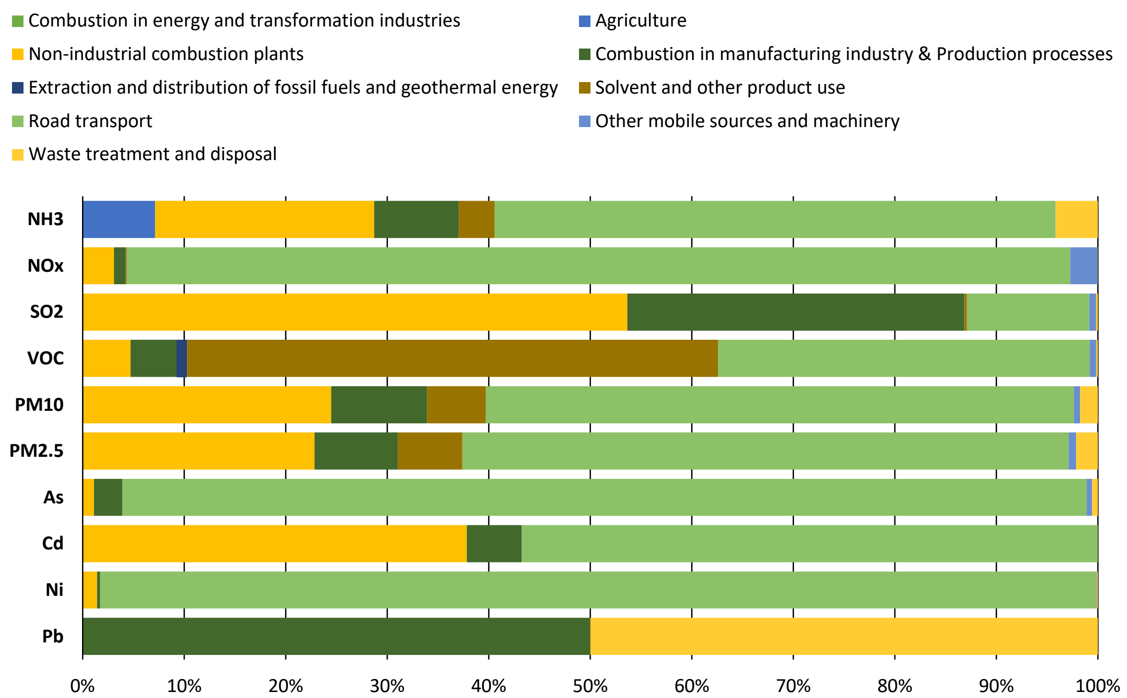


Figure 4.2 – Share of Porto municipality emissions (in %) of the main pollutants, by sector group in 2015.

Other municipalities of the metropolitan area of Porto

- Figure 4.3 shows the Porto metropolitan area (excluding the Porto municipality) emissions in 2015, for the main gas pollutants (NH_3, NOx, SO_2 and VOC), particulate matter (PM10 and PM2.5) and heavy metals (As, Cd, Ni and Pb), per activity sector.

- The "combustion in manufacturing industry & production processes" sector group was the largest contributor to total emissions of SO_2 (65%) and heavy metals (56% for As, 72% for Cd, 83% for Ni and 62% for Pb).
- The "Agriculture" sector contributed to 80% of NH3 emissions.
- Road transport was the largest source of NO_X (60%).
- The sector that presented the highest contribution for PM (39% for PM10 and 38% for PM2.5) was the "Non-industrial combustion plants", followed by "Combustion in manufacturing industry & Production processes" (30% for PM10 and 27% for PM2.5) and "road transport" (18% for PM10 and 20% for PM2.5). The "Non-industrial combustion plants" sector includes the residential, institutional and commercial plants.
- "Solvent and other product use" was the largest source of VOC (37%).
- Most of the pollutant emissions from combustion processes, which includes "combustion in manufacturing industry & production processes" and "non-industrial combustion plants" sectors, come from the other municipalities of the metropolitan area of Porto.

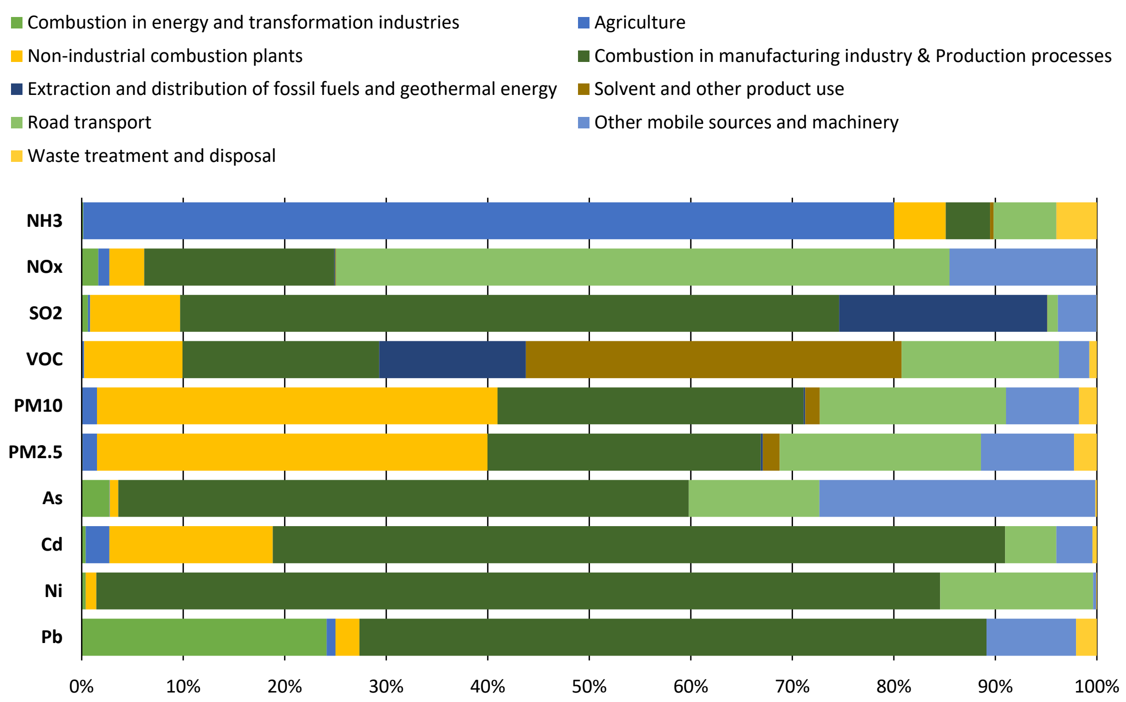


Figure 4.3 – Share of Porto metropolitan area (excluding the Porto municipality) emissions (in %) of the main pollutants, by sector group in 2015.

- In the other municipalities of the metropolitan area of Porto are observed higher pollutant emissions (Table 4.1) than in the municipality of Porto.
- In Porto municipality, the VOC showed the highest total emission of 2015 (5735 t/year) followed by NOx (2583 t/year).
- Similarly, in the other municipalities of the metropolitan area of Porto, the VOC had the highest total emission (56755 t/year) followed by NOx (16549 t/year).

- Regarding the heavy metals, in both Porto municipality and other municipalities of the metropolitan area of Porto the highest emissions were registered for Ni, with values of 204 and 5775 kg/year, respectively.

Table 4.1 – Total emissions of the main pollutants in 2015 for the Porto municipality and the other municipalities of the metropolitan area of Porto.

	NH_3	NOx	SO_2	VOC	PM10	PM2.5	As	Cd	Ni	Pb
	Total									
	t/year						kg/year			
Porto Municipality	74	2583	30	5735	328	268	18	4	204	0
Other municipalities of the metropolitan area of Porto	2754	16549	1464	56755	4309	3379	552	180	5775	34

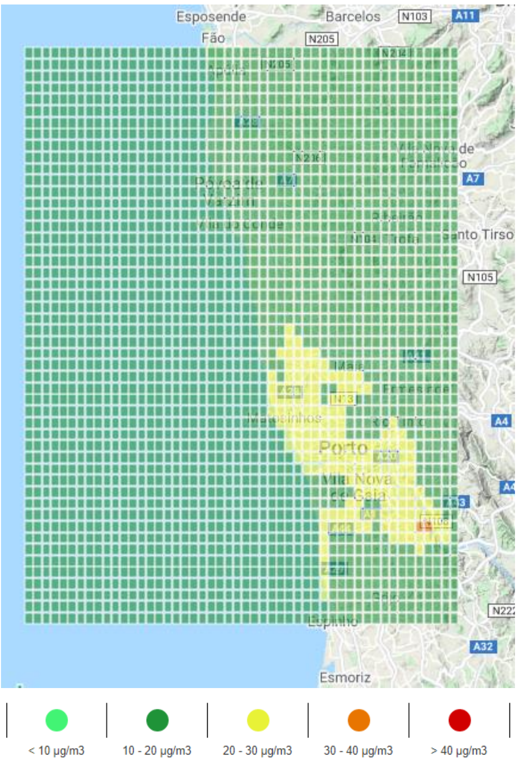
AMBIENT CONCENTRATIONS

- PM10 annual average concentration in Porto Municipality was 21 µg/m^3. The worst annual average concentration was 22 µg/m^3, which did not exceed the annual limit value of 40 µg/m^3 defined by the EU Directive. However, both average and maximum values were higher than the guideline defined by the WHO (20 µg/m^3).
- PM10 annual average concentration in the other municipalities of the metropolitan area of Porto was 16 µg/m^3 and the highest average concentration was 38 µg/m^3. This maximum value exceeded the annual guideline defined by the WHO.
- PM2.5 annual average concentration in Porto Municipality was 5 µg/m^3. Both average and maximum values did not exceed the annual limit value defined by the EU Directive (25 µg/m^3) and the guideline defined by the WHO (10 µg/m^3).
- PM2.5 annual average concentration in the other municipalities of the metropolitan area of Porto was 4 µg/m^3 and the highest average concentration was 8 µg/m^3.
- In Porto municipality the annual mean concentrations of As (0.34 ng/m^3), Cd (0.10 ng/m^3) and Ni (2.24 ng/m^3) did not exceeded neither the target values established by the EU Directive (6, 5 and 20 ng/m^3 for As, Cd and Ni, respectively) nor the WHO estimated reference levels for As (6.6 ng/m^3) and Ni (25 ng/m^3) and the WHO air quality guideline for Cd (5 ng/m^3). The annual mean Pb concentration (5.87 ng/m^3) was much lower than the EU Directive limit value and WHO air quality guideline of 0.5 µg/m^3.
- In the other municipalities of the metropolitan area of Porto the annual mean concentrations of As (0.28 ng/m^3), Cd (0.08 ng/m^3), Ni (1.55 ng/m^3) and Pb (4.66 ng/m^3) were lower than those obtained in Porto municipality.
- On average, for Porto municipality, the ambient mean concentrations of both PM10 and PM2.5 in winter were 46% higher than in summer. For heavy metals, the mean concentrations in winter were between 20% (for Cd) and 30% (for Pb) higher than in summer. The high concentrations in winter can be attributed not only to additional emission sources, such as domestic wood combustion for residential heating, but also to natural phenomenon of thermal inversion that limits the pollutants dispersion.
- For the other municipalities of the metropolitan area of Porto, the PM10 and PM2.5 ambient mean concentrations in winter were 55% higher than in summer. For heavy metals, the

mean concentrations in winter were between 29% (for Pb) and 45% (for Cd) higher than in summer.

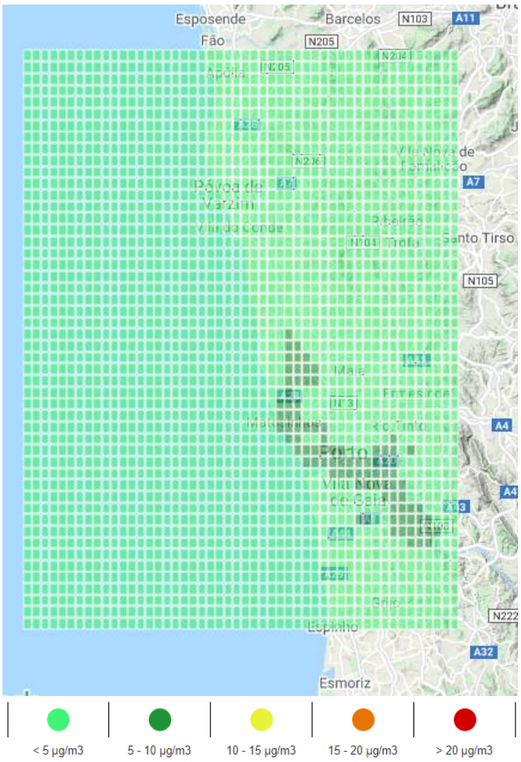
- Observing the Ni map in Figure 4.4, it is shown that the highest Ni concentrations occur at the sea mainly because of the shipping emissions.

PM10



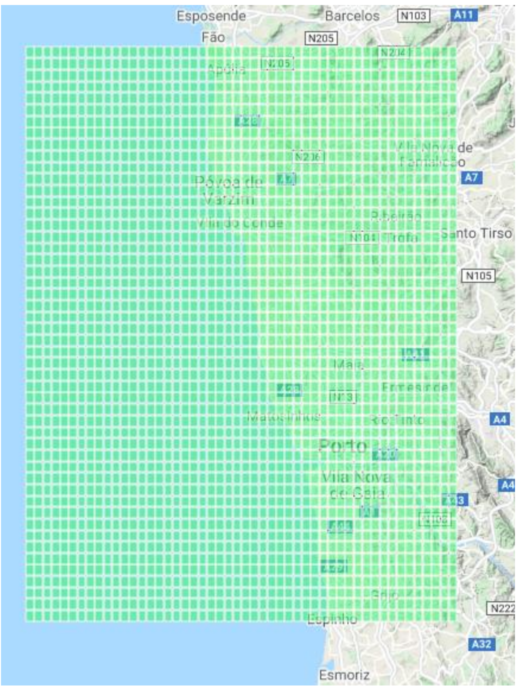
	Average	Minimum	Maximum
Porto Municipality	20.87	18.91	22.15
Other municipalities of the metropolitan area of Porto	16.20	11.68	37.87

PM2.5

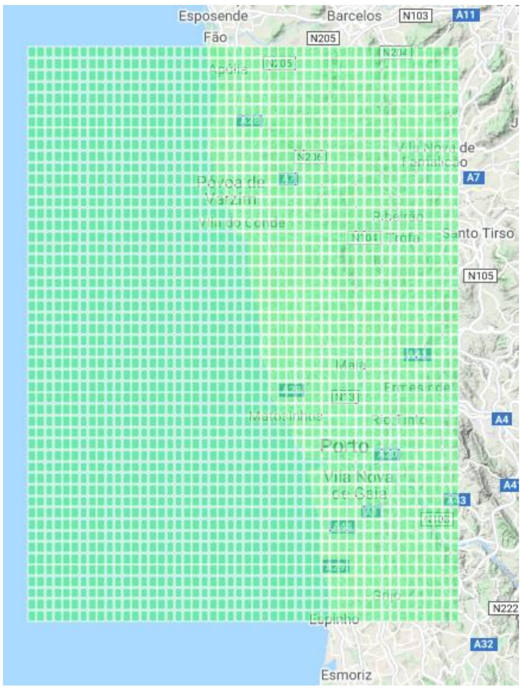


	Average	Minimum	Maximum
Porto Municipality	5.04	4.59	5.34
Other municipalities of the metropolitan area of Porto	3.95	2.90	8.02

As



Cd



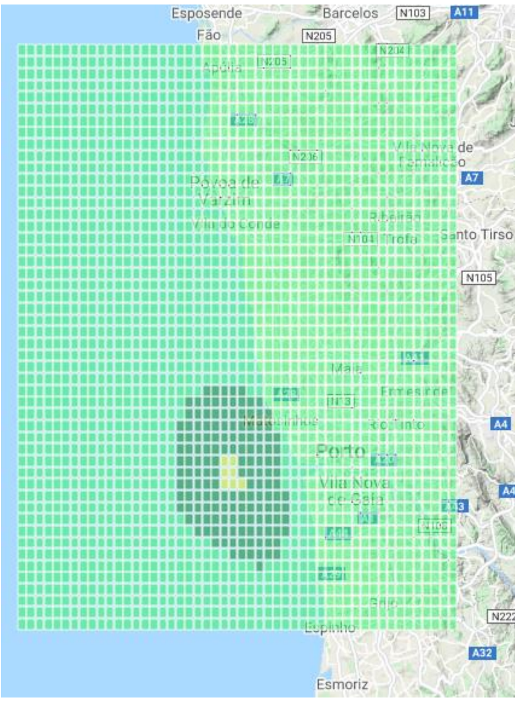
< 1.5 ng/m3	1.5 - 3.0 ng/m3	3.0 - 4.5 ng/m3	4.5 - 6.0 ng/m3	> 6.0 ng/m3

	Average	Minimum	Maximum
Porto Municipality	0.34	0.29	0.48
Other municipalities of the metropolitan area of Porto	0.28	0.20	0.96

< 0.5 ng/m3	0.5 - 2.0 ng/m3	2.0 - 3.5 ng/m3	3.5 - 5.0 ng/m3	> 5.0 ng/m3

	Average	Minimum	Maximum
Porto Municipality	0.10	0.08	0.12
Other municipalities of the metropolitan area of Porto	0.08	0.04	0.60

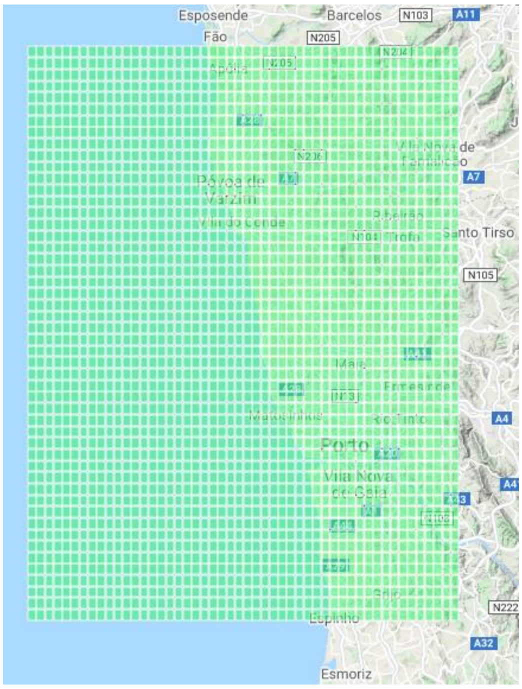
Ni



< 5 ng/m3	5 - 10 ng/m3	10 - 15 ng/m3	15 - 20 ng/m3	> 20 ng/m3

	Average	Minimum	Maximum
Porto Municipality	2.24	1.73	3.91
Other municipalities of the metropolitan area of Porto	1.55	0.91	6.68

Pb



< 125 ng/m3	125 - 250 ng/m3	250 - 375 ng/m3	375 - 500 ng/m3	> 500 ng/m3

	Average	Minimum	Maximum
Porto Municipality	5.87	3.85	9.11
Other municipalities of the metropolitan area of Porto	4.66	1.48	108.04

Figure 4.4 – Annual average ambient concentrations of PM (in µg/m^3) and heavy metals (in ng/m^3) in Porto.

PM10 Exceedances

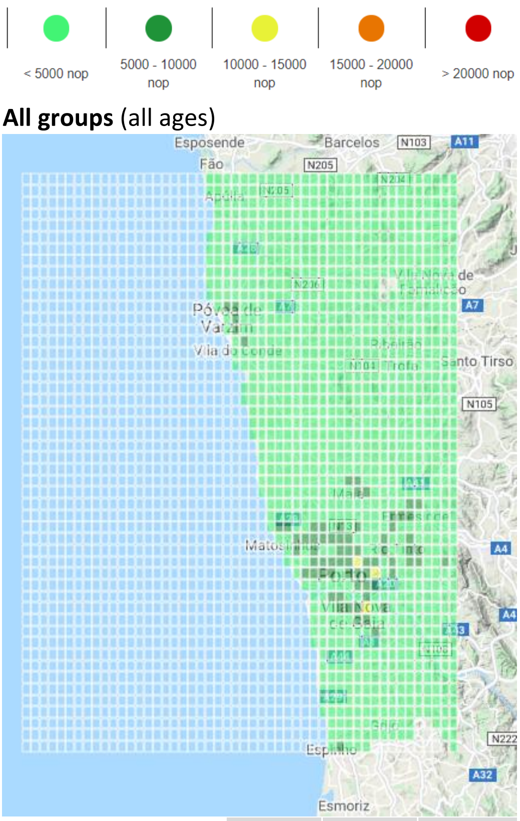
- For PM10, the current EU legislation defined in the Directive 2008/50/EC, with the objective of protecting human health and the environment, presents a daily limit value of 50 µg/m^3, which should not be exceeded more than 35 times a year.
- In Porto Municipality this EU air quality standard was exceeded in some cells, being the worst condition registered in a cell where a maximum of 13 days showed a daily average value higher than 50 µg/m^3 (Table 4.2).
- In the other municipalities of the metropolitan area of Porto this indicator was also not fulfilled in some cells, occurring a maximum of 76 exceedance days during the year in the worst cell (Table 4.2).

Table 4.2 – Number of PM10 exceedance days in 2015 for Porto.

	Minimum	Maximum
Porto Municipality	2	13
Other municipalities of the metropolitan area of Porto	0	76

POPULATION GROUPS

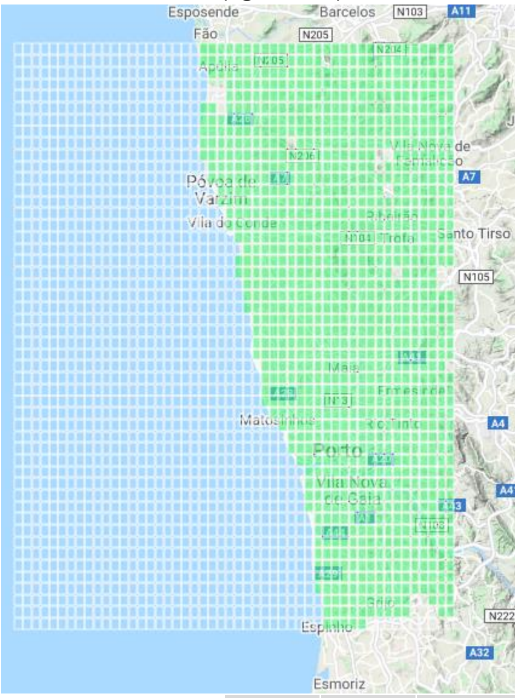
- The population in the study area was divided into 5 age groups characterised by different inhalation rates, activities and responses to the air pollution.
- Mean population density in Porto Municipality is 4864 inhabitants per km^2 (Figure 4.5).
- In Porto Municipality the largest fraction (54%) of the population is in the range 26-65 years old (working adults), 24% are elderly people and the remaining population are children and adolescents under 26. The latter are divided into students (15%, 11-25 years old), elementary school children (4%, 5-10 years old) and pre-school children (3%, <5 years old).
- The other municipalities of the metropolitan area of Porto have a mean population density of 1077 inhabitants per km^2, with a population distribution similar to that in the Porto Municipality for working adults (58%), students (17%), pre-school (5%) and elementary school (5%) children. The elderly people are slightly smaller (15%).



	Average	Minimum	Maximum
Porto Municipality	4864	0	10506
Other municipalities of the metropolitan area of Porto	1077	0	11233

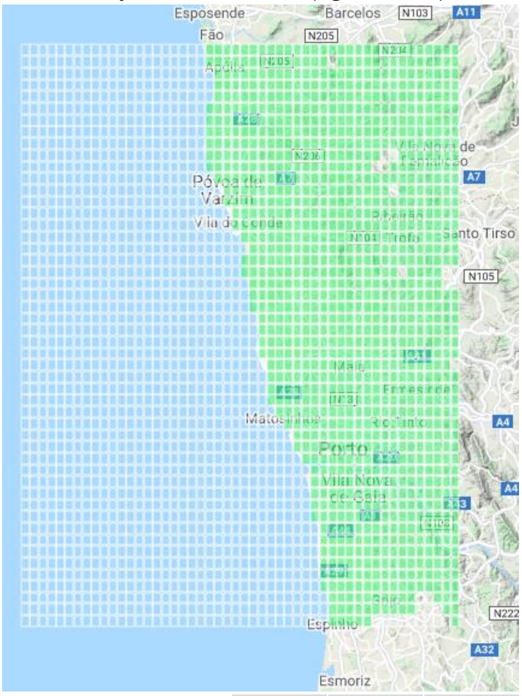
Figure 4.5 – Map with spatial distribution (1 km x 1 km) of all population across Porto, expressed in number of people (nop). The average, minimum and maximum population densities are expressed in nop/km^2.

Pre-school children (ages 0 – 4)



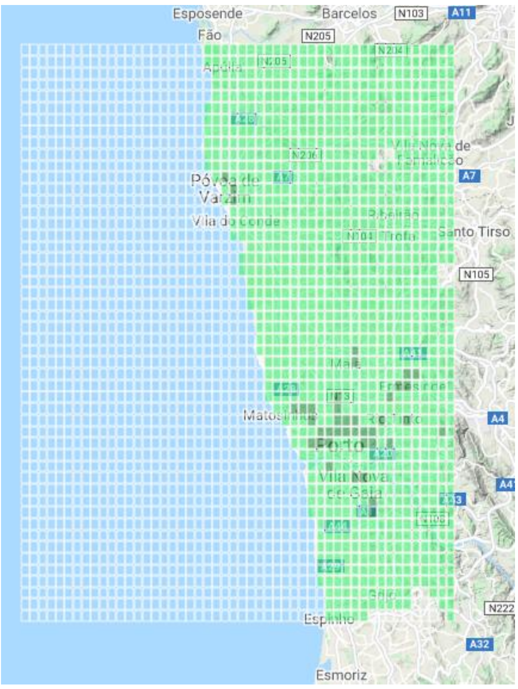
	Average	Minimum	Maximum
Porto Municipality	172	0	359
Municipalities of the metropolitan area of Porto	52	0	504

Elementary school children (ages 5 – 10)



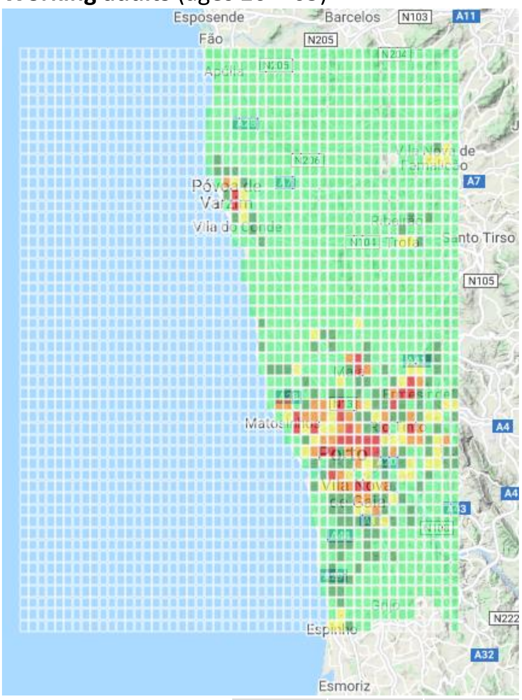
	Average	Minimum	Maximum
Porto Municipality	187	0	402
Municipalities of the metropolitan area of Porto	56	0	481

Students (ages 11 – 25)



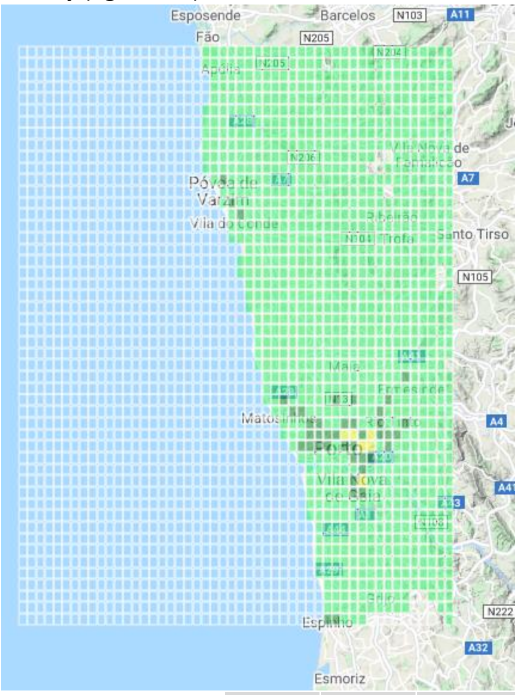
	Average	Minimum	Maximum
Porto Municipality	723	0	1442
Municipalities of the metropolitan area of Porto	179	0	1768

Working adults (ages 26 – 65)



	Average	Minimum	Maximum
Porto Municipality	2631	0	5548
Municipalities of the metropolitan area of Porto	628	0	6518

Elderly (ages > 65)



	Average	Minimum	Maximum
Porto Municipality	1151	0	2809
Municipalities of the metropolitan area of Porto	163	0	2160

Figure 4.6 – Maps with spatial distribution (1 km x 1 km) of population across Porto for each population group, expressed in number of people (nop). The average, minimum and maximum population densities are expressed in nop/km^2.

POPULATION EXPOSURE

- The population exposure (the product of the pollutant and population exposed to it) was categorised into 5 subgroups in addition to the overall group ("all groups") for the Porto Municipality and the other municipalities of the metropolitan area of Porto. This exposure is estimated considering the time-activity patterns.
- Table 4.3 shows the annual average exposure to PM and heavy metals weighted by the number of people present in the Porto study case domain.
- In Porto Municipality, in 2015 the population exposure was 97000 µg/m^3.nop for PM10 and 40000 µg/m^3.nop for PM2.5. Regarding the heavy metals, the highest population exposure was obtained for Pb (26000 ng/m^3.nop), followed by Ni (9600 ng/m^3.nop), As (1500 ng/m^3.nop) and Cd (460 ng/m^3.nop).
- For the other municipalities of the metropolitan area of Porto, all the population was exposed to 20000 µg/m^3.nop for PM10 and 8500 µg/m^3.nop for PM2.5. For the heavy metals the highest population exposure was obtained for Pb (5900 ng/m^3.nop) followed by Ni (1900 ng/m^3.nop) and the lowest was for Cd (110 ng/m^3.nop).
- Population exposure was higher in Porto municipality not only because of the difference in the pollutant concentrations (Figure 4.4), but also because the population exposed is higher in Porto municipality (Figure 4.5).

Table 4.3 – PM and heavy metals exposure for each population sub-group in Porto.

		PM10	PM2.5	As	Cd	Ni	Pb
		µg/m³.nop		ng/m³.nop			
Porto Municipality	All groups	97000	40000	1500	460	9600	26000
	Pre-school children	3900	1500	55	17	360	960
	Elementary school children	4100	1600	59	18	390	1000
	Students	16000	6200	230	70	1500	4000
	Working adults	51000	19000	810	240	5300	14000
	Elderly	19000	8800	330	100	2100	5900
Other municipalities of the metropolitan area of Porto	All groups	20000	8500	310	110	1900	5900
	Pre-school children	1100	430	16	5.4	93	290
	Elementary school children	1100	460	17	5.7	98	310
	Students	3600	1500	53	18	310	1000
	Working adults	11000	4300	190	60	1100	3400
	Elderly	2500	1200	45	15	270	840

DEPOSITED DOSE

- The deposited dose of PM10 and PM2.5 was divided into 5 population sub-groups: pre-school children, elementary school children, students, working adults and elderly. The deposited dose is estimated through the individual exposure, the inhalation rate and other standardize anatomical characteristics of the individual sub-groups.
- In Figure 4.7 and Figure 4.9 is represented the daily variability of the deposited dose of PM10 and PM2.5, respectively. By observing the graphs, it is possible to identify which microenvironment or activity is contributing most to the daily deposited dose.
- For pre-school children the highest PM10 and PM2.5 deposited doses were obtained when the children were at school during the weekdays and outdoors on the weekend. The lowest PM10 and PM2.5 deposited doses were observed at home on both weekdays and weekends.
- For elementary school children and students, on weekdays the highest PM10 and PM2.5 deposited doses were observed outdoors followed by school microenvironment, and the lowest values were at home. On the weekends, the highest PM10 and PM2.5 deposited doses were observed outdoors followed by indoors-other, and the lowest doses occurred at home. The difference of the PM deposited doses between these two population groups and the first one (pre-school children) may be due to the age difference, i.e. younger children have lower ventilation rates and also lower physical activity intensity.
- For working adults and elderly, both on weekdays and weekends the highest deposited doses of PM10 and PM2.5 occurred outdoors and the lowest were at home. In general, the working adults with office work had PM deposited doses very similar to those observed at home.
- PM10 and PM2.5 deposited doses showed to be higher on weekdays than weekends for all population sub-groups, except for working adults. For elderly this difference was negligible.

PM10

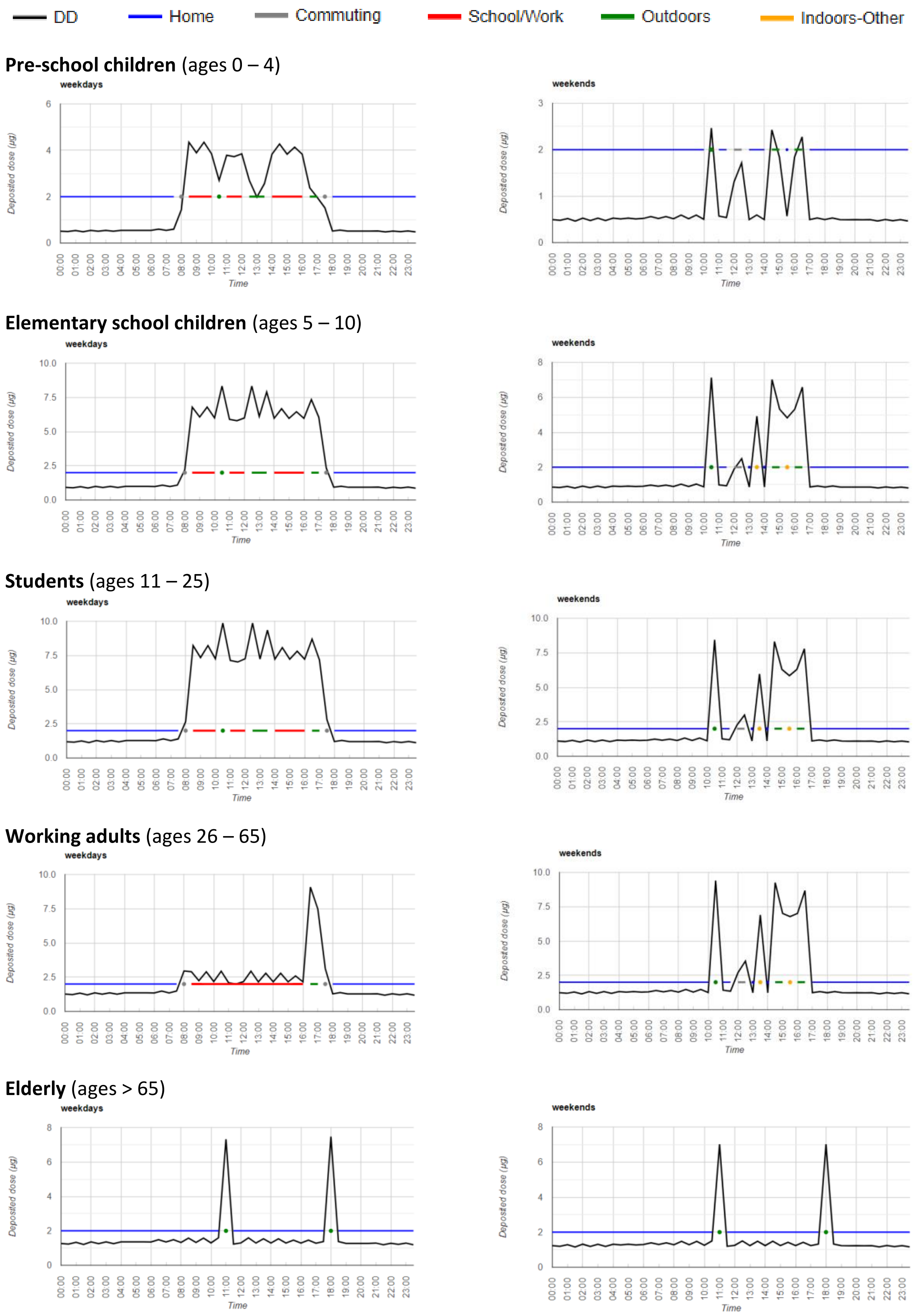


Figure 4.7 – PM10 dose (in all regions) throughout the day for each population group in Porto metropolitan area.

- The distribution of the PM10 deposited dose in the different regions of the human respiratory tract (HRT) is represented in Figure 4.8.
- For all population sub-groups the highest amount of PM10 deposited on the upper airways (anterior nasal passages – ET1) and the lowest values were obtained in the BB region, which is composed by trachea and bronchi.
- Due to the highest PM10 deposited dose during the weekdays, the students presented the highest PM10 deposited dose along one year, followed by elementary school children, working adults, elderly and pre-school children.

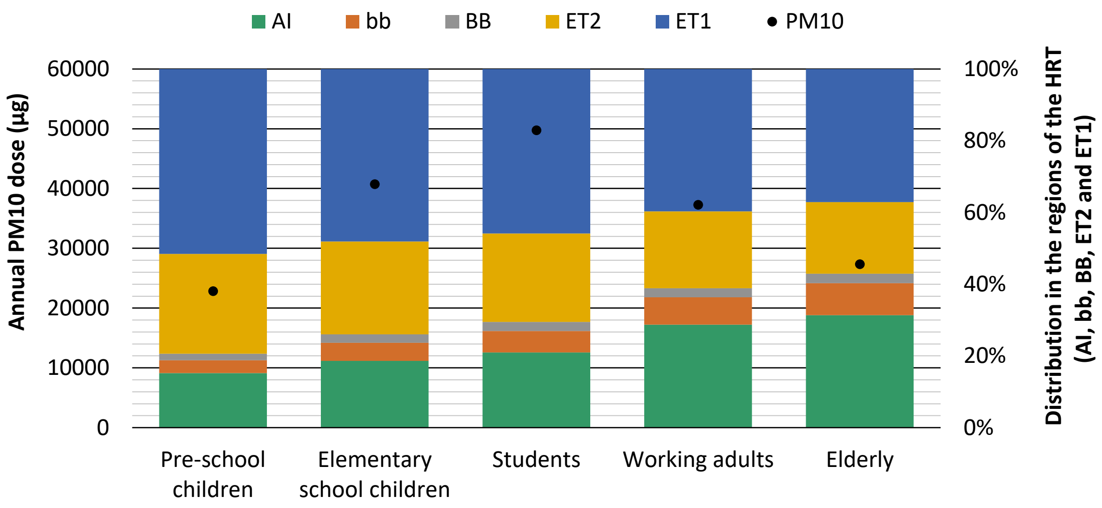
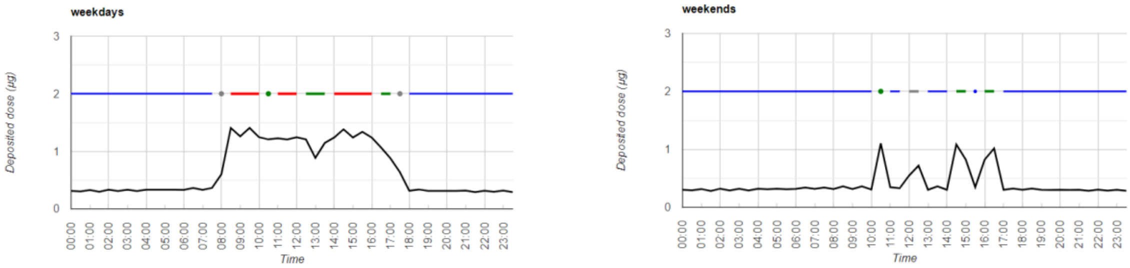


Figure 4.8 – Annual cumulative dose for PM10 (µg) and its distribution in the different regions of the HRT for each population group in Porto metropolitan area.

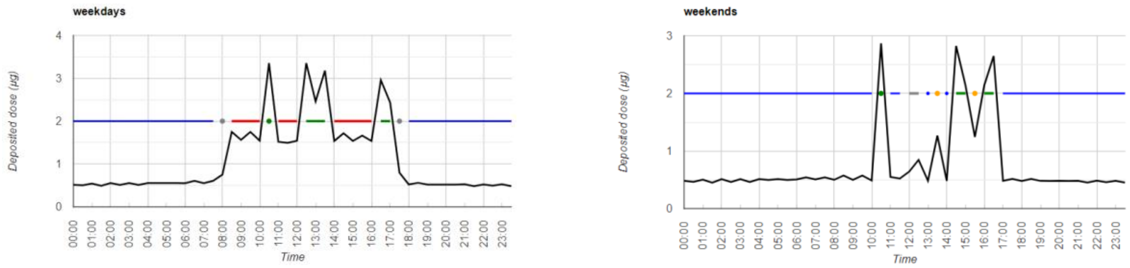
PM2.5

DD — Home — Commuting — School/Work — Outdoors — Indoors-Other

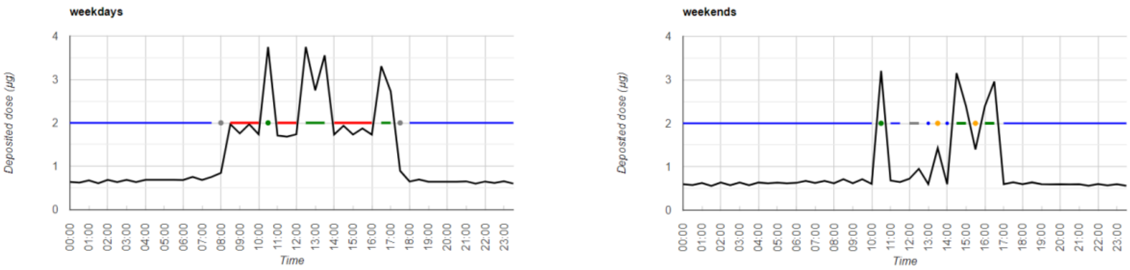
Pre-school children (ages 0 – 4)



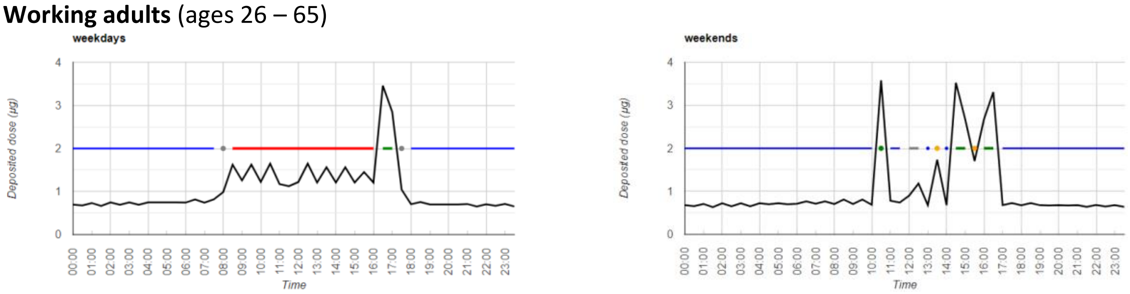
Elementary school children (ages 5 – 10)



Students (ages 11 – 25)



Working adults (ages 26 – 65)



Elderly (ages > 65)

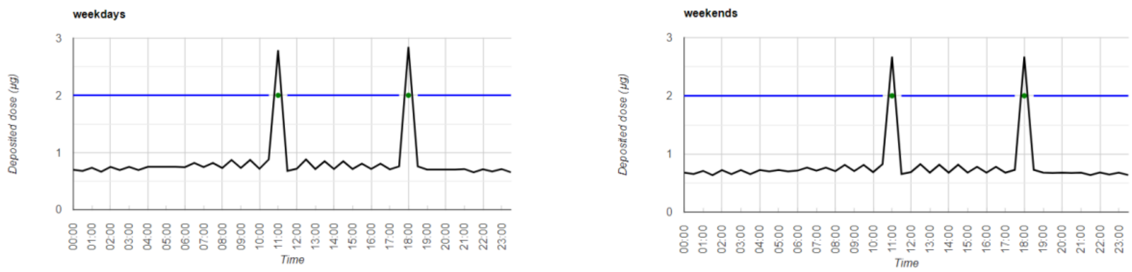


Figure 4.9 – PM2.5 dose (in all regions) throughout the day for each population group in Porto metropolitan area.

- The distribution of the PM2.5 deposited dose in the different regions of the human respiratory tract (HRT) is represented in Figure 4.10.
- For pre-school children the highest amount of PM2.5 deposited on the upper airways (anterior nasal passages – ET1), while for the remaining population sub-groups was on the lower airways (terminal bronchiole), which consists of respiratory bronchioles, alveolar ducts, alveolar sacs, and alveoli.
- The lowest PM2.5 deposited doses were obtained in the BB region for all population sub-groups.
- Due to the highest PM2.5 deposited dose during the weekdays, the students presented the highest PM2.5 deposited dose along one year, followed by working adults, elementary school children, elderly and pre-school children.

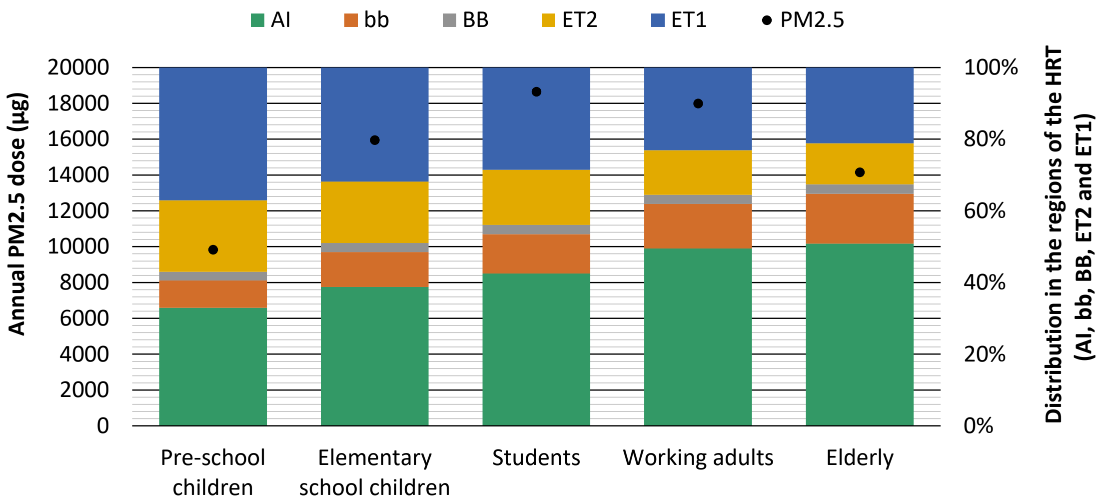


Figure 4.10 – Annual cumulative dose for PM2.5 (µg) and its distribution in the different regions of the HRT for each population group in Porto metropolitan area.

- The comparison of the PM10 and PM2.5 deposited dose highlights the low penetration of the coarser particles through the lower respiratory regions. In fact, most of the particles larger than 2.5 µm deposited in the extra-thoracic regions, ET1 and ET2.

Burden of Disease

- The health impacts associated with exposure to PM2.5 concentration levels in 2015 were estimated using Burden of Disease (BoD) methods.
- BoD is a comparable metric to measure health losses, including both premature mortality and morbidity. In addition, estimates for sick days and school absenteeism are provided for elementary school children.
- BoD parameters are provided as a total for the whole city, as well as spatially distributed across the city.

- As shown in Table 4.4, BoD is quantified based on Upper Respiratory Infections in the case of the children population groups (pre-school children and elementary school children) and on Natural Mortality in the case of adults over 25 years old (working adults and elderly).
- BoD is measured in disability adjusted life years (DALY), which is calculated as the sum of years of life lost due to premature mortality (YLL) and disability weighted years lived with disabilities (YLD), and may be expressed in YLL, YLD, DALY, or in number of deaths.
- In metropolitan area of Porto, for children and adults was estimated 0.03 and 1700 DALY attributed to PM2.5 exposure.
- The YLL and YLD estimations for adults over 25 years old were 1100 and 600, respectively, whereas for children were overlooked.
- In total, 74 premature deaths were attributed to PM2.5 exposure in 2015.

Table 4.4 – Upper respiratory infections and natural mortality per population sub-group in Porto metropolitan area.

	Upper Respiratory Infections			Natural Mortality		
	Pre-school children	**Elementary school children**	**All groups**	**Working adults**	**Elderly**	**All groups**
DALY	0.01	0.02	0.03	680	1100	1700
YLL	0.00	0.00	0.00	360	790	1100
YLD	0.01	0.02	0.03	320	270	600
Deaths	0.00	0.00	0.00	10	63	74
Sick days (mild)	–	140.00	–	–	–	–
Sick days (moderate)	–	90.00	–	–	–	–
Sick days (severe)	–	1.80	–	–	–	–
Days of school absenteeism	–	45.00	–	–	–	–
Total sick days	–	230.00	–	–	–	–

Built-up of Policy Making Scenarios

The builder scenarios are based on ANN algorithms. This is an approximation that causes a bias error on the result. The results of base case from CAMx model is not exactly equal to the ones obtained with ANN. For this reason, the modified scenarios outputs are compared with the base outputs obtained with the ANN algorithms.

The assessment of the modified scenarios/mitigation measures is performed by comparing the modified outputs for air quality, population exposure, deposited dose and burden of disease with the respective outputs for the base case. The mitigation measures tested in the tool are indicated in Table 2.1.

PM Ambient Concentrations

- Relative changes (%) in PM10 and PM2.5 concentrations between the reference case and the modified scenarios (S1 – S10) are indicated in Table 4.5. The base case values are in $\mu g/m^3$.
- The PM10 and PM2.5 concentrations are different among modified scenarios.
- The total electrification of the passenger cars (scenario S2) had the highest impact in the PM10 and PM2.5 concentrations in both Porto municipality and the other municipalities of the metropolitan area of Porto. The highest relative changes were observed for PM10 concentrations in Porto municipality, with reductions between 4 and 7 $\mu g/m^3$ comparing with the reference case.
- The PM concentration reductions obtained for cars fleet scenarios were more relevant during the winter period and less during the summer.
- The modified scenarios applied to buses fleet in S6 and cruise ships (both S9 and S10) did not seem affect the average PM concentrations in both Porto municipality and other municipalities of the metropolitan area of Porto. The impact of these scenarios may be detected mainly on local area. Thus, the spatial resolution of 1 x 1 km^2 used in the tool may not be sensible to these local variations. Future work should focus on this issue.
- The scenarios S5 (50% of buses are EURO V and 50% are EURO VI) and S8 (20% reduction of wood consumed) showed to have impact only on PM10 concentrations for Porto municipality.
- The modified scenarios had higher impact on PM concentrations in Porto municipality than in the other municipalities of the metropolitan area of Porto.

Table 4.5 – Relative changes (%) in PM10 and PM2.5 concentrations between the reference case and the modified scenarios (S1 – S10) in Porto.

		Base	Road traffic						Residential heating		Cruise ships	
		Reference	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
		µg/m³	Relative changes (%) in PM concentrations									
PORTO MUNICIPALITY												
PM10	Annual	21	-13.4	-26.4	-14.1	-17.5	-3.5	*	-11.8	-4.8	*	*
	Winter	28	-13.2	-26.4	-13.8	-17.2	-3.2	*	-11.8	-4.9	*	*
	Summer	15	-13.4	-26.4	-14.2	-17.5	-3.4	*	-11.8	-4.9	*	*
	Spring	22	-13.4	-26.4	-14.0	-17.5	-3.5	*	-11.8	-4.9	*	*
	Autumn	18	-13.3	-26.4	-14.0	-17.3	-3.3	*	-11.8	-4.8	*	*
PM2.5	Annual	5	-10.9	-11.1	-5.9	-10.5	*	*	-5.8	*	*	*
	Winter	7	-10.9	-11.1	-6.0	-10.5	*	*	-5.6	*	*	*
	Summer	4	-10.9	-11.1	-6.0	-10.3	*	*	-5.7	*	*	*
	Spring	5	-10.8	-11.0	-6.0	-10.4	*	*	-5.8	*	*	*
	Autumn	4	-11.0	-11.2	-5.9	-10.5	*	*	-5.7	*	*	*
OTHER MUNICIPALITIES OF THE METROPOLITAN AREA OF PORTO												
PM10	Annual	16	-6.2	-6.8	-3.8	-4.8	*	*	-7.0	*	*	*
	Winter	25	-5.9	-6.5	-3.7	-4.6	*	*	-6.9	*	*	*
	Summer	11	-6.3	-7.0	-3.9	-4.8	*	*	-7.1	*	*	*
	Spring	17	-6.2	-6.8	-3.8	-4.7	*	*	-7.1	*	*	*
	Autumn	14	-6.2	-6.8	-3.8	-4.7	*	*	-7.0	*	*	*
PM2.5	Annual	4	-5.0	-5.2	-2.5	-3.7	*	*	-4.5	*	*	*
	Winter	6	-4.5	-4.8	-2.4	-3.7	*	*	-4.5	*	*	*
	Summer	3	-4.8	-5.1	-2.6	-3.7	*	*	-4.4	*	*	*
	Spring	4	-4.8	-5.1	-2.5	-3.9	*	*	-4.4	*	*	*
	Autumn	4	-4.8	-5.1	-2.6	-3.7	*	*	-4.5	*	*	*

* Value is within the range of uncertainty of the Tool (± 2%).

Population Exposure

- Relative changes (%) in PM10 and PM2.5 population exposure between the reference case and the modified scenarios (S1 – S10) are indicated in Table 4.6. The base case values are in $\mu g/m^3 \cdot$ nop.
- According to the PM ambient concentrations, the PM10 and PM2.5 population exposure are also different among modified scenarios.
- The total electrification of the passenger cars (scenario S2) had the highest impact in the average PM10 and PM2.5 population exposure in both Porto municipality and the other municipalities of the metropolitan area of Porto (up to 15266 $\mu g/m^3 \cdot$ nop of reduction).
- In Porto municipality, the highest relative changes for PM10 population exposure were observed for working adults while for PM2.5 population exposure were for pre-school children, both for cars fleet scenarios (S1 – S4).
- In general, the differences in PM2.5 exposure between the reference case and the modified scenarios were lower for elderly sub-group than for the remaining sub-groups in both Porto municipality and other municipalities of the metropolitan area of Porto. The differences in PM10 exposure for elderly were among the highest.

- As observed for PM ambient concentrations, the modified scenarios seem to have higher impact on PM population exposure in Porto municipality than in the other municipalities of the metropolitan area of Porto.

Table 4.6 – Relative changes (%) in PM10 and PM2.5 population exposure between the reference case and the modified scenarios (S1 – S10) in Porto.

		Base	Road traffic						Residential heating		Cruise ships	
		Reference	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
		μg/m³ · nop	Relative changes (%) in PM population exposure									
PORTO MUNICIPALITY												
PM10	All groups	95667	-8.5	-16.0	-6.4	-12.8	-2.1	*	-8.3	-4.2	*	*
PM10	Pre-school children	3867	-7.9	-15.8	-5.3	-10.5	-2.6	*	-7.7	-2.6	*	*
PM10	Elementary school children	4067	-7.5	-15.0	-5.0	-12.5	-2.5	*	-9.8	-2.4	*	*
PM10	Students	15667	-6.7	-13.3	-6.7	-6.7	*	*	-6.3	-6.3	*	*
PM10	Working adults	50000	-10.2	-18.4	-8.2	-14.3	-2.0	*	-8.0	-4.0	*	*
PM10	Elderly	18667	-5.6	-16.7	-5.6	-11.1	*	*	-10.5	-5.3	*	*
PM2.5	All groups	40000	-5.0	-5.0	-2.5	-5.0	*	*	-2.5	*	*	*
PM2.5	Pre-school children	1500	-6.7	-6.7	*	-6.7	*	*	*	*	*	*
PM2.5	Elementary school children	1600	-6.3	-6.3	*	-6.3	*	*	*	*	*	*
PM2.5	Students	6200	-4.8	-4.8	*	-4.8	*	*	-3.2	*	*	*
PM2.5	Working adults	19000	-5.3	-5.3	*	-5.3	*	*	-5.3	*	*	*
PM2.5	Elderly	8767	-4.5	-4.5	-3.4	-4.5	*	*	-2.3	*	*	*
OTHER MUNICIPALITIES OF THE METROPOLITAN AREA OF PORTO												
PM10	All groups	22667	-8.7	-8.7	-4.3	-4.3	-4.3	*	-4.5	*	*	*
PM10	Pre-school children	1267	-7.7	-7.7	-7.7	-7.7	-7.7	*	*	*	*	*
PM10	Elementary school children	1300	-7.7	-7.7	*	-7.7	*	*	-7.7	*	*	*
PM10	Students	4133	-4.9	-4.9	-2.4	-4.9	*	*	-7.3	-2.4	*	*
PM10	Working adults	12667	-7.7	-7.7	-7.7	-7.7	-7.7	*	*	*	*	*
PM10	Elderly	2867	-6.9	-6.9	-3.4	-6.9	-3.4	*	-3.6	*	*	*
PM2.5	All groups	9900	-3.0	-3.0	*	-2.0	*	*	-2.0	*	*	*
PM2.5	Pre-school children	510	-3.9	-3.9	*	-3.9	*	*	*	*	*	*
PM2.5	Elementary school children	530	-3.8	-3.8	*	-3.8	*	*	*	*	*	*
PM2.5	Students	1700	-5.9	-5.9	*	-5.9	*	*	*	*	*	*
PM2.5	Working adults	5000	-4.0	-4.0	*	-4.0	*	*	*	*	*	*
PM2.5	Elderly	1400	*	*	*	*	*	*	*	*	*	*

* Value is within the range of uncertainty of the Tool (± 2%).

DEPOSITED DOSE

- Relative changes (%) in PM10 and PM2.5 deposited dose between the reference case and the modified scenarios (S1 – S10) are indicated in Table 4.7. The base case values are in μg.
- Reduction in the PM10 and PM2.5 deposited dose were observed for the scenarios applied to the cars fleet (S1, S2 and S4) and to the first scenario related to the residential heating

(S7), which considers the total replacement of conventional residential fireplaces (open fireplaces), woodstoves, and salamander stoves by more efficient fireplaces.

- The highest relative changes for PM10 and PM2.5 deposited dose were observed for working adults, while the lowest reductions were for pre-school children.

Table 4.7 – Relative changes (%) in PM10 and PM2.5 deposited dose between the reference case and the modified scenarios (S1 – S10) in Porto.

		PORTO METROPOLITAN AREA										
		Base	Road traffic						Residential heating		Cruise ships	
		Reference	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
		μg	Relative changes (%) in PM deposited dose									
PM10	Pre-school children	22945	-2.3	-2.7	*	*	*	*	-2.5	*	*	*
	Elementary school children	40952	-2.5	-3.0	*	-2.1	*	*	-2.8	*	*	*
	Students	50007	-2.5	-3.0	*	-2.1	*	*	-2.8	*	*	*
	Working adults	37528	-3.0	-3.6	*	-2.5	*	*	-3.3	*	*	*
	Elderly	27490	-2.6	-3.1	*	-2.2	*	*	-2.9	*	*	*
PM2.5	Pre-school children	9882	-2.4	-2.9	*	-2.0	*	*	-2.7	*	*	*
	Elementary school children	15441	-2.6	-3.1	*	-2.2	*	*	9.4	11.9	*	*
	Students	18749	-2.6	-3.1	*	-2.2	*	*	-2.9	*	*	*
	Working adults	18107	-3.0	-3.6	*	-2.5	*	*	-3.3	*	*	*
	Elderly	14229	-2.6	-3.1	*	-2.2	*	*	-2.8	*	*	*

∗ Value is within the range of uncertainty of the Tool (± 2%).

BURDEN OF DISEASE

- Relative changes (%) in health impacts due to exposure to PM2.5 between the reference case and the modified scenarios (S1 – S10) are indicated in Table 4.8. The base case values are in number.
- Changes in the buses fleet (S5 and S6) and cruise ships (S9 and S10) have negligible effects on health impacts (most of the values are within the range of uncertainty of the Tool).
- Among the modified scenarios applied to cars fleet (S1 – S4) and residential heating (S7), the elementary school children can have a reduction of the number of sick days and days of school absenteeism of up to 20 (S1, S2 and S4) and 10 (S3 and S7), respectively.
- The population of the Porto metropolitan area can have reductions of up to:
  - 5 deaths (S1, S2 and S4);
  - 100 disability adjusted life years (S1 – S5);
  - 90 years of life lost due to premature mortality (S2);
  - 50 disability weighted years lived with disabilities (S2);

Table 4.8 – Relative changes (%) in health impacts due to exposure to PM2.5 between the reference case and the modified scenarios (S1 – S10) in Porto.

		PORTO METROPOLITAN AREA										
		Base	Road traffic						Residential heating		Cruise ships	
		Reference	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
		no.	Relative changes (%) in health impacts due to exposure to PM2.5									
Upper respiratory infections - Elementary school children	Sick days (mild)	120	-8.3	-8.3	-8.3	-8.3	*	*	-8.3	*	*	*
	Sick days (moderate)	74	-6.8	-6.8	-4.1	-6.8	*	*	-4.1	*	*	*
	Sick days (severe)	2	-6.7	-6.7	-6.7	-6.7	*	*	-6.7	*	*	*
	Days of school absenteeism	37	-5.4	-5.4	-2.7	-5.4	*	*	-5.4	*	*	*
	Total sick days	197	-10.0	-10.0	-5.0	-10.0	-5.0	-5.0	-5.3	*	*	*
Natural Mortality - all groups	DALY	1500	-6.7	-6.7	-6.7	-6.7	*	*	-6.7	*	*	*
	YLL	980	-8.2	-9.2	-5.1	-8.2	*	*	-5.1	-2.0	*	*
	YLD	510	-7.8	-9.8	-5.9	-7.8	*	*	-5.9	*	*	*
	Deaths	63	-7.9	-7.9	-4.8	-7.9	*	*	-4.8	*	*	*

* Value is within the range of uncertainty of the Tool (± 2%).

5. IMPLEMENTATION OF THE MANAGEMENT TOOL IN ATHENS

CHARACTERISATION OF ATHENS

PHYSICAL GEOGRAPHY

Athens is the capital and largest city of Greece, as well as one of the biggest economic centres in south Eastern Europe. The city is located on the eastern edge of Central Greece (at 37°59'N and 23°43'E). It sprawls across the central plain of Attica that is often referred to as the Athens Basin or the Attica Basin. The basin is bounded by four large mountains: Mount Aigaleo to the west, Mount Parnitha to the north, Mount Pentelicus to the northeast and Mount Hymettus to the east. The Municipality of Athens (also City of Athens) constitutes a small administrative unit of the entire city, covering an area of around 39 km^2. The Athens Metropolitan Area extends beyond its administrative municipal city limits, over an area of 2929 km^2 and includes a total of 58 municipalities.

DEMOGRAPHY

According to Eurostat, in 2011, the Metropolitan Area of Athens was the 9th most populous in the European Union (the 6th most populous capital city of the EU), with a population of 3.8 million people. The municipality of Athens is the most populous in Greece, with a population of 664046 people.

CLIMATE

Athens has a subtropical Mediterranean climate, with prolonged hot and dry summers, due to the dry and hot winds blowing from the Sahara, and mild winters with moderate rainfall, due to the influence of the westerly winds. Annual precipitation in Athens is lower than most other parts of Greece, especially western Greece, and amounts on average to 433 mm yearly. Rainfall occurs largely between the months of October and April, while July and August are the driest months. Daily average temperature highs for July have been measured around 34 °C in downtown Athens. Due to the large area covered by the Athens Metropolitan Area, there are notable climatic differences between parts of the urban conglomeration. The northern suburbs tend to be wetter and cooler in winter, whereas the southern suburbs are some of the driest locations in Greece and record very high minimum temperatures in summer. Snowfall is infrequent.

TRANSPORT

Road

According to the TomTom Traffic Index, in 2017, the congestion level in Athens was 38%, corresponding to a congestion level of 23% in highways and 41% in other roads; in 2020 the congestion level has dropped to 34%. The Tom Tom navigation data reveal that the rush hours are during weekdays between 8 and 10 AM and 5 to 7 PM. According to the annual report of the Hellenic Statistical Authority, the Athens fleet in 2019 included 2991572 passenger vehicles, 701924 motorcycles and 2,53 buses.

Rail

The rail public transport in Athens includes both underground (Athens metro) and overground electric railway lines (tram and suburban railway). According to the Hellenic Statistical Authority, in 2014 at total of 275122 passengers were transported by the different railway systems.

Maritime

The Athens port, Piraeus, is both the largest passenger port in Europe, and the second largest in the world. In 2014, Piraeus handled about 18.6 million passengers. In 2019, Piraeus welcomed 622 cruise liners, carrying 1098091 passengers. In addition, since its privatization in 2009, the port's container handling is growing rapidly, making it the busiest cargo port in Greece and the largest container port in the country and the East Mediterranean Sea Basin.

Air

The Athens International Airport Eleftherios Venizelos (AIA) is the largest international airport in Greece, serving the city of Athens and region of Attica. AIA is the 19th busiest airport in Europe, with 25.57 million passengers in 2019.

INDUSTRY

The manufacturing sector in Athens is dominated by medium to low technology sectors, such as the food industry, metal products, chemicals - pharmaceuticals, textiles and shipbuilding. The majority of industrial facilities is located in the Thriasian Plain, in western Attica, where two oil refining complexes are also situated.

ATMOSPHERIC POLLUTION

Athens has been known to suffer from air pollution problems, due a combination of factors, including the impact of anthropogenic emission sources related to the city's economic activities and high population density, climatic conditions that favour the formation and accumulation of pollutants (such as low precipitation rates and high solar radiation) and the complex topography and urban planning of the city which do not promote dispersion of pollution (Diapouli et al., 2017). A number of control measures have been implemented since the 1990s, mainly related to traffic management and vehicle emission reductions, as well as reduction in fossil fuel use due to energy efficiency improvements or interventions in favour of alternative fuels and renewable energy sources. These resulted in reductions of atmospheric pollution and changes in emission source contributions; however, the financial crisis which started on 2009 had a negative impact on air quality management, including also a significant increase of residential wood burning as a result of the rising price of heating oil.

According to a source apportionment study conducted at a suburban site in Athens, the major contributors to PM10 and PM2.5 concentrations are secondary aerosol formation (mainly organics and sulphate) and vehicular traffic. A significant contribution from local dust and long-range transport of desert dust was also identified in the case of PM10 (Figure 5.1). Similar key sources were identified in an urban traffic site, with high contributions again from vehicular traffic (33% for PM10 and 26% for PM2.5) and secondary sulphate (17% for PM10 and 30% for

PM2.5), but also from secondary nitrate (15% for PM10 and 12% for PM2.5) and biomass burning (12% for PM10 and 20% for PM2.5) (Manousakas et al., 2021).

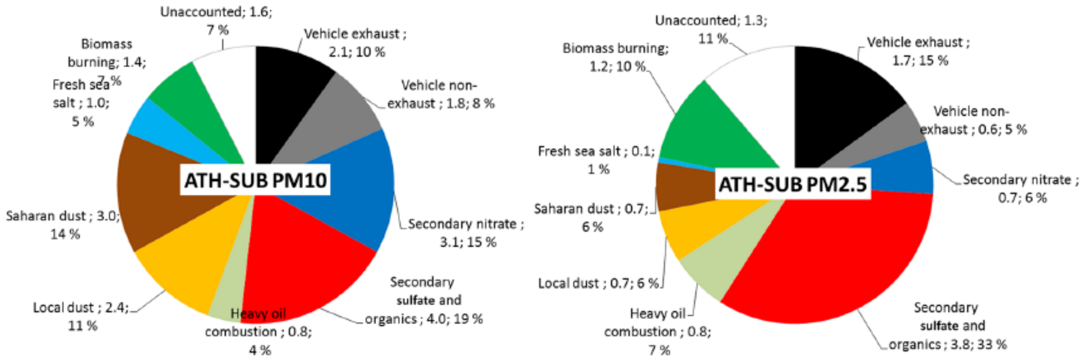


Figure 5.1 – Contribution (in μg/m^3 and as % of total) of major sources to PM10 and PM2.5 concentrations measured at a suburban site in Athens, Greece (Amato et al., 2016).

BASE CASE

The base case scenario corresponds to the air quality condition verified over the city of Athens in the year 2015. The base case is based on the CAMx model integrated with the data obtained in the air monitoring stations.

EMISSIONS

Athens municipality

Figure 5.2 shows the Athens municipality emissions in 2015, for the main gaseous pollutants (NH_3, NOx, SO_2 and VOC), particulate matter (PM10 and PM2.5) and heavy metals, per activity sector.

- The road transport sector was the largest source of NH_3 (77%), NOx (90%), VOC (54%), PM10 (46%) and PM2.5 (50%) emissions.
- The combustion in manufacturing industry & production processes sector was the largest source of SO_2 (92%) and Ni (51%) emissions.
- The solvent and other product use sector was the largest source of As (84%) emissions.
- The waste treatment and disposal sector was the largest source of Cd (68%) emissions.
- The combustion in manufacturing industry & production processes sector and the waste treatment and disposal sector equally contributed to Pb emissions (by 50% each).

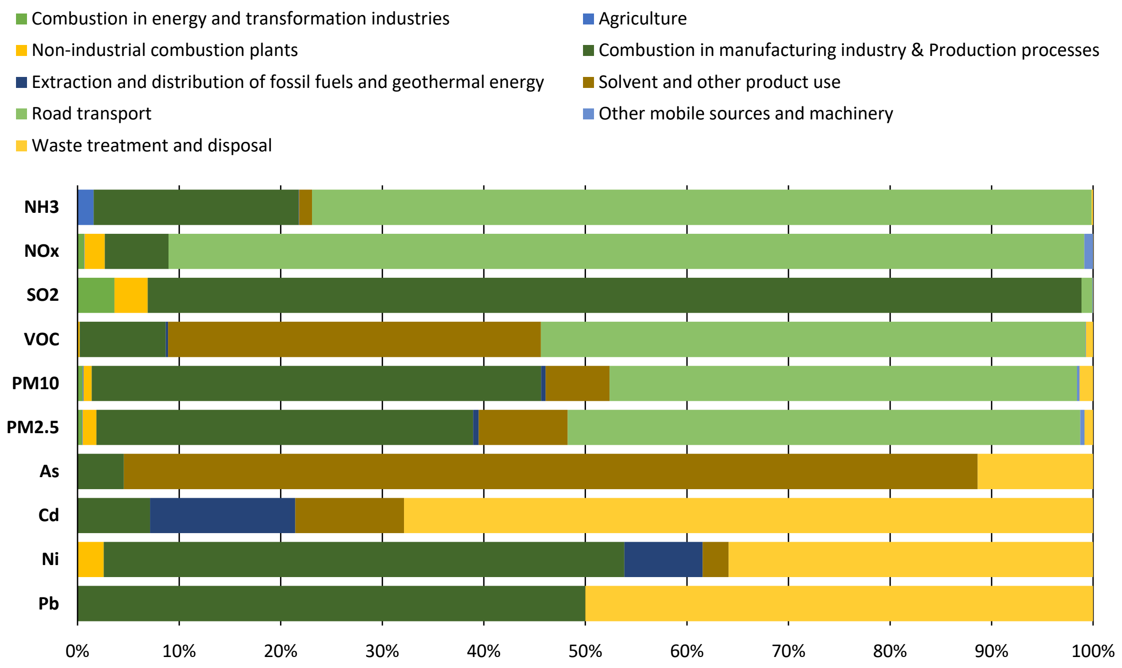


Figure 5.2 – Share of Athens municipality emissions (in %) of the main pollutants, by sector group in 2015.

Other municipalities of the metropolitan area of Athens

Figure 5.3 shows the Athens metropolitan area (excluding the Athens municipality) emissions in 2015, for the main gaseous pollutants (NH_3, NOx, SO_2 and VOC), particulate matter (PM10 and PM2.5) and heavy metals, per activity sector.

- The combustion in manufacturing industry & production processes sector was the largest source of NH_3 (56%), SO_2 (57%), PM10 (62%) and PM2.5 (53%) emissions.
- The road transport sector was the largest source of NO_2 (48%) emissions.
- The solvent and other product use sector was the largest source of VOC (59%) emissions.
- The combustion in energy and transformation industries sector was the largest source of As (83%), Ni (33%) and Pb (92%) emissions.
- The extraction and distribution of fossil fuels and geothermal energy sector was the largest source of Cd (52%) emissions.
- In the Athens municipality, VOC displayed the highest total emissions for 2015 (35422.6 t/year), followed by NOx (6542.3 t/year) (Table 5.1).
- Similarly, in the other municipalities of the metropolitan area of Athens, VOC had the highest total emissions (339700 t/year), followed by NOx (39737 t/year).
- Regarding heavy metals, the other municipalities of the metropolitan area of Athens displayed much higher emissions in comparison to the Athens municipality.

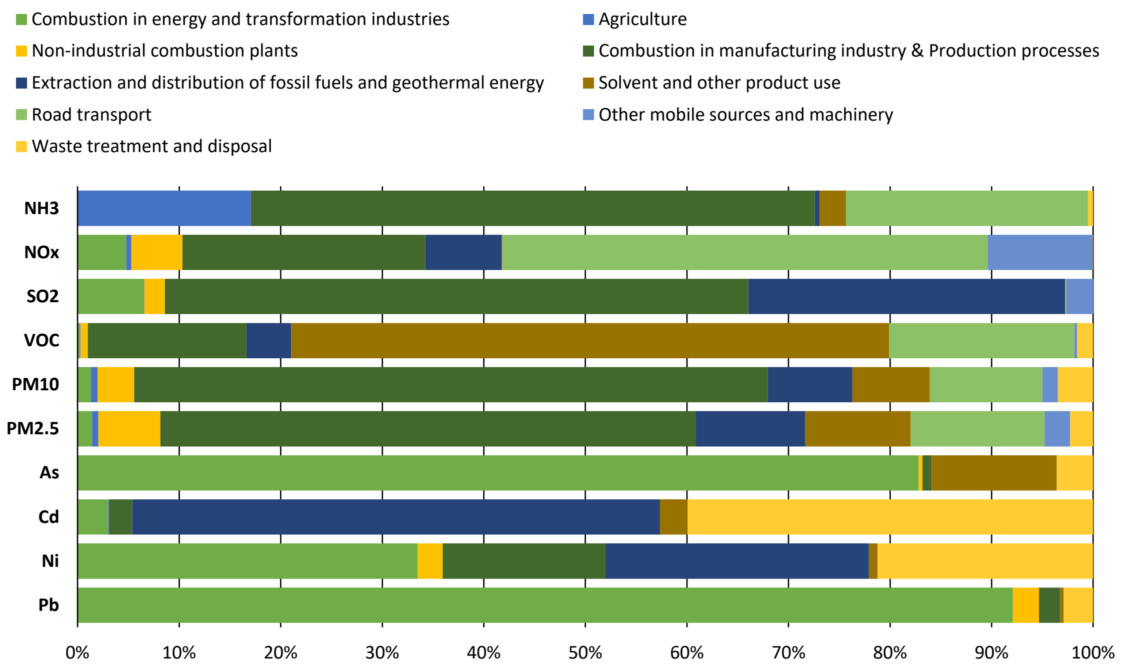


Figure 5.3 – Share of Athens metropolitan area (excluding the Athens municipality) emissions (in %) of the main pollutants, by sector group in 2015.

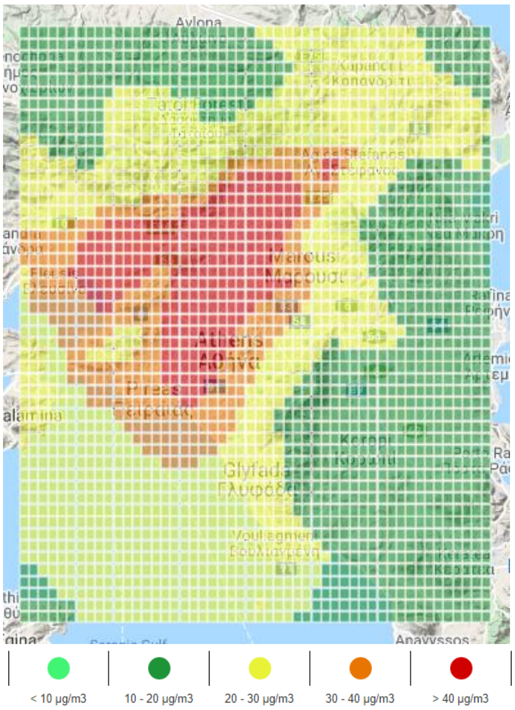
Table 5.1 – Total emissions of the main pollutants in 2015 for the Athens municipality and the other municipalities of the metropolitan area of Athens.

	NH_3	NOx	SO_2	VOC	PM10	PM2.5	As	Cd	Ni	Pb
	Total									
	t/year						kg/year			
Athens Municipality	247	6542	826	35423	1130	674	4.4	2.8	3.9	0.2
Other municipalities of the metropolitan area of Athens	2521	39737	24363	339700	14423	8351	446.9	157.8	212.0	61.9

AMBIENT CONCENTRATIONS

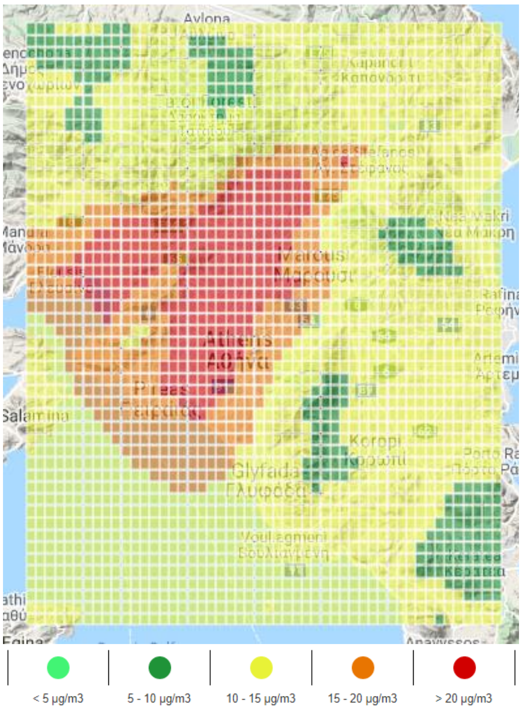
- PM10 average concentration in the Athens Municipality was 40.17 μg/m^3. The highest annual average concentration was 67.67 μg/m^3, exceeding the annual limit value of 40 μg/m^3 defined by the EU Directive, and the guideline defined by WHO (20 μg/m^3).
- PM10 average concentration in the other municipalities of the metropolitan area of Athens was 26.31 μg/m^3 and the highest annual average concentration was 106.46 μg/m^3, exceeding the annual limit value defined by the EU Directive, and the guideline defined by WHO.
- In the Athens municipality, the annual mean concentrations of As (2.51 ng/m^3), Cd (0.36 ng/m^3) and Ni (3.17 ng/m^3) did not exceeded neither the target values established by the EU Directive (6, 5 and 20 ng/m^3 for As, Cd and Ni, respectively) nor the WHO estimated reference levels for As (6.6 ng/m^3) and Ni (25 ng/m^3) and the WHO air quality guideline for Cd (5 ng/m^3). The annual mean Pb concentration (5.02 ng/m^3) was much lower than the EU Directive limit value and WHO air quality guideline of 0.5 μg/m^3.
- In the other municipalities of the metropolitan area of Athens the annual mean concentrations of As (3.13 ng/m^3), Cd (0.28 ng/m^3), Ni (3.55 ng/m^3) and Pb (5.25 ng/m^3) were similar to those observed in the Athens municipality.
- On average, for the Athens municipality, the ambient concentrations of PM10 and PM2.5 in winter was around 67% higher than in summer. The same trend was observed in the heavy metals' concentrations, with the winter displaying higher levels by 55% (for Cd) to 244% (for Pb).
- For the other municipalities of the metropolitan area of Athens, the PM10 and PM2.5 ambient concentrations in winter were about 38% higher than in summer. The same trend was observed in the heavy metals' concentrations, with the winter displaying higher levels by 73% (for Ni) to 279% (for Pb).

PM10



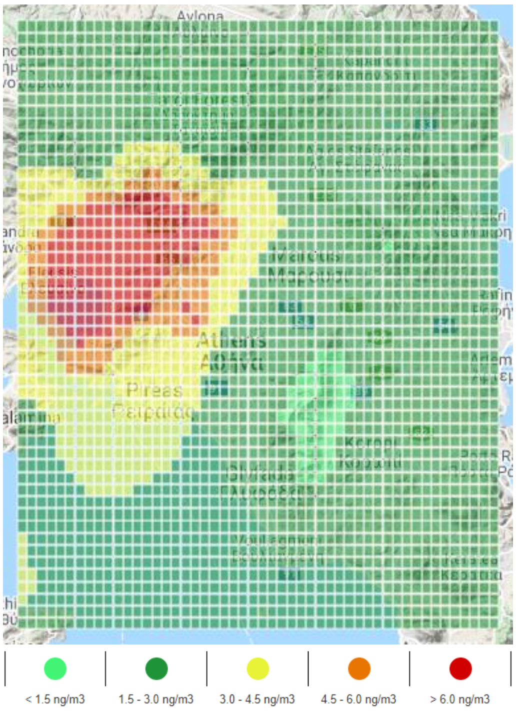
	Average	Minimum	Maximum
Athens Municipality	40.17	25.15	67.67
Municipalities of the metropolitan area of Athens	26.31	17.25	106.46

PM2.5



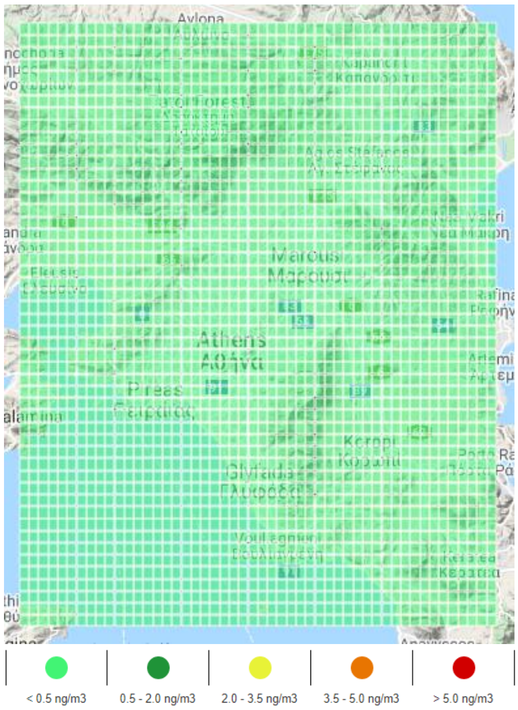
	Average	Minimum	Maximum
Athens Municipality	20.96	13.58	32.33
Municipalities of the metropolitan area of Athens	13.81	9.49	43.20

As



	Average	Minimum	Maximum
Athens Municipality	2.51	1.74	4.20
Municipalities of the metropolitan area of Athens	3.13	1.25	48.12

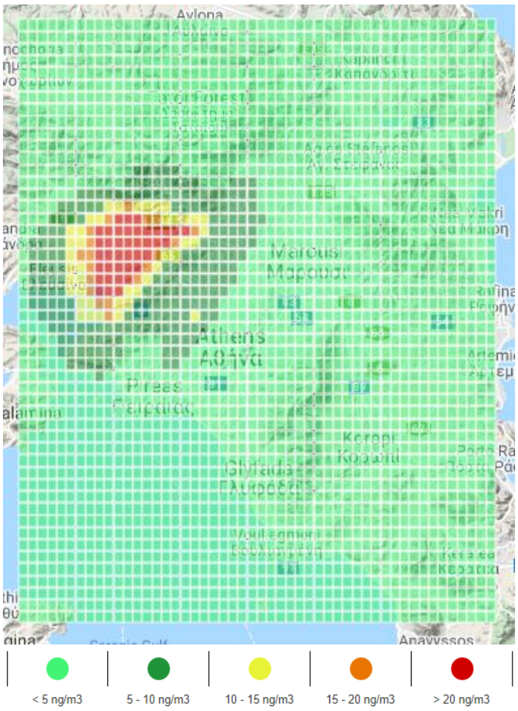
Cd



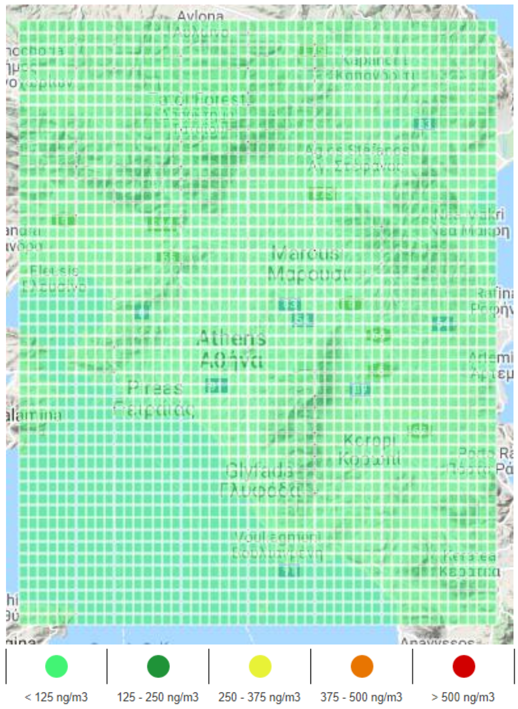
	Average	Minimum	Maximum
Athens Municipality	0.36	0.19	0.72
Municipalities of the metropolitan area of Athens	0.28	0.09	1.44

Ni

Pb



	Average	Minimum	Maximum
Athens Municipality	3.17	1.69	5.76
Municipalities of the metropolitan area of Athens	3.55	1.01	68.71



	Average	Minimum	Maximum
Athens Municipality	5.02	4.28	6.24
Municipalities of the metropolitan area of Athens	5.25	3.25	13.15

Figure 5.4 – Annual average ambient concentrations of PM (in μg/m^3) and heavy metals (in ng/m^3) in Athens.

PM10 Exceedances

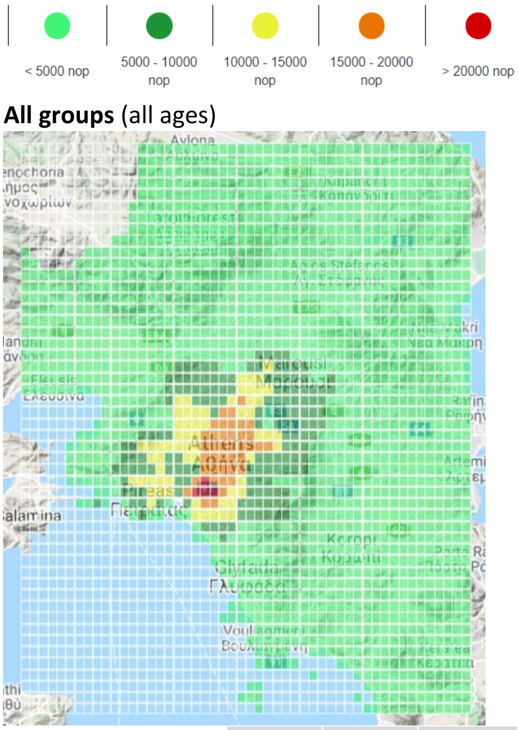
- For PM10, the current EU legislation described by Directive 2008/50/EC, with the objective of protecting human health and the environment, defines a daily limit value of 50 μg/m^3, which should not be exceeded more than 35 times a year.
- Both in the Athens Municipality and the other municipalities of the metropolitan area of Athens, several areas displayed more than 35 exceedance days of the daily limit value, with the worst cases being 246 days in the Athens Municipality and 281 days in other municipalities of the metropolitan area of Athens (Table 5.2).

Table 5.2 – Number of PM10 exceedance days in 2015 for Athens.

	Minimum	Maximum
Athens Municipality	31	246
Other municipalities of the metropolitan area of Athens	14	281

POPULATION GROUPS

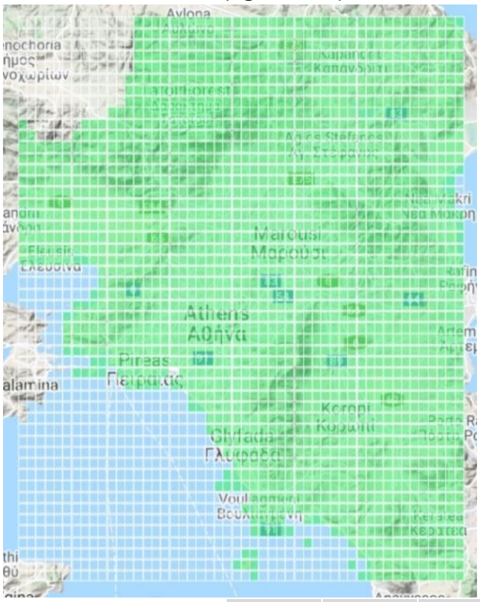
- The population in the study area was divided into 5 age groups characterised by different inhalation rates, activities and responses to the air pollution.
- Mean population density in the Athens Municipality is 14420 inhabitants per km^2 (Figure 5.5).
- The largest fraction (59%) of the population is in the range 26-65 years old (working adults), 19% are elderly people and the remaining population are children and adolescents under 26. The latter are divided into students (15%, 11-25 years old), elementary school children (4%, 5-10 years old) and pre-school children (4%, <5 years old).
- The other municipalities of the metropolitan area of Athens have a mean population density of 1559 inhabitants per km^2, with a population distribution similar to that in the Athens municipality: working adults (58%), elderly (17%), students (15%), pre-school (5%) and elementary school (5%) children.



	Average	Minimum	Maximum
Athens Municipality	14420	5880	20243
Municipalities of the metropolitan area of Athens	1559	0	21140

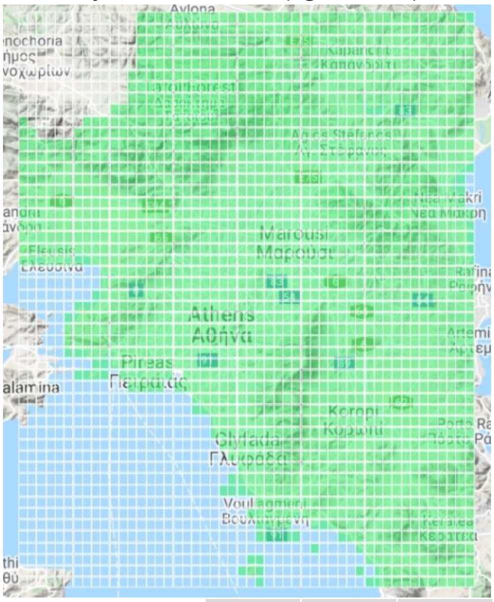
Figure 5.5 – Map of spatial distribution (1 km x 1 km) of all population across Athens, expressed in number of people (nop). The average, minimum and maximum population densities are expressed in nop/km^2.

Pre-school children (ages 0 – 4)



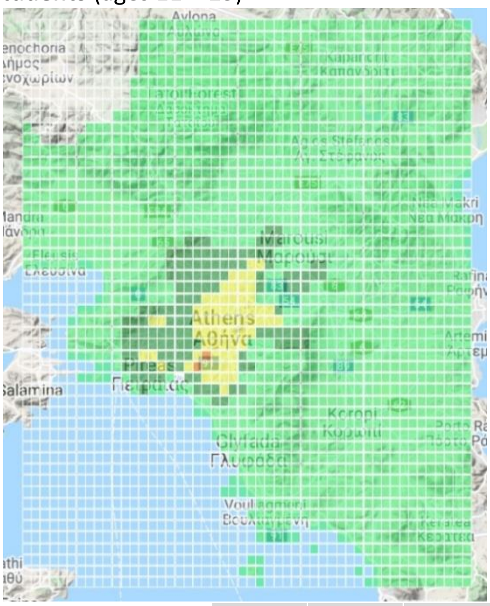
	Average	Minimum	Maximum
Athens Municipality	577	237	890
Municipalities of the metropolitan area of Athens	81	0	884

Elementary school children (ages 5 – 10)



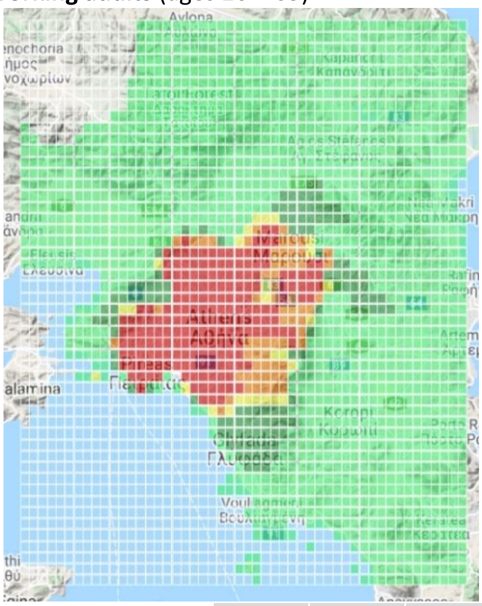
	Average	Minimum	Maximum
Athens Municipality	536	212	813
Municipalities of the metropolitan area of Athens	75	0	806

Students (ages 11 – 25)



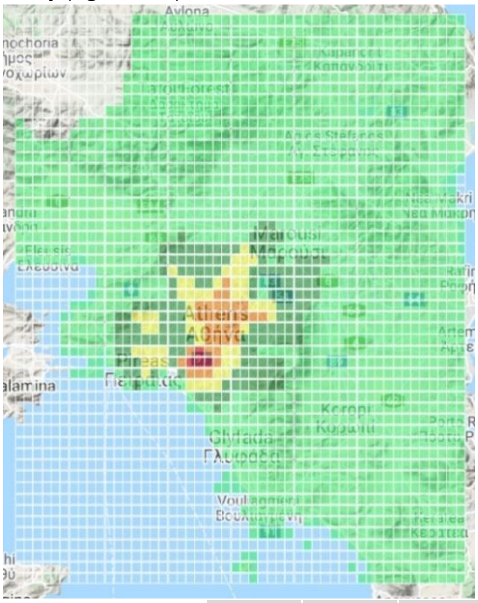
	Average	Minimum	Maximum
Athens Municipality	2127	780	2753
Municipalities of the metropolitan area of Athens	236	0	3048

Working adults (ages 26 – 65)



	Average	Minimum	Maximum
Athens Municipality	8471	3335	11779
Municipalities of the metropolitan area of Athens	905	0	12377

Elderly (ages > 65)



	Average	Minimum	Maximum
Athens Municipality	2709	1124	4052
Municipalities of the metropolitan area of Athens	262	0	4097

Figure 5.6 – Maps of spatial distribution (1 km x 1 km) of population across Athens for each population group, expressed in number of people (nop). The average, minimum and maximum population densities are expressed in nop/km^2.

POPULATION EXPOSURE

- The population exposure (the product of the pollutant concentration by the number of people exposed to it) was categorised into 5 subgroups, in addition to the overall group ("all groups"), for the Athens Municipality and the other municipalities of the metropolitan area of Athens.
- Table 5.3 shows the annual average exposure to PM and heavy metals, weighted by the number of people present in the Athens study case domain.
- In the Athens Municipality, in 2015 the population exposure was 510000 µg/m^3.nop for PM10 and 280000 µg/m^3.nop for PM2.5. Regarding the heavy metals, the highest population exposure was obtained for Pb (64000 ng/m^3.nop), followed by Ni (42000 ng/m^3.nop), As (32000 ng/m^3.nop) and Cd (4900 ng/m^3.nop).
- For the other municipalities of the metropolitan area of Athens, all the population was exposed to 49000 µg/m^3.nop for PM10 and 27000 µg/m^3.nop for PM2.5. For the heavy metals the highest population exposure was obtained for Pb (7100 ng/m^3.nop) followed by Ni (5400 ng/m^3.nop), As (4200 ng/m^3.nop) and Cd (600 ng/m^3.nop).
- Population exposure was higher in the Athens municipality not only because of the difference in the pollutant concentrations (Figure 5.4), but also because the number of people exposed is higher in the Athens municipality (Figure 5.5).

Table 5.3 – PM and heavy metals annual average exposure for each population group in Athens.

		PM10	PM2.5	As	Cd	Ni	Pb
		μg/m³.nop		ng/m³.nop			
Athens Municipality	All groups	510000	280000	32000	4900	42000	64000
	Pre-school children	22000	12000	1300	200	1700	2600
	Elementary school children	21000	11000	1200	190	1600	2400
	Students	81000	44000	4900	740	6400	9700
	Working adults	300000	170000	19000	2800	25000	37000
	Elderly	84000	48000	5700	880	7400	11000
Other municipalities of the metropolitan area of Athens	All groups	49000	27000	4200	600	5400	7100
	Pre-school children	2700	1400	230	32	290	380
	Elementary school children	2600	1300	210	29	270	350
	Students	8100	4300	680	95	860	1100
	Working adults	28000	16000	2500	340	3200	4100
	Elderly	7200	4100	660	95	830	1100

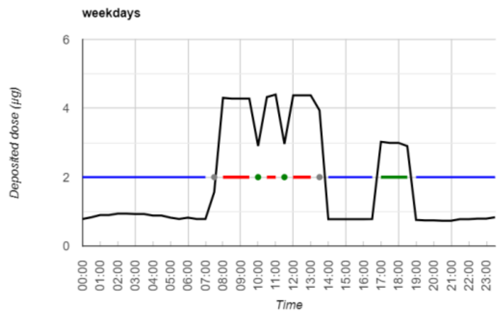
Deposited Dose

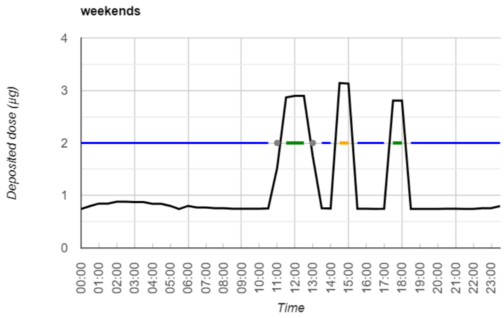
- The deposited dose is divided into 5 population sub-groups: pre-school children, elementary school children, students, working adults and elderly. The tool in this output estimates the PM10 and PM2.5 deposited doses (Figure 5.7 – Figure 5.10).
- For pre-school children the highest PM10 and PM2.5 deposited doses were obtained when the children were in school during the weekdays and outdoors or in indoor recreational places on the weekend. The lowest PM10 and PM2.5 deposited doses were observed at home for both weekdays and weekends.
- For the elementary school children and students, on weekdays the highest PM10 and PM2.5 deposited doses were observed at school and outdoors and the lowest were at home. On the weekends, the highest deposited doses were outdoors and in indoor recreational places, and the lowest were again at home. The difference between these two groups and the first (pre-school children) may be due to the age difference, which leads to diverse anatomical and physiological parameters that define inhalation and deposition of particles.
- For the working adults, on the weekdays the highest deposited doses were during commuting and at work, while on the weekends were again outdoors and in indoor recreational places. The lowest deposited dose was always at home, for both pollutants.
- For the elderly, the highest deposited doses were outdoors and the lowest were at home.
- In general, PM10 and PM2.5 deposited doses for the population sub-groups were higher on weekdays than on weekends, except for working adults.

PM10

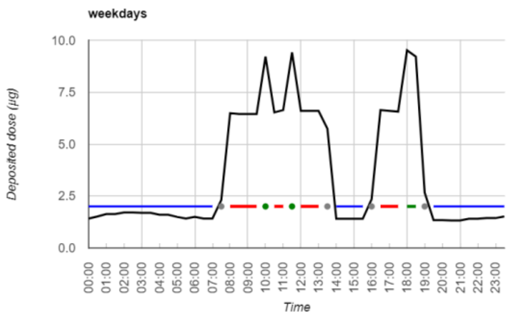
DD — Home — Commuting — School/Work — Outdoors — Indoors-Other

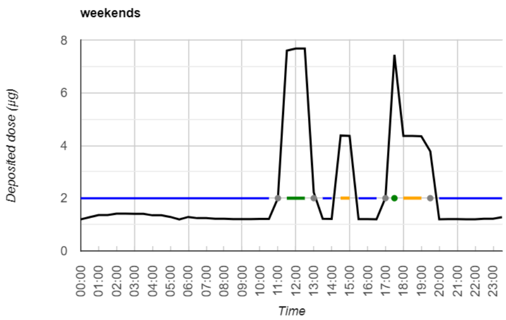
Pre-school children (ages 0 – 4)



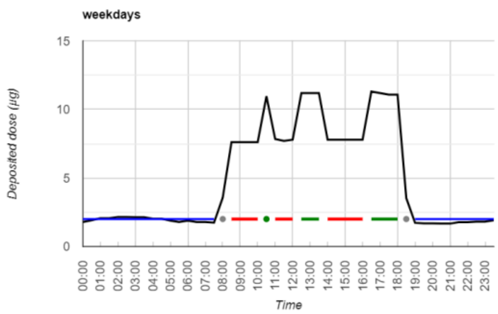


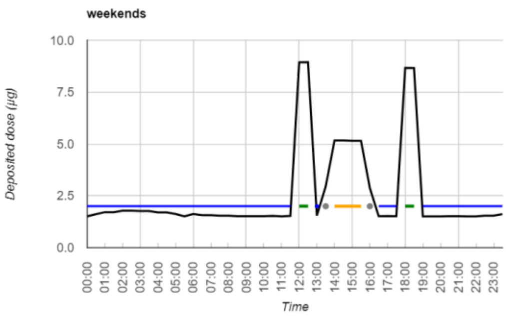
Elementary school children (ages 5 – 10)



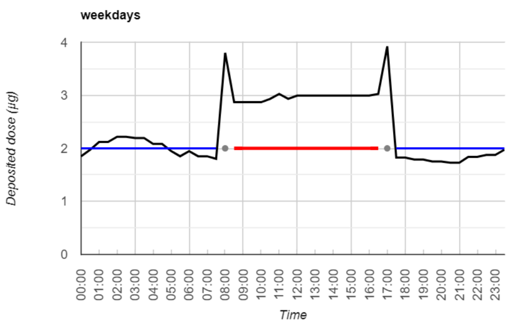


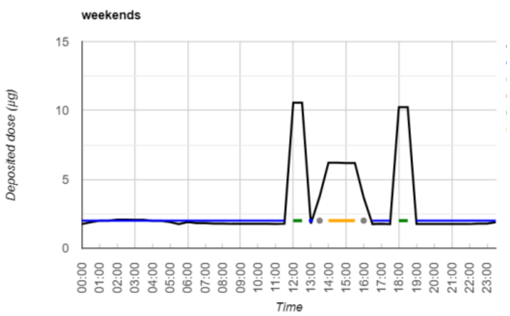
Students (ages 11 – 25)





Working adults (ages 26 – 65)





Elderly (ages > 65)

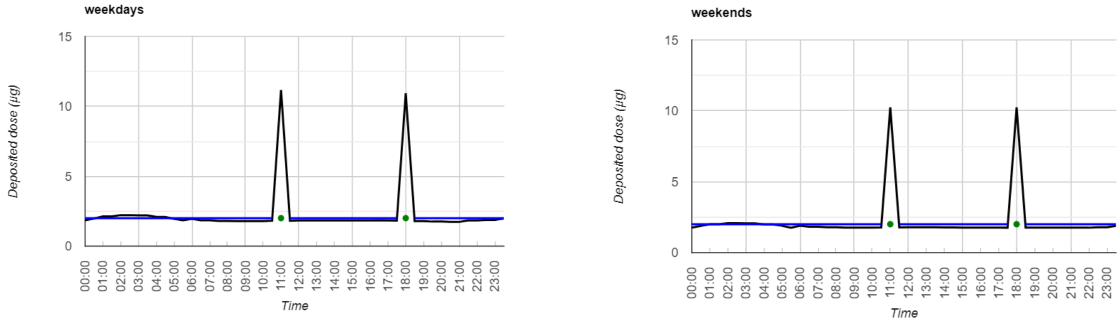


Figure 5.7 – PM10 deposited dose (in all regions of the respiratory tract) throughout the day, for each population group, in Athens.

- Considering the distribution of the PM10 deposited in the human respiratory tract (HRT) (Figure 5.8), the BB received the lowest deposited dose and the upper region (ET1 and ET2) the highest dose.
- Considering the distribution of the PM2.5 deposited in the HRT (Figure 5.10), the BB received the lowest deposited dose and the lower airways (Al) the highest.

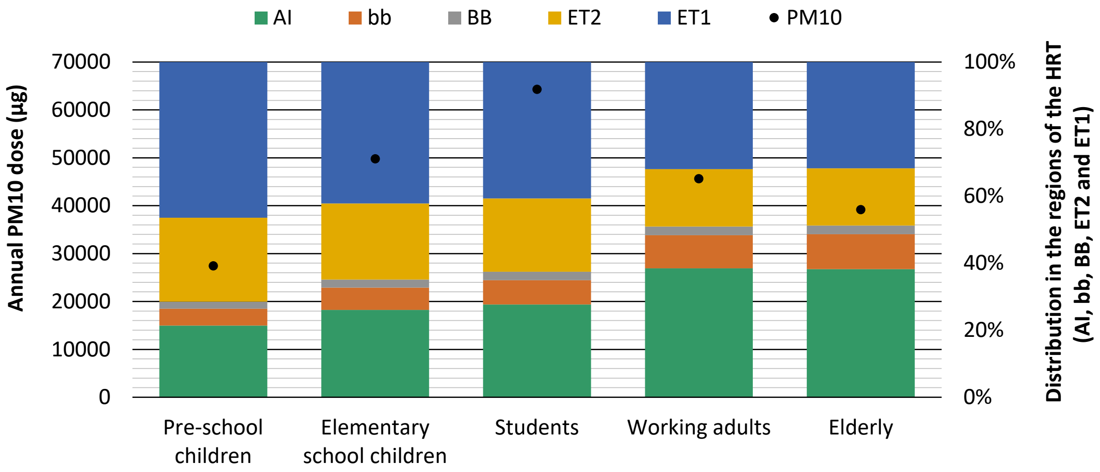
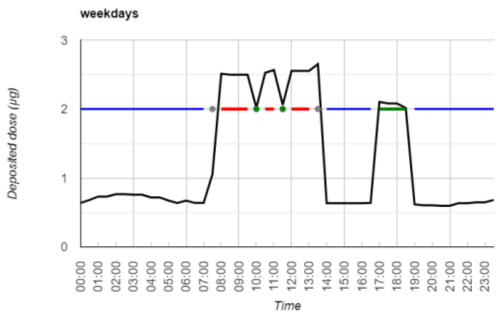


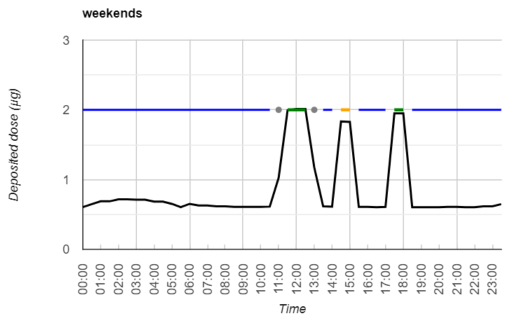
Figure 5.8 – Annual cumulative dose for PM10 (μg) and its distribution in the different regions of the HRT for each population group in Athens metropolitan area.

PM2.5

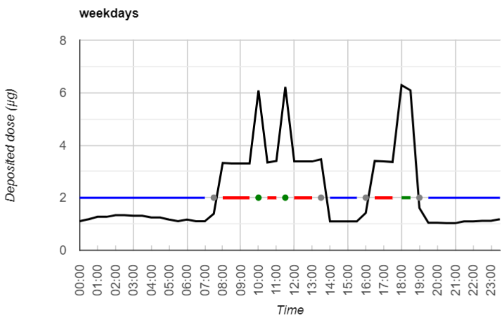
DD — Home — Commuting — School/Work — Outdoors — Indoors-Other

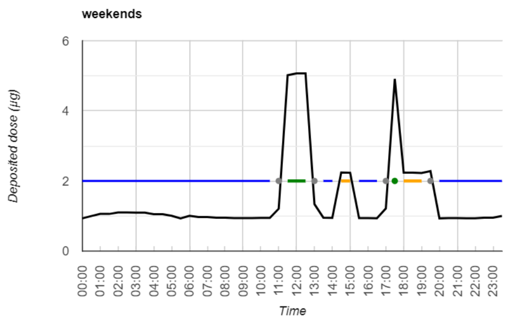
Pre-school children (ages 0 – 4)



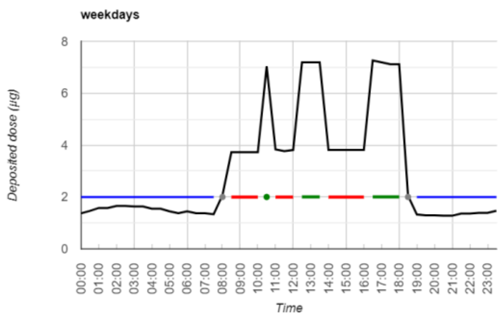


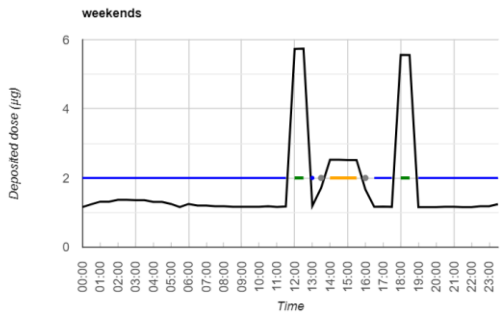
Elementary school children (ages 5 – 10)



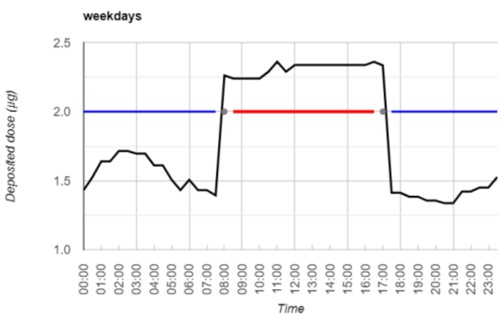


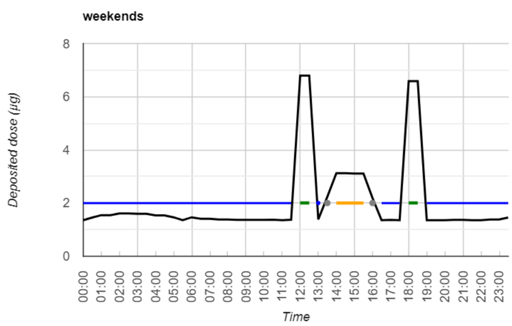
Students (ages 11 – 25)





Working adults (ages 26 – 65)





Elderly (ages > 65)

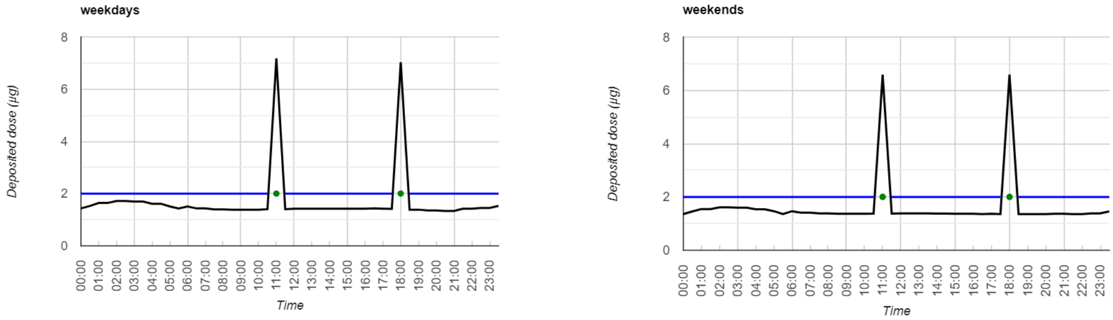


Figure 5.9 – PM2.5 deposited dose (in all regions of the respiratory tract) throughout the day, for each population group, in Athens.

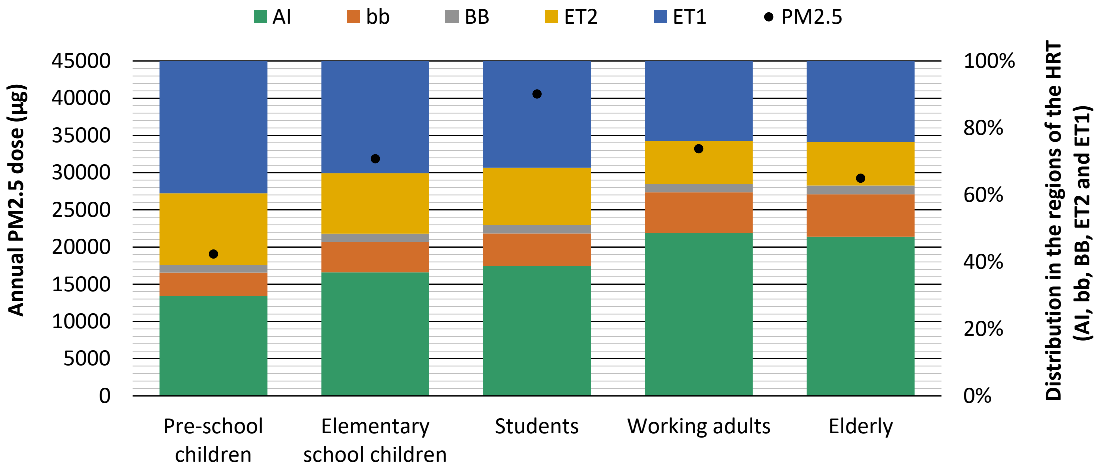


Figure 5.10 – Annual cumulative dose for PM2.5 (µg) and its distribution in the different regions of the HRT for each population group in Athens metropolitan area.

Burden of Disease

- The health impacts associated with exposure to PM2.5 concentration levels in 2015 were estimated using Burden of Disease (BoD) methods.
- BoD is a comparable metric to measure health losses, including both premature mortality and morbidity. In addition, estimates for sick days and school absenteeism are provided for elementary school children.
- BoD parameters are provided as a total for the whole city, as well as spatially distributed across the city.
- As shown in Table 5.4, BoD is quantified based on Upper Respiratory Infections in the case of the children population groups (pre-school children and elementary school children) and on Natural Mortality in the case of adults over 25 years old (adults and elderly).

- BoD is measured in disability adjusted life years (DALY), which is calculated as the sum of years of life lost due to premature mortality (YLL) and disability weighted years lived with disabilities (YLD), and may be expressed in YLL, YLD, DALY, or in number of deaths.
- In the Metropolitan area of Athens, for children and adults, DALY attributed to PM2.5 exposure was estimated equal to 2.20 (for upper respiratory infections) and 100000 (for natural mortality).
- The YLL and YLD estimations for adults over 25 years old were 66000 and 36000, respectively, whereas for children no impact was observed.
- In total, 4100 premature deaths were attributed to PM2.5 exposure in 2015.
- For elementary school children, exposure to PM2.5 resulted in 19000 sick days and 3500 days of school absenteeism, during 2015.

Table 5.4 – Upper respiratory infections and natural mortality per population sub-group in Athens metropolitan area.

	Upper Respiratory Infections			Natural Mortality		
	Pre-school children	Elementary school children	All groups	Working adults	Elderly	All groups
DALY	1.20	1.10	2.20	46000	56000	100000
YLL	0.00	0.00	0.00	23000	43000	66000
YLD	1.20	1.10	2.20	23000	13000	36000
Deaths	0.00	0.00	0.00	640	3400	4100
Sick days (mild)	–	11000	–	–	–	–
Sick days (moderate)	–	7200	–	–	–	–
Sick days (severe)	–	140	–	–	–	–
Days of school absenteeism	–	3500	–	–	–	–
Total sick days	–	19000	–	–	–	–

Built-up of Policy Making Scenarios

The builder scenarios are based on ANN algorithms. This is an approximation that causes a bias error on the result. The results of base case from CAMx model are not exactly equal to the ones obtained with ANN. For this reason, the modified scenarios outputs are compared with the base outputs obtained with the ANN algorithms.

The assessment of the modified scenarios/mitigation measures is performed by comparing the modified outputs for air quality, population exposure, deposited dose and burden of disease with the respective outputs for the base case. The mitigation measures tested in the tool are indicated in Table 2.1.

PM Ambient Concentrations

- Relative changes (%) in PM10 and PM2.5 concentrations between the reference case and the modified scenarios (S1 – S10) are indicated in Table 5.5. The base case values are in $\mu g/m^3$.
- The PM10 and PM2.5 concentrations are different among modified scenarios.
- The highest relative changes for PM10 concentrations, for both Athens municipality and other municipalities of the metropolitan area of Athens, were observed for scenario S2, where all cars are considered to be electric; in this case, the annual PM10 concentration was reduced by 2.1 $\mu g/m^3$ in the Athens municipality and by 0.8 $\mu g/m^3$ in the other municipalities, in comparison to the reference case.
- Assuming a modified apportionment of passenger cars in terms of EURO emission standards (50% of cars are EURO V and 50% are EURO VI) (scenario S4) had the highest impact in the average PM2.5 concentrations in the Athens municipality, allowing for a reduction of the mean annual PM2.5 concentration by 1.4 $\mu g/m^3$.
- The modified scenarios applied to buses fleet (S5 and S6) and cruise ships (S9 and S10) did not have significant impact on the average PM2.5 concentrations in the Athens municipality and the other municipalities of the metropolitan area of Athens. When no cruise shipping emissions were included (S10), the mean annual PM10 concentration in the Athens municipality was reduced by 1.3 $\mu g/m^3$.
- Changes in the passenger car fleet (S1-S4) seem to be more efficient in reducing PM concentrations in comparison to other mitigation measures; in addition, their impact is greater in the Athens municipality than in the other municipalities of the metropolitan area of Athens. This is expected given that the Athens municipality is densely populated, displaying many areas with heavy vehicular traffic.

Table 5.5 – Relative changes (%) in PM10 and PM2.5 concentrations between the reference case and the modified scenarios (S1 – S10) in Athens.

		Base	Road traffic						Residential heating		Cruise ships	
		Reference	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
		$\mu g/m^3$	Relative changes (%) in PM concentrations									
ATHENS MUNICIPALITY												
PM10	Annual	39	-5.4	-5.6	-2.5	-5.4	*	*	*	*	*	-3.3
	Winter	47	-5.6	-5.5	-2.3	-5.2	*	*	*	*	*	-3.4
	Summer	28	-5.4	-5.5	-2.4	-5.2	*	*	*	*	*	-3.3
	Spring	45	-5.4	-5.6	-2.6	-5.5	*	*	*	*	*	-3.3
	Autumn	39	-5.5	-5.6	-2.5	-5.3	*	*	*	*	*	-3.3
PM2.5	Annual	21	-5.0	-4.9	-2.3	-6.4	*	*	*	*	*	*
	Winter	25	-5.0	-5.0	-2.3	-6.4	*	*	*	*	*	*
	Summer	15	-5.0	-4.9	-2.3	-6.4	*	*	*	*	*	*
	Spring	24	-5.0	-4.9	-2.3	-6.4	*	*	*	*	*	*
	Autumn	21	-5.0	-5.0	-2.3	-6.4	*	*	*	*	*	*
OTHER MUNICIPALITIES OF THE METROPOLITAN AREA OF ATHENS												
PM10	Annual	28	-2.6	-2.8	*	-2.5	*	*	*	*	*	*
	Winter	26	-2.7	-2.9	*	-2.7	*	*	*	*	*	*
	Summer	19	-2.6	-2.8	*	-2.5	*	*	*	*	*	*
	Spring	35	-2.5	-2.7	*	-2.4	*	*	*	*	*	*
	Autumn	26	-2.5	-2.8	*	-2.5	*	*	*	*	*	*
PM2.5	Annual	15	*	*	*	*	*	*	*	*	*	*
	Winter	14	*	*	*	*	*	*	*	*	*	*
	Summer	10	*	*	*	*	*	*	*	*	*	*
	Spring	18	*	*	*	*	*	*	*	*	*	*
	Autumn	14	*	*	*	*	*	*	*	*	*	*

* Value is within the range of uncertainty of the Tool (± 2%).

POPULATION EXPOSURE

- Relative changes (%) in PM10 and PM2.5 population exposure between the reference case and the modified scenarios (S1 – S10) are indicated in Table 5.6. The base case values are in $\mu g/m^3 \cdot$ nop.
- Similar to the PM ambient concentrations, the PM10 and PM2.5 population exposures are also different among modified scenarios.
- Exposure to PM is more affected by mitigation measures related to vehicular traffic, and especially the passenger vehicle fleet, for both PM10 and PM2.5.
- In the Athens municipality, the total electrification of the passenger cars' fleet (scenario S2), for PM10 exposure, and the modified share of the fleet (50% EURO V and 50% EURO VI) (scenario S4), for both PM10 and PM2.5 exposures, displayed the highest impacts. Both measures achieved an annual reduction of PM10 exposure by 30000 $\mu g/m^3 \cdot$ nop for the total population and up to 20000 $\mu g/m^3 \cdot$ nop, depending on the age group. Scenario S4 resulted in an annual reduction of PM2.5 exposure by 10000 $\mu g/m^3 \cdot$ nop for the total population.
- In the other municipalities of the metropolitan area of Athens, all four measures related to the passenger vehicle fleet (S1 – S4), resulted in a similar reduction of 1000 $\mu g/m^3 \cdot$ nop for both PM10 and PM2.5 exposures.

Table 5.6 – Relative changes (%) in PM10 and PM2.5 population exposure between the reference case and the modified scenarios (S1 – S10) in Athens.

		Base	Road traffic						Residential heating		Cruise ships	
		Reference	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
		μg/m³ · nop	Relative changes (%) in PM population exposure									
ATHENS MUNICIPALITY												
PM10	All groups	420000	-4.8	-7.1	-2.4	-7.1	-2.4	-4.8	*	*	*	*
PM10	Pre-school children	18000	-5.6	-5.6	-5.6	-5.6	-5.6	-5.6	*	*	*	*
PM10	Elementary school children	17000	-5.9	-5.9	*	-5.9	-5.9	-5.9	*	*	*	*
PM10	Students	67000	-4.5	-6.0	-3.0	-6.0	-3.0	-3.0	*	*	*	*
PM10	Working adults	240000	-4.2	-8.3	-4.2	-8.3	-4.2	-4.2	*	*	*	*
PM10	Elderly	69333	-4.3	-5.8	-2.9	-5.8	-2.9	-2.9	*	*	*	*
PM2.5	All groups	230000	*	*	*	-4.3	*	*	*	*	*	*
PM2.5	Pre-school children	9700	-3.1	-3.1	*	-4.1	*	*	*	*	*	*
PM2.5	Elementary school children	9200	-3.3	-3.3	*	-4.3	*	*	*	*	*	*
PM2.5	Students	36000	-2.8	-2.8	*	-2.8	*	*	*	*	*	*
PM2.5	Working adults	140000	-7.1	-7.1	-7.1	-7.1	*	*	*	*	*	*
PM2.5	Elderly	40000	-2.5	-2.5	*	-5.0	*	*	*	*	*	*
OTHER MUNICIPALITIES OF THE METROPOLITAN AREA OF ATHENS												
PM10	All groups	58000	*	*	*	*	*	*	*	*	*	*
PM10	Pre-school children	3200	-3.1	-3.1	-3.1	-3.1	*	*	*	*	*	*
PM10	Elementary school children	3033	-3.3	*	*	-3.3	*	*	*	*	*	-3.2
PM10	Students	9433	-2.2	*	*	-2.2	*	*	*	*	*	*
PM10	Working adults	33333	-3.0	-3.0	-3.0	-3.0	*	*	*	*	-2.9	-2.9
PM10	Elderly	8600	-2.4	-2.4	*	-2.4	*	*	*	*	*	*
PM2.5	All groups	32000	-3.1	-3.1	-3.1	-3.1	*	*	*	*	*	*
PM2.5	Pre-school children	1700	*	*	*	*	*	*	*	*	*	*
PM2.5	Elementary school children	1600	*	*	*	*	*	*	*	*	*	*
PM2.5	Students	5067	*	*	*	-3.9	*	*	*	*	*	*
PM2.5	Working adults	18000	*	*	*	*	*	*	*	*	*	*
PM2.5	Elderly	4900	-2.0	-2.0	*	-2.0	*	*	*	*	*	*

* Value is within the range of uncertainty of the Tool (± 2%).

DEPOSITED DOSE

- Relative changes (%) in PM10 and PM2.5 deposited dose between the reference case and the modified scenarios (S1 – S10) are indicated in Table 5.7. The base case values are in μg.
- Reductions in the PM10 and PM2.5 deposited dose were observed for scenarios S1 and S2, which relate to the replacement of all diesel passenger vehicles with electric and the total electrification of the passenger car fleet, respectively.
- The highest relative changes for PM10 and PM2.5 deposited dose were observed for working adults, while no impact was observed for pre-school and elementary school children.

Table 5.7 – Relative changes (%) in PM10 and PM2.5 deposited dose between the reference case and the modified scenarios (S1 – S10) in Athens.

		ATHENS METROPOLITAN AREA										
		Base	Road traffic						Residential heating		Cruise ships	
		Reference	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
		μg	Relative changes (%) in PM deposited dose									
PM10	Pre-school children	28667	*	*	*	*	*	*	*	*	*	*
	Elementary school children	52035	*	*	*	*	*	*	*	*	*	*
	Students	67461	*	-2.1	*	*	*	*	*	*	*	*
	Working adults	47980	-2.0	-2.2	*	*	*	*	*	*	*	*
	Elderly	41034	*	-2.0	*	*	*	*	*	*	*	*
PM2.5	Pre-school children	19967	*	*	*	*	*	*	*	*	*	*
	Elementary school children	33351	*	*	*	*	*	*	*	*	*	*
	Students	42623	*	-2.1	*	*	*	*	*	*	*	*
	Working adults	34952	-2.1	-2.2	*	*	*	*	*	*	*	*
	Elderly	30638	*	*	*	*	*	*	*	*	*	*

* Value is within the range of uncertainty of the Tool (± 2%).

BURDEN OF DISEASE

- Relative changes (%) in health impacts due to exposure to PM2.5 between the reference case and the modified scenarios (S1 – S10) are indicated in Table 5.8. The base case values are in number.
- Changes in the buses fleet (S5 and S6) and cruise ships (S9 and S10) have negligible effects on health impacts (most of the values are within the range of uncertainty of the Tool).
- The highest impacts were observed for mitigation measures targeting the passenger car fleet, and specifically, the replacement of all diesel passenger cars by electric (S1), the total electrification of the passenger cars' fleet (S2), and the modified distribution of EURO emission standards on the fleet (50% EURO V and 50% EURO VI) (scenario S4). These measures resulted in a reduction of 200 days in the number of days of school absenteeism for elementary school children. In the case of adults, the reductions achieved are:
  - 200 deaths
  - 4000 disability adjusted life years
  - 3000 years of life lost due to premature mortality
  - 2000 years lived with disabilities.

Table 5.8 – Relative changes (%) in health impacts due to exposure to PM2.5 between the reference case and the modified scenarios (S1 – S10) in Athens.

		ATHENS METROPOLITAN AREA										
		Base	**Road traffic**						**Residential heating**		**Cruise ships**	
		Reference	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
		no.	**Relative changes (%) in health impacts due to exposure to PM2.5**									
Upper respiratory infections - Elementary school children	Sick days (mild)	11000	*	*	*	*	*	*	*	*	*	*
	Sick days (moderate)	7000	-4.3	-4.3	*	-4.3	*	*	*	*	*	*
	Sick days (severe)	140	-7.1	-7.1	*	-7.1	*	*	*	*	*	*
	Days of school absenteeism	3500	-5.7	-5.7	-2.9	-5.7	*	*	*	*	*	*
	Total sick days	18000	*	*	*	*	*	*	*	*	*	*
Natural Mortality - all groups	DALY	100000	-4.0	-4.0	*	-4.0	*	*	*	*	*	*
	YLL	65000	-4.6	-4.6	*	-4.6	*	*	*	*	*	*
	YLD	35000	-5.7	-5.7	-2.9	-5.7	*	*	*	*	*	*
	Deaths	4000	-5.0	-5.0	-2.5	-5.0	*	*	*	*	*	*

* Value is within the range of uncertainty of the Tool (± 2%).

6. IMPLEMENTATION OF THE MANAGEMENT TOOL IN KUOPIO

CHARACTERISATION OF KUOPIO

PHYSICAL GEOGRAPHY

Kuopio municipality is located in central of Finland in North Savo region at a latitude of 62.89 and longitude of 27.68. The total area of Kuopio was 3 726 km^2 in 2015. The LIFE Index-Air tool modelling domain size was 324 km^2, covering the central areas of Kuopio. Kuopio belongs to a boreal region, which has a vast expanse of coniferous forests, lakes and mires. Central areas of Kuopio are largely surrounded by the Lake Kallavesi.

DEMOGRAPHY

Kuopio was the eight most populous city in Finland in 2015 with 111 thousand inhabitants and a population density of 57 inhabitants per square kilometre. Most of the population lived in the central areas with 84 thousand inhabitants and population density of 415 inhabitants/km^2 (Statistics Finland, 2018a)(Statistics Finland, 2021).

CLIMATE

In North Savo region the annual average temperature is +2...+3 ˚C. The coldest months are January and February (-9…-11 ˚C) and the warmest July (+15.5…+17 °C). Annual precipitation ranges from 550 to 650 mm. Rainiest month is usually August (80-90 mm) and driest February-April (30-35 mm) (Kersalo & Pirinen, 2009). In Finland wind blows most commonly from southwest and least commonly from northeast. Relative humidity in the air is lowest in May-June (65-70%) and highest in November (90%) (FMI, 2021).

TRANSPORT

Road traffic

In Kuopio there were 53.1 thousand passenger cars and 122 busses registered for the traffic use in 2015 (Statistics Finland, 2018b). On average 2.7 travels/day were made in Finland in 2016. Kuopio is classified as one of the big cities of Finland, and typically in these cities 38% of the travels are made by walking or cycling, 7% by busses, and 43% by car. Average distance travelled per day was around 39 kilometres/person. Most of the distance was travelled by a car (driver 17.8km and passenger 10 km) and least by walking (1.2km) or by bike (1km) (Finnish Transport Agency, 2018).

Rail traffic

The main railway runs through the central parts of Kuopio. On daily basis approximately 5 to 10 express trains pass through along with freight trains. In 2015 number of train travels made to north was 280 and to south 580 thousand (Finnish Transport Agency, 2016).

Maritime traffic

In the summertime (June-August) Kuopio passenger harbour is the base for the small ship daily cruises around the Lake Kallavesi. Deep port of Kumpusaari is handling the freight traffic. Freight traffic in Kuopio is small-scale with 41 visits by domestic freight ships in 2015 (Statistics Finland, 2018b).

Air traffic

Kuopio airport is situated roughly 14km to the north of Kuopio city centre. In 2015 number of landings was around 2000 and number of passengers 230 thousand (Finavia, 2021).

INDUSTRY

Most important point sources of air pollution emissions in 2015 were Kuopion Energia power plant in Haapaniemi located 1.5km to south from city centre and Mondi Powerflute mill in Sorsasalo (about 6 km to north from city centre) manufacturing semi-chemical fluting (Kuopion kaupunki, 2016).

ATMOSPHERIC POLLUTION

The main local emission sources of air pollutants are road traffic and residential combustion, especially in areas without central district heating. Long-range transport contributes largely to concentrations of fine particulate matter. Street dust in springtime raises concentrations of particulate matter due to traction sand and studded tires, which are used during winters. In the spring when snow and ice have melted and streets dried, dust particles are released to air, worsening the air quality (Kuopion kaupunki, 2016).

Base Case

The base case scenario corresponds to the air quality condition verified over the city of Kuopio in the year 2015. The base case is based on the CAMx model integrated with the data obtained in the air monitoring stations.

Emissions

In Kuopio municipality total emissions ranged from 21 tons (SO_2) to 2063 tons per year (VOC) and heavy metal emissions from 0.3 (Pb) to 3.5 kilograms per year (Ni) (Table 6.1). In the other municipalities emissions were considerably lower.

Table 6.1 – Total emissions of the main pollutants (tons or kilograms / year) in 2015 for the Kuopio municipality and the other municipalities in the modelling domain.

	NH_3	NOx	SO_2	VOC	PM10	PM2.5	As	Cd	Ni	Pb
	Total									
	t/year						kg/year			
Kuopio Municipality	29	495	21	2063	295	126	2.7	0.4	3.5	0.3
Other municipalities of the metropolitan area of Kuopio	2	44	6	49	7	5	0.1	0.0	0.2	0.0

Road transport sector were the largest source for PM10 (75%), PM2.5 (48%) and NO_X (73%), combustion in manufacturing industry & production processes sector for SO_2 (57%) and for the heavy metals (56-83%), agriculture for NH_3 (65%) and solvent and other product use for VOC (53%) (Figure 6.1). In the other municipalities the largest source for all pollutants was combustion in manufacturing industry and production processes (Figure 6.2).

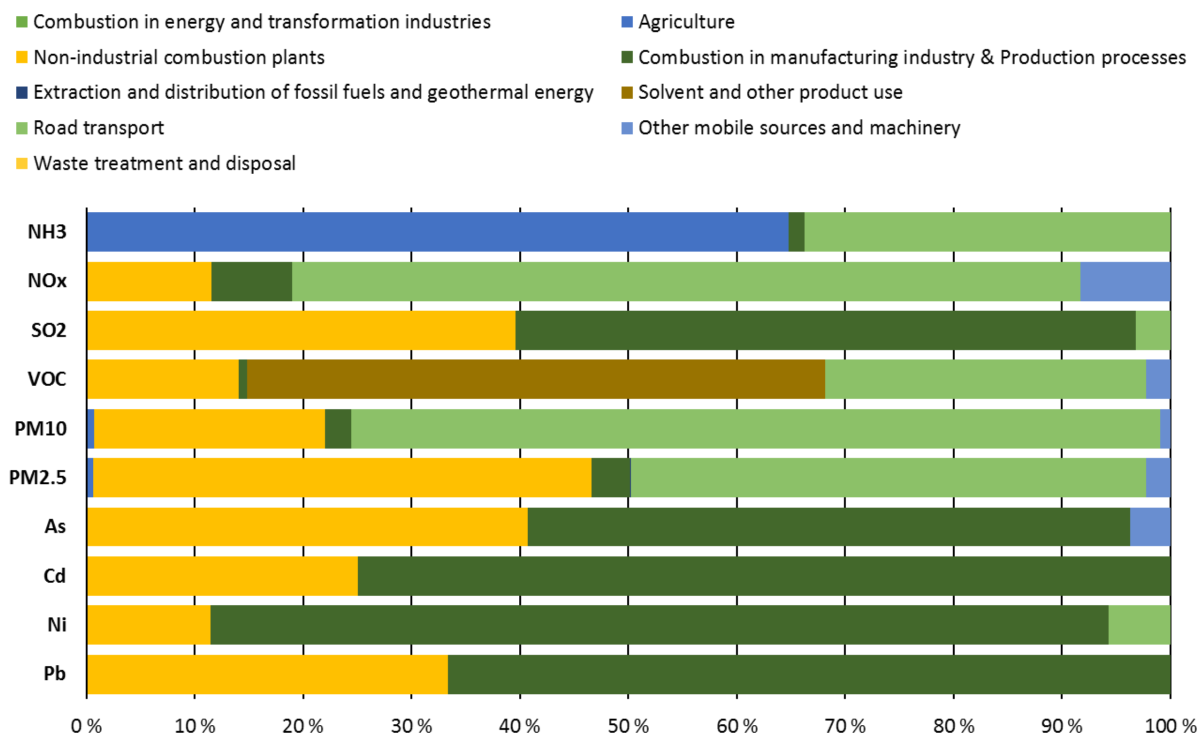


Figure 6.1 – Share of Kuopio municipality emissions (in %) of the main pollutants, by sector group in 2015.

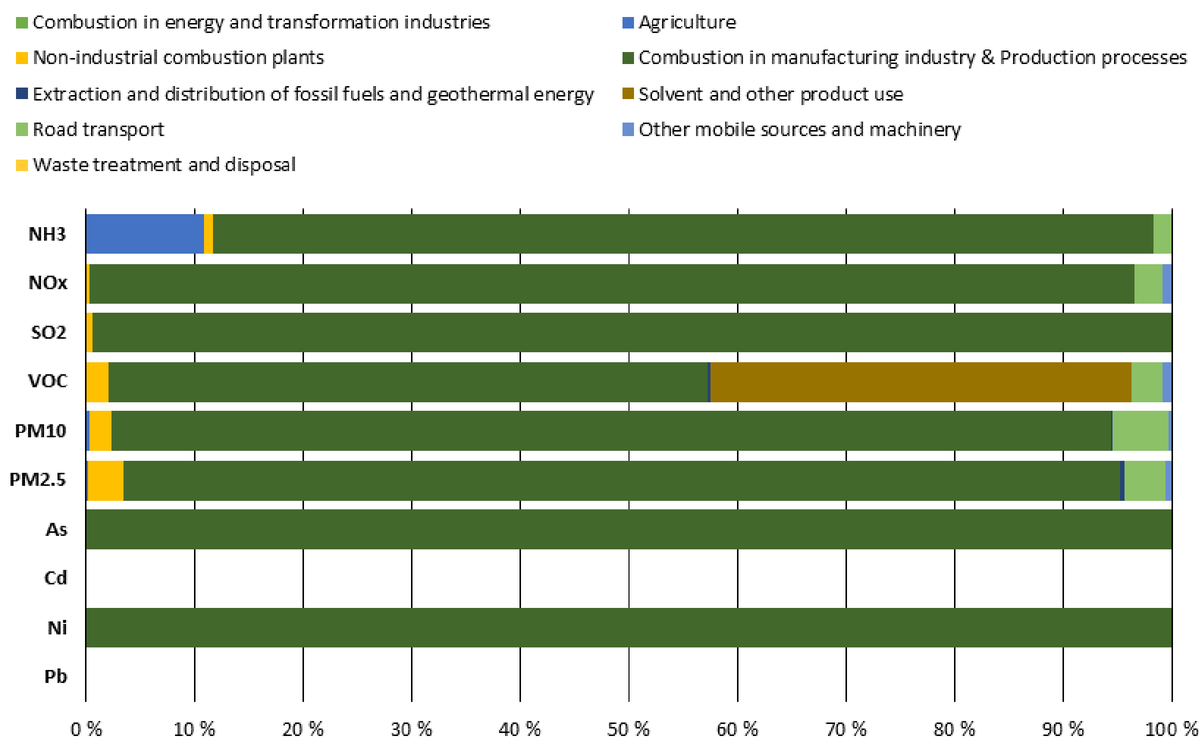


Figure 6.2 – Share of the other municipalities emissions (in %) of the main pollutants, by sector group in 2015.

AMBIENT CONCENTRATIONS

The annual average concentration over the Kuopio municipality for PM2.5 was 6.2 µg/m^3 with minimum and maximum of 6 and 7 µg/m^3, respectively, and 11.9 µg/m^3 (11.1 – 13.9 µg/m^3) for PM10 (Table 6.2). Heavy metal concentration of arsenic and cadmium were around 0.2 ng/m^3, nickel 0.6 ng/m^3 and lead 1.6 ng/m^3. In other municipalities concentrations were only slightly lower.

Table 6.2 – Annual average ambient concentrations of PM (in µg/m^3) and heavy metals (in ng/m^3) in Kuopio municipality and the other municipalities in the modelling domain.

		PM10	PM2.5	As	Cd	Ni	Pb
		µg/m^3		ng/m^3			
Kuopio Municipality	**Average**	11.92	6.23	0.20	0.16	0.61	1.59
	Minimum	11.11	5.97	0.17	0.15	0.55	1.46
	Maximum	13.89	7.02	0.21	0.17	0.65	1.67
Other municipalities of the metropolitan area of Kuopio	**Average**	11.41	6.09	0.18	0.15	0.56	1.47
	Minimum	11.15	5.98	0.17	0.15	0.54	1.45
	Maximum	12.01	6.30	0.18	0.16	0.58	1.50

PM10 Exceedances

For PM10 daily limit value of 50 µg/m^3 is the objective of protecting human health and environment (EU directive 2008/50/EC), which should not be exceeded more than 35 times a year. In Kuopio municipality this value was exceeded 3 times in 2015 (Table 6.3).

Table 6.3 – Number of PM10 exceedance days in 2015 for Kuopio and the other municipalities in the modelling domain.

	Minimum	Maximum
Kuopio Municipality	3	3
Other municipalities of the metropolitan area of Kuopio	3	3

POPULATION GROUPS

The population in the study area was divided into 5 sub-groups. Pre-school children (< 5 years old), elementary school children (5-10 years old), students (11-25 years old), working adults (26-65 years old) and elderly (> 65 years old). Average population density in Kuopio municipality was 222 inhabitants per grid cell. The largest fraction of the population was working adults (51%), followed by students (20%) and elderly (18%). Share of elementary school and pre-school children were 5.4% and 5.0%, respectively.

Table 6.4 – The average, minimum and maximum population densities in Kuopio municipality per grid cell.

	Average	Minimum	Maximum
	(number of people / grid cell)		
All groups	222	0	2658
Pre-school children (< 5 years old)	11	0	80
Elementary school children (5-10 years old)	12	0	92
Students (11-25 years old)	44	0	465
Working adults (26-65 years old)	114	0	1382
Elderly (> 65 years old)	40	0	700

POPULATION EXPOSURE

The annual average exposure to PM and heavy metals was weighted by the number of people (nop) present in the Kuopio study case domain. The average population exposure in Kuopio municipality (all age groups) to PM2.5 and PM10 were 1600 and 2700 µg/m^3.nop, respectively (Table 6.5). Heavy metal exposures ranged from 33 (Cd) to 240 (Pb) ng/m^3.nop. In the other municipalities exposures were close to zero.

Table 6.5 – PM and heavy metals annual average exposure for each population group in Kuopio municipality and the other municipalities in the modelling domain.

		PM10	PM2.5	As	Cd	Ni	Pb
		µg/m^3.nop		ng/m^3.nop			
Kuopio Municipality	All groups	2700	1600	38	33	120	240
	Pre-school children	150	83	1.9	1.6	6	12
	Elementary school children	160	92	2.1	1.9	6.8	13
	Students	590	340	7.8	6.8	25	48
	Working adults	1300	740	19	16	60	130
	Elderly	250	260	6.5	5.7	21	43
Other municipalities of the metropolitan area of Kuopio	All groups	0.11	0.07	0	0	0	0.01
	Pre-school children	0.01	0	0	0	0	0
	Elementary school children	0.01	0	0	0	0	0
	Students	0.03	0.01	0	0	0	0
	Working adults	0.05	0.03	0	0	0	0.01
	Elderly	0	0.01	0	0	0	0

DEPOSITED DOSE

The highest cumulative daily PM2.5 dose among pre-school children (25 µg), elementary school children (36.3 µg) and students (39.7 µg) were obtained during the workdays (Table 6.6). Among the elderly, due the similar daily routines in the workdays and weekends, doses were only slightly higher during the workdays (27.9 µg) in comparison to weekends (27.2 µg). Among the working adults the highest doses were obtained in the weekend days (32.8 µg).

Table 6.6 – Daily cumulative dose for PM2.5 (µg) and its distribution in the different regions of the human respiratory tract (HRT) for each population subgroup in Kuopio.

		ET1	ET2	BB	bb	AI	All regions
Pre-school children	Workdays	9.6	5.2	0.6	1.7	7.9	25.0
	Weekends	5.4	2.9	0.3	1.0	4.3	13.9
Elementary school children	Workdays	11.5	6.2	0.9	3.5	14.1	36.3
	Weekends	8.2	4.4	0.6	2.2	8.8	24.2
Students	Workdays	10.9	5.9	1.0	4.5	17.4	39.7
	Weekends	8.1	4.4	0.7	3.0	11.6	27.8
Working adults	Workdays	7.2	3.9	0.7	3.4	13.9	29.0
	Weekends	9.1	4.9	0.8	3.5	14.6	32.8
Elderly	Workdays	7.4	4.0	0.7	3.2	12.8	27.9
	Weekends	7.2	3.9	0.7	3.1	12.4	27.2

Annually the highest PM2.5 dose was received by the students (12 360 µg) and the lowest by the pre-school children (7470 µg) (Figure 6.3). Most of the PM2.5 dose (70-73%) was accumulated to alveolar interstitial (AI) and anterior nasal passage (ET1).

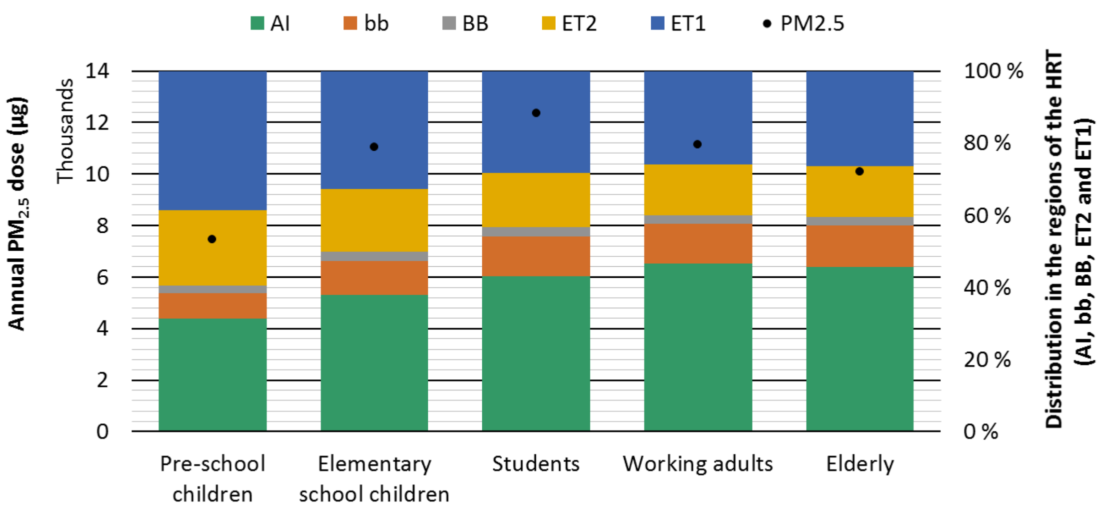


Figure 6.3 – Annual cumulative dose for PM2.5 (µg) and its distribution in the different regions of the human respiratory tract (HRT) for each population group in Kuopio.

The highest daily PM10 dose among pre-school children (57.7 µg), elementary school children (96.6 µg) and students (113.8 µg) were obtained during the workdays (Table 6.7). Among the elderly doses were only slightly higher during the workdays (77.4 µg) in comparison to weekends (75.3 µg). Among the working adults the highest doses were obtained in the weekend days (89.1 µg).

Table 6.7 – Daily cumulative dose for PM10 (µg) and its distribution in the different regions of the human respiratory tract (HRT) for each population subgroup in Kuopio.

		ET1	ET2	BB	bb	AI	All regions
Pre-school children	Workdays	30.1	16.2	1.0	1.9	8.5	57.7
	Weekends	16.8	9.0	0.6	1.2	4.7	32.2
Elementary school children	Workdays	46.2	24.9	2.2	4.9	18.4	96.6
	Weekends	29.9	16.1	1.4	3.1	11.5	62.0
Students	Workdays	51.3	27.6	2.8	7.2	24.9	113.8
	Weekends	35.1	18.9	1.9	4.8	16.5	77.2
Working adults	Workdays	35.1	18.9	2.0	5.4	20.0	81.5
	Weekends	39.4	21.2	2.2	5.6	20.7	89.1
Elderly	Workdays	33.7	18.2	1.9	5.2	18.4	77.4
	Weekends	32.8	17.7	1.9	5.0	17.9	75.3

Annually the highest PM10 dose was received by the students (34 940 µg) and the lowest by the pre-school children (17298 µg) (Figure 6.4). Most of the PM10 dose (70-80%) among the pre-school and elementary school children and students were accumulated to upper region namely to anterior (ET1) and posterior (ET2) nasal passage, followed by alveolar interstitial (15-22%). Among working adults and eldelry PM10 was accumulated to anterior nasal passage (ET1, 44%), followed by alveolar interstitial (AI, 24%) and posterior nasal passage (ET1, 23%).

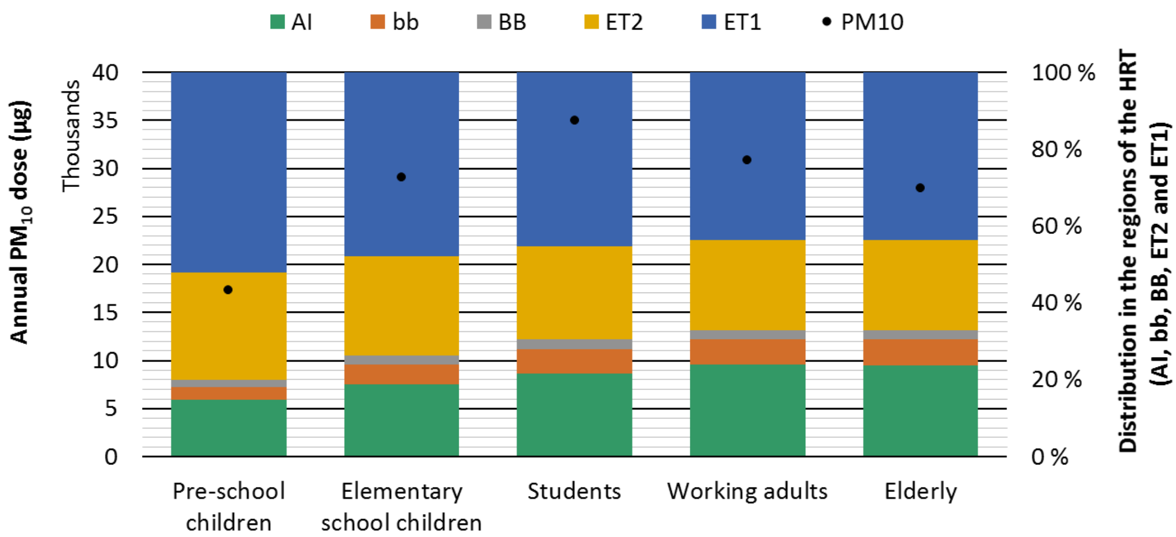


Figure 6.4 – Annual cumulative dose for PM10 (µg) and its distribution in the different regions of the human respiratory tract (HRT) for each population group in Kuopio.

Burden of Disease

The health impacts associated to PM2.5 exposure were estimated using Burden of Disease (BoD) method, which is measured in disability adjusted life years (DALY) calculated as the sum of years of life lost (YLL) due to premature mortality and disability weighted years lived with disabilities (YLD), and may be expressed in YLL, YLD, DALY or in number of deaths. BoD was quantified based on upper respiratory infections in the case of the children (pre-school and elementary school children) and on natural mortality in the case of adults over 25 years old (working adults and elderly).

In Kuopio municipality it was estimated that for children 0.026 DALYs and for adults 1060 DALYs and 41 premature deaths were attributed to PM2.5 exposure (Table 6.8). Among children PM2.5 exposure was estimated to be associated with in total 230 sick days of which 140 were mild, 86 moderate and 1.7 severe.

Table 6.8 – Upper respiratory infections and natural mortality attributable to PM2.5 exposure per population sub-group in Kuopio.

	Upper Respiratory Infections (n)			Natural Mortality (n)		
	Pre-school children	**Elementary school children**	**All groups**	**Working adults**	**Elderly**	**All groups**
DALY	0.014	0.012	0.026	480	580	1060
YLL	0.000	0.000	0.000	240	430	670
YLD	0.014	0.012	0.026	240	150	390
Deaths	0.000	0.000	0.000	7	34	41
Sick days (mild)	–	140	–	–	–	–
Sick days (moderate)	–	86	–	–	–	–
Sick days (severe)	–	1.7	–	–	–	–
Days of school absenteeism	–	45	–	–	–	–
Total sick days	–	230	–	–	–	–

Built-up of Policy Making Scenarios

In total 8 emission reduction scenarios were applied in Kuopio (S1-S8, Table 2.1). In scenarios 1-6 electrification, reduction or renewal of the passenger car or bus fleet were considered. In scenario 7 inefficient small-scale combustion devices were replaced with more efficient ones and in scenario 8 total consumption of wood was reduced by 20%. The results that were within the range of the uncertainty of the tool (± 2% change in comparison to base scenario reference value) were not considered to be effective enough.

PM Ambient Concentrations

Considering all passenger cars as electric (S2) and replacing inefficient small-scale wood combustion devices with more efficient (S7) resulted to PM10 concentration reductions of -2.4% and -4.2%, respectively (Table 6.9). Reducing wood consumption by -20% suggested that PM10 concentrations would increase by 2%. There was no reduction in concentrations in other municipalities.

Table 6.9 – Base scenario PM concentrations (µg/m^3) in Kuopio municipality and the other municipalities in the modelling domain and reduction (%) when road traffic (S1-S6) and residential heating scenarios (S7-S8) are applied.

		Base	Road traffic						Residential heating	
		Reference	S1	S2	S3	S4	S5	S6	S7	S8
		µg/m^3	Relative changes (%) in PM concentrations							
KUOPIO MUNICIPALITY										
PM10	Annual	11.7	*	-2.4	*	*	*	*	-4.2	2.0
PM2.5	Annual	6.3	*	*	*	*	*	*	*	*
OTHER MUNICIPALITIES OF THE METROPOLITAN AREA OF KUOPIO										
PM10	Annual	11.7	*	*	*	*	*	*	*	*
PM2.5	Annual	6.2	*	*	*	*	*	*	*	*

* Value is within the range of uncertainty of the Tool (± 2%).

Population Exposure

The highest reduction of PM10 exposures were achieved with residential heating scenarios (S7 and S8) ranging from -15% among pre-school children to -22% among working adults (Table 6.10). Replacing diesel passenger cars with electric cars resulted to PM10 reduction of -3.1%, -6.7% and -2% among all groups, working adults and elderly, respectively. In other municipalities residential heating scenarios resulted in around 50 to 60 % reduction of PM10 exposures among all groups.

Table 6.10 – The base scenario of PM exposures (µg/m^3 · nop) in Kuopio municipality and the other municipalities in the modelling domain and the reduction (%) of exposure when road traffic (S1-S6) and residential heating scenarios (S7-S8) are applied.

		Base	Road traffic						Residential heating	
		Reference	S1	S2	S3	S4	S5	S6	S7	S8
		µg/m^3 · nop	Relative changes (%) in PM population exposure							
KUOPIO MUNICIPALITY										
PM10	All groups	3400	-3.1	*	*	*	*	*	-13.9	-13.9
	Pre-school children	185	*	*	*	*	*	*	-15.0	-15.0
	Elementary school children	205	*	*	*	*	*	*	-18.2	-18.2
	Students	760	*	*	*	*	*	*	-16.0	-14.8
	Working adults	1650	-6.7	*	*	*	*	*	-22.2	-22.2
	Elderly	525	-2.0	*	*	*	*	*	-16.1	-16.1
PM2.5	All groups	2000	*	*	*	*	*	*	*	*
	Pre-school children	100	*	*	*	*	*	*	*	*
	Elementary school children	110	*	*	*	*	*	*	*	*
	Students	420	*	*	*	*	*	*	*	*
	Working adults	920	*	*	*	*	*	*	*	*
	Elderly	320	*	*	*	*	*	*	*	*
OTHER MUNICIPALITIES OF THE METROPOLITAN AREA OF KUOPIO										
PM10	All groups	0.9	*	*	*	*	*	*	-60.0	-50.0
	Pre-school children	0.1	*	*	*	*	*	*	-55.6	-55.6
	Elementary school children	0.1	*	*	*	*	*	*	-60.0	-50.0
	Students	0.2	*	*	*	*	*	*	-59.3	-48.1
	Working adults	0.4	*	*	*	*	*	*	-69.4	-59.7
	Elderly	0.1	*	*	*	*	*	*	-65.0	-55.0
PM2.5	All groups	0.4	*	*	*	*	*	*	*	*
	Pre-school children	0.0	*	*	*	*	*	*	*	*
	Elementary school children	0.0	*	*	*	*	*	*	*	*
	Students	0.1	*	*	*	*	*	*	*	*
	Working adults	0.2	*	*	*	*	*	*	*	*
	Elderly	0.1	*	*	*	*	*	*	*	*

* Value is within the range of uncertainty of the Tool (± 2%).

Deposited Dose

The highest reduction in PM10 and PM2.5 doses were achieved with residential heating scenarios (S7 and S8) ranging from -2.1 to -4.8% (Table 6.11). Also, when all passenger cars were considered as electric (S2) pre-school children PM10 dose decreased by -6.3%.

Table 6.11 – The base scenario of PM dose (μg) in Kuopio municipality and the reduction (%) of dose when road traffic (S1-S6) and residential heating scenarios (S7-S8) are applied.

		KUOPIO METROPOLITAN AREA								
		Base	Road traffic						Residential heating	
		Reference	S1	S2	S3	S4	S5	S6	S7	S8
		μg	Relative changes (%) in PM deposited dose							
PM10	Pre-school children	17 404	*	-6.3	*	*	*	*	-3.2	*
	Elementary school children	29 228	*	*	*	*	*	*	-3.6	-2.1
	Students	35 167	*	*	*	*	*	*	-3.4	*
	Working adults	31 138	*	*	*	*	*	*	-4.7	-2.7
	Elderly	28 166	*	*	*	*	*	*	-4.2	-2.4
PM2.5	Pre-school children	7 518	*	*	*	*	*	*	-3.3	*
	Elementary school children	11 140	*	*	*	*	*	*	-3.8	-2.2
	Students	12 445	*	*	*	*	*	*	-3.5	-2.1
	Working adults	11 255	*	*	*	*	*	*	-4.8	-2.8
	Elderly	10 166	*	*	*	*	*	*	-4.3	-2.5

∗ Value is within the range of uncertainty of the Tool (± 2%).

Burden of Disease

Residential heating scenarios (S7-S8) were the only measures that was estimated to benefit the health of elementary school children (Table 6.12). Mild sick days in both cases would decrease by -7.1%. On the contrary road traffic scenarios (S2 and S3) would increase number of mild sick days by 7.7%.

Table 6.12 – The base scenario of health impacts due to PM2.5 exposure (n) in Kuopio municipality and the change (%) in health impacts when road traffic (S1-S6) and residential heating scenarios (S7-S8) are applied.

		KUOPIO METROPOLITAN AREA								
		Base	Road traffic						Residential heating	
		Reference	S1	S2	S3	S4	S5	S6	S7	S8
		n	Relative changes (%) in PM deposited dose							
Upper respiratory infections - Elementary school children	Sick days (mild)	135	*	7.7	7.7	*	*	*	-7.1	-7.1
	Sick days (moderate)	84	*	*	*	*	*	*	*	*
	Sick days (severe)	2	*	*	*	*	*	*	*	*
	Days of school absenteeism	44	*	*	*	*	*	*	*	*
	Total sick days	220	*	*	*	*	*	*	*	*
Natural Mortality - all groups	DALY	1000	*	*	*	*	*	*	*	*
	YLL	660	*	*	*	*	*	*	*	*
	YLD	380	*	*	*	*	*	*	*	*
	Deaths	40	*	*	*	*	*	*	*	*

∗ Value is within the range of uncertainty of the Tool (± 2%).

7. IMPLEMENTATION OF THE MANAGEMENT TOOL IN TREVISO

CHARACTERISATION OF TREVISO

PHYSICAL GEOGRAPHY

The Metropolitan Area of Treviso is located in the region of Veneto in the North-Eastern part of Italy (approximately 30 km North of Venice) and crossed by the river Sile and three other minor rivers (Gallucci et al. 2007).

DEMOGRAPHY

The province of Treviso has 95 municipalities with total population of 883,522 (in 2020). The population was increased by 0.09%/year in the period of 2011-2020 (City Population, 2021).

CLIMATE

Regarding climate, the summers are warm and humid while the winters are very cold (Weather Spark, 2021). The average temperature of the coldest month (January) is equal to 3.2 °C while for the warmest month (July) is equal to 23.3 °C (World climate guide).

TRANSPORT

Road

The National Roads and Motorways constitute the main road network of the Metropolitan Area of Treviso. The motorisation rate is high in Metropolitan Area of Treviso. Specifically, 550-650 passenger cars per 1,000 inhabitants (Eurostat).

Rail

The Treviso central railway station has 7,000,000 million passenger movements each year (Centostazioni, 2021).

Air

Treviso has an airport with 24,116 aircraft movements and 3,254,731 passengers in 2019 (Assaeroporti, 2019).

INDUSTRY

There are many small and medium size production companies such as mechanical field, textile, furniture, construction and paper milling.

BASE CASE

The base case scenario corresponds to the air quality condition verified over the city of Treviso in the year 2015. The base case is based on the CAMx model integrated with the data obtained in the air monitoring stations.

EMISSIONS

Treviso municipality

Figure 7.1 presents the Treviso municipality emissions by sector group in 2015, for the main gas pollutants (NH_3, NO_x, SO_2 and VOC), particulate matter (PM10 and PM2.5) and heavy metals (As, Cd, Ni and Pb). The agriculture sector was the largest source of NH_3 (89%). The non-industrial combustion plants sector was the largest source of SO_2 (81%), particulate matter (71 % for PM10 and 76% PM2.5) and metals (96% for As, 75% for Cd, 79 % for Ni and 100 % for Pb). The solvent and other product use sector was the largest source of VOC (53%) and the road transport sector was the largest source of NOx (59%).

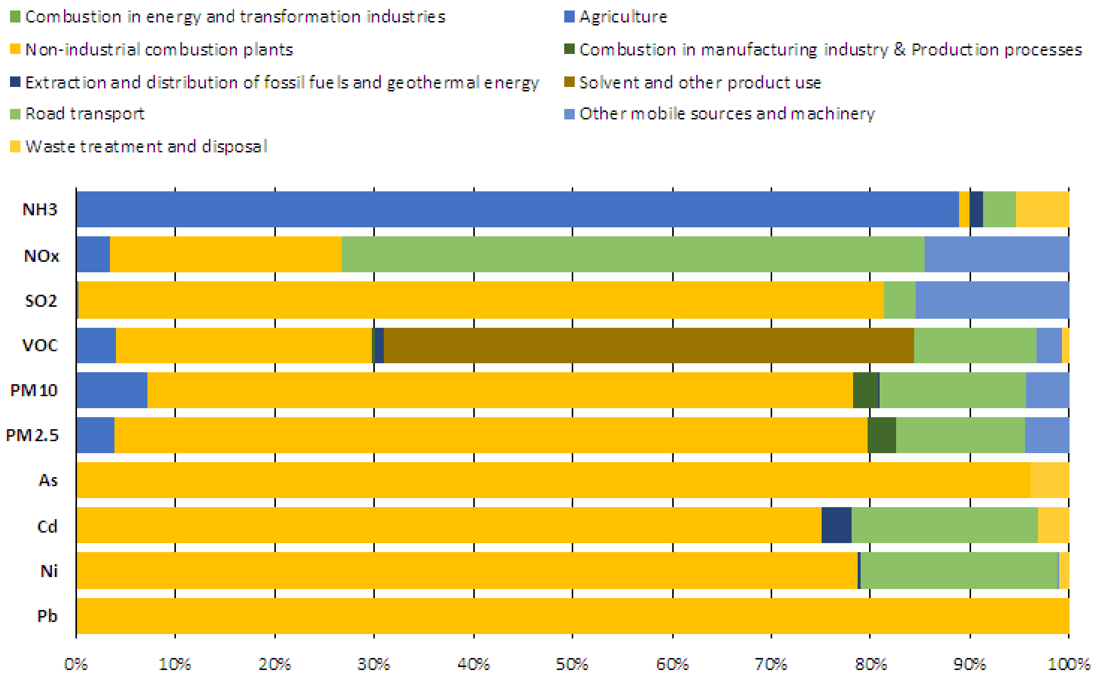


Figure 7.1 – Share of Treviso municipality emissions (in %) of the main pollutants, by sector group in 2015.

Other municipalities of the metropolitan area of Treviso

Figure 7.2 shows the emissions of other municipalities of the metropolitan area of Treviso in 2015, for the main gas pollutants, particulate matter and heavy metals, per activity sector. Agriculture was the largest source of NH_3 (94%), the other mobile sources and machinery was the largest source of SO_2 (70%), the road transport was the largest source of NO_X (50%) and solvent and other product use was the largest source of VOC (41%). The highest emissions of particulate matter and metals were associated to the sector Non-industrial combustion plants.

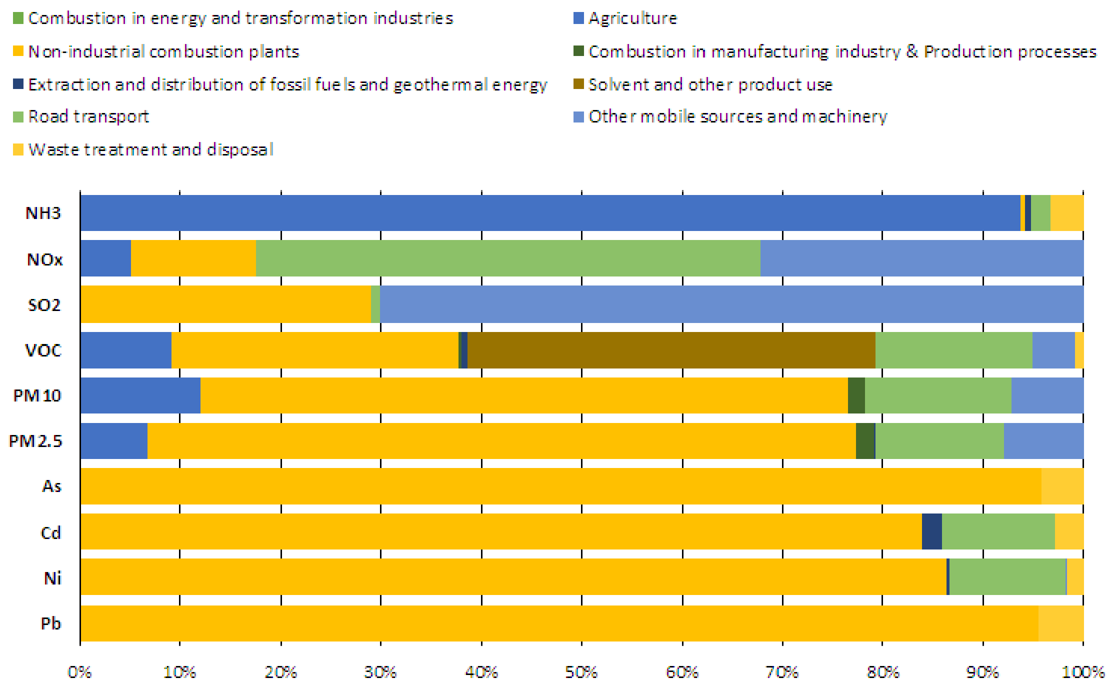


Figure 7.2 – Share of other municipalities of the metropolitan area of Treviso emissions (%) of the main pollutants, by sector group in 2015.

Table 7.1 shows that the VOC had the highest total emission (3557 t/year) followed by NOx (683 t/year) in Treviso municipality. Likewise, in the other municipalities of the metropolitan area of Treviso, the VOC had the highest total emission (8362 t/year) followed by NOx (2390 t/year).

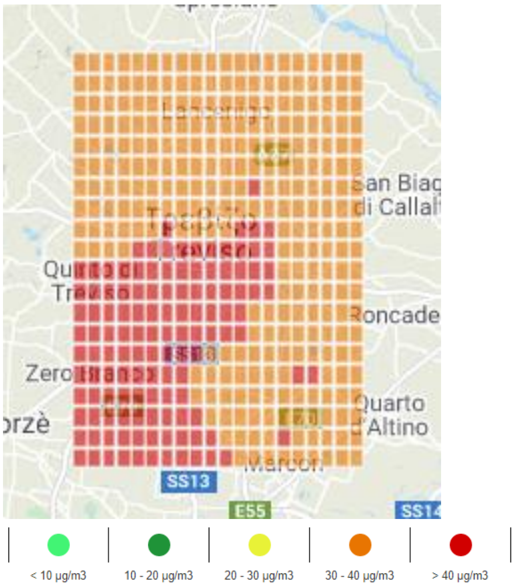
Table 7.1 – Total emissions of the main pollutants in 2015 for Treviso municipality and other municipalities of metropolitan area of Treviso.

	NH_3	NOx	SO_2	VOC	PM10	PM2.5	As	Cd	Ni	Pb
	Total									
	t/year						kg/year			
Treviso Municipality	202	683	12	3557	183	171	3	3	90	1
Other municipalities of the metropolitan area of Treviso	929	2390	121	8362	543	496	10	11	301	2

Ambient Concentrations

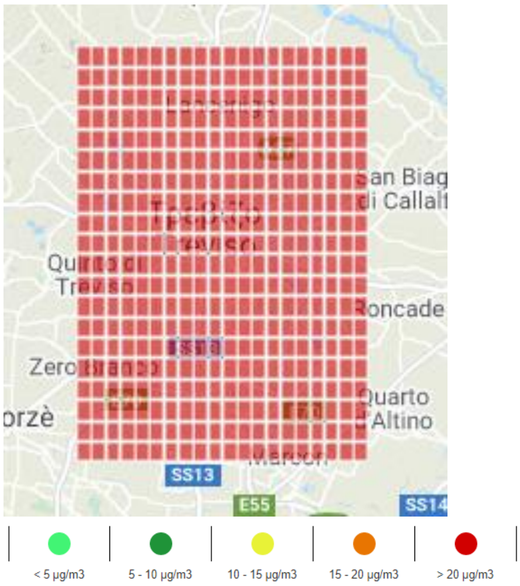
The EU air quality standard sets an annual limit for PM10 equal to 40 µg/m^3 while for PM2.5 the annual limit is 20 µg/m^3. In this work the average annual PM10 concentrations were below the annual limit value while the average annual PM2.5 concentrations were above the annual limit value. Specifically, the annual PM10 concentration was equal to 39.4 µg/m^3 and 38.7 µg/m^3 for Treviso municipality and other municipalities of the metropolitan area of Treviso, respectively. Additionally, the annual PM2.5 concentration was equal to 26.5 µg/m^3 and 26.1 µg/m^3 for Treviso municipality and other municipalities of the metropolitan area of Treviso, respectively. Finally, the annual concentrations of metals were below the annual limit values for the protection of human health as shown in Figure 7.3.

PM10



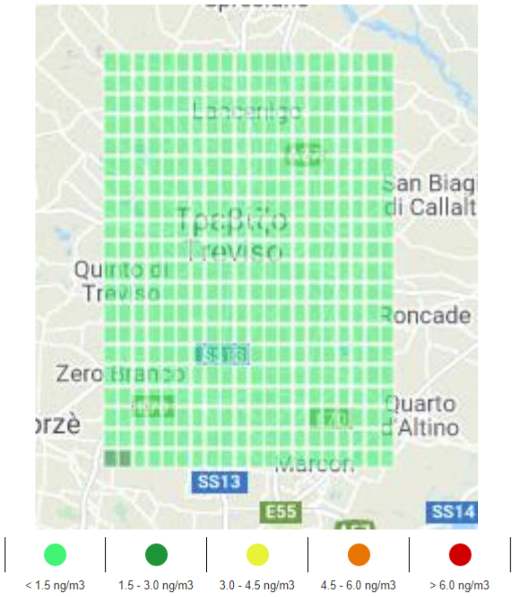
	Average	Minimum	Maximum
Treviso Municipality	39.37	37.53	42.92
Other municipalities of the metropolitan area of Treviso	38.66	35.36	44.75

PM2.5



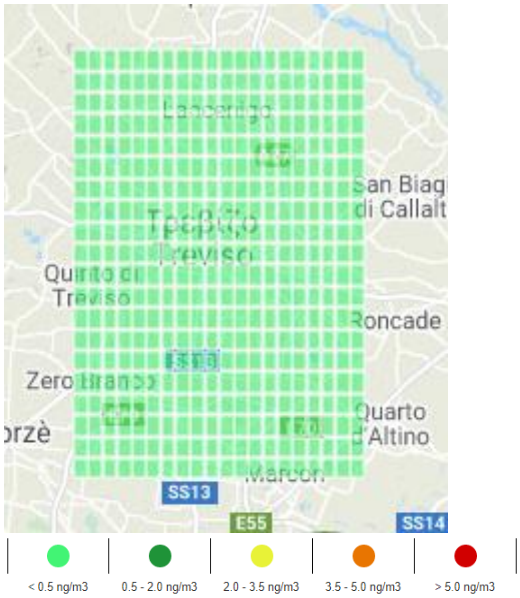
	Average	Minimum	Maximum
Treviso Municipality	26.54	25.33	28.95
Other municipalities of the metropolitan area of Treviso	26.05	23.81	30.18

As



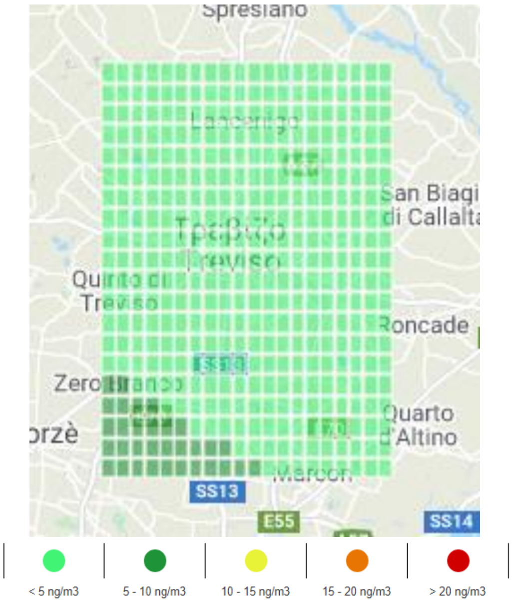
	Average	Minimum	Maximum
Treviso Municipality	0.67	0.60	0.75
Other municipalities of the metropolitan area of Treviso	0.77	0.52	1.55

Cd



	Average	Minimum	Maximum
Treviso Municipality	0.47	0.44	0.52
Other municipalities of the metropolitan area of Treviso	0.46	0.42	0.57

Ni



	Average	Minimum	Maximum
Treviso Municipality	2.46	2.02	2.98
Other municipalities of the metropolitan area of Treviso	3.21	1.76	8.39

Pb

	Average	Minimum	Maximum
Treviso Municipality	5.96	5.69	6.17
Other municipalities of the metropolitan area of Treviso	5.71	5.03	6.33

Figure 7.3 – Annual average ambient concentrations of PM (in µg/m3) and heavy metals (in ng/m3) in Treviso.

PM10 Exceedances

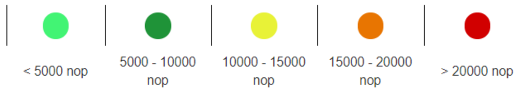
The current EU legislation defined in the Directive 2008/50/EC presents a daily limit value of 50 µg/m^3 for PM10. The daily limit value should not be exceeded more than 35 times a year. Both in the Treviso municipality (112 exceedances/year) and the other municipalities of the metropolitan area (118 exceedances/year) the EU guidelines were exceeded.

Table 7.2 – Number of PM10 exceedance days in 2015 for Treviso.

	Minimum	Maximum
Treviso Municipality	91	112
Other municipalities of the metropolitan area of Treviso	83	118

Population Groups

The population was divided into 5 sub-groups (pre-school children, elementary school children, students, working adults and elderly) characterised by different inhalation rates, activities and responses to the air pollution. Treviso municipality has a population density of 1003 inhabitants/km^2. Specifically, 56% of the population were working adults (26-65 years old), 25% were elderly people (> 65 year old), 12 % students (11-25 years old), 4 % elementary school children (5-10 years old) and 3 % pre-school children (<5 years old).



All groups (all ages)

	Average	Minimum	Maximum
Treviso Municipality	1003	8	5286
Other municipalities of the metropolitan area of Treviso	470	10	3333

Figure 7.4 – Map with spatial distribution (1 km x 1 km) of all population across Treviso, expressed in number of people (nop). The average, minimum and maximum population densities are expressed in nop/km^2.

Pre-school children (ages 0 – 4)

	Average	Minimum	Maximum
Treviso Municipality	35	0	161
Municipalities of the metropolitan area of Treviso	17	0	153

Elementary school children (ages 5 – 10)

	Average	Minimum	Maximum
Treviso Municipality	37	0	182
Municipalities of the metropolitan area of Treviso	16	0	163

Students (ages 11 – 25)

	Average	Minimum	Maximum
Treviso Municipality	123	0	557
Municipalities of the metropolitan area of Treviso	57	1	433

Working adults (ages 26 – 65)

	Average	Minimum	Maximum
Treviso Municipality	561	4	3102
Municipalities of the metropolitan area of Treviso	265	7	1816

Elderly (ages > 65)

	Average	Minimum	Maximum
Treviso Municipality	247	2	1284
Municipalities of the metropolitan area of Treviso	115	1	768

Figure 7.5 – Maps with spatial distribution (1 km x 1 km) of population across Treviso for each population group, expressed in number of people (nop). The average, minimum and maximum population densities are expressed in nop/km^2.

POPULATION EXPOSURE

The population exposure was categorised into 5 subgroups for the Treviso Municipality and the other Municipalities of the metropolitan area of Treviso. Table 7.3 shows the annual average exposure to PM and heavy metals weighted by the number of people present in the Treviso study case domain.

Regarding Treviso Municipality, the population (all groups) was exposed to 31000 µg/m^3 of PM10 and 23000 µg/m^3 of PM2.5. Regarding the heavy metal, the highest population exposure was obtained for Pb (5200 ng/m^3), followed by Ni (2200 ng/m^3), As (600 ng/m^3) and Cd (440 ng/m^3).

For the other municipalities of the metropolitan area of Treviso, the population (all groups) was exposed to 14000 µg/m^3 of PM10 and 11000 µg/m^3 of PM2.5 while for the heavy metals the highest population exposure was obtained for Pb (2400 ng/m^3) followed by Ni (1400 ng/m^3), As (330 ng/m^3) and Cd (210 ng/m^3).

Population exposure is higher in Treviso municipality due of the difference in the pollutant concentrations (Figure 7.3) and also the population exposed is higher in Treviso municipality (Figure 7.4).

Table 7.3 – PM and heavy metals annual average exposure for each population group in Treviso.

		PM10	PM2.5	As	Cd	Ni	Pb
		µg/m^3.nop		ng/m^3.nop			
Treviso Municipality	All groups	31000	23000	600	440	2200	5200
	Pre-school children	1200	840	22	16	81	190
	Elementary school children	1200	870	22	17	83	200
	Students	4200	2900	76	56	280	660
	Working adults	18000	13000	340	240	1300	2900
	Elderly	6800	5200	140	100	530	1200
Other municipalities of the metropolitan area of Treviso	All groups	14000	11000	330	210	1400	2400
	Pre-school children	590	410	12	7.8	47	90
	Elementary school children	540	380	12	7.2	49	83
	Students	1900	1300	42	26	180	290
	Working adults	8200	6100	190	110	790	1300
	Elderly	3100	2400	80	48	350	550

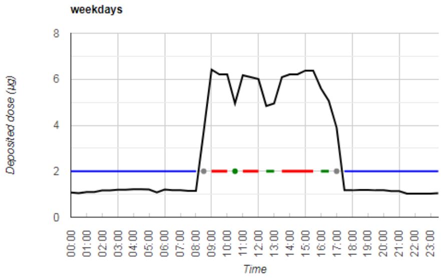
Deposited Dose

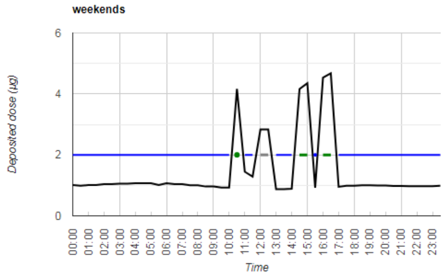
The deposited dose is divided into 5 population sub-groups (pre-school children, elementary school children, students, working adults and elderly). For pre-school children the highest deposited dose of PM10 were obtained in school environment on the weekdays and outdoor on the weekend (Figure 7.6) while for PM2.5 the highest deposited dose were observed outdoor on both weekdays and weekends (Figure 7.8). The lowest deposited dose of PM10 and PM2.5 were observed at home on both weekdays and weekends. For the other groups (elementary school children, students, working adults and elderly) the highest deposited dose of PM10 and PM2.5 was observed outdoor on both weekdays and weekends while the lowest deposited dose were observed at home. Higher deposited dose of PM10 and PM2.5 was observed on weekdays than on weekends.

PM10

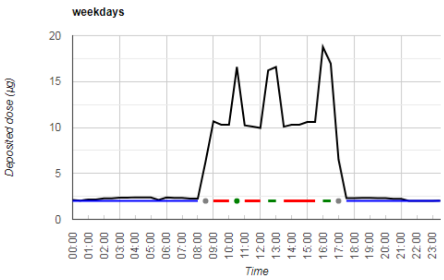
DD | Home | Commuting | School/Work | Outdoors | Indoors-Other

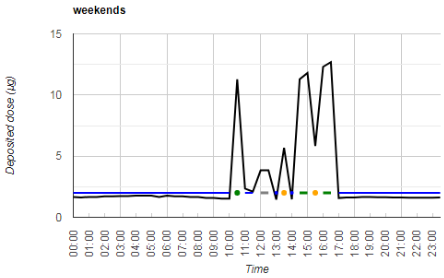
Pre-school children (ages 0 – 4)



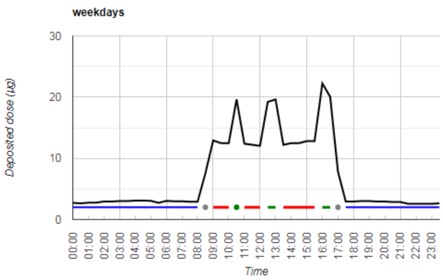


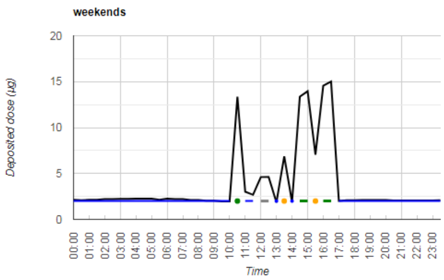
Elementary school children (ages 5 – 10)



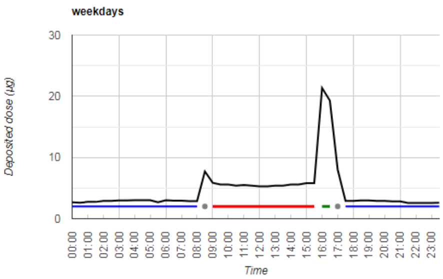


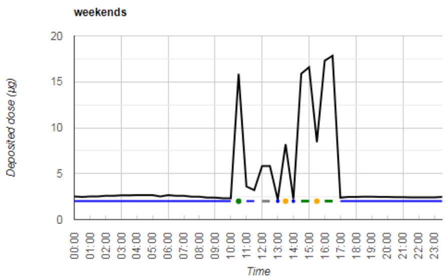
Students (ages 11 – 25)





Working adults (ages 26 – 65)





Elderly (ages > 65)

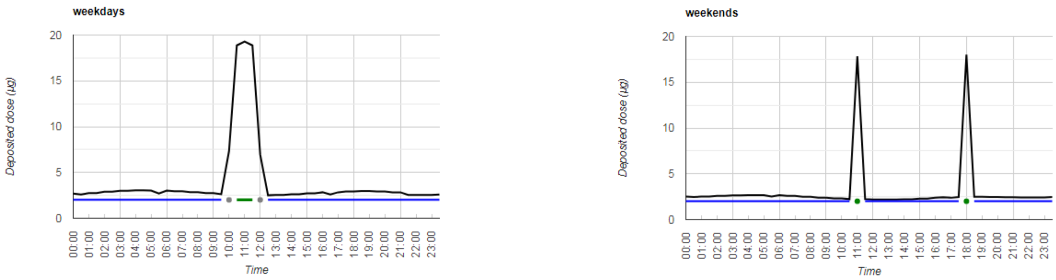


Figure 7.6 – PM10 deposited dose (in all regions) throughout the day for each population group in Treviso metropolitan area.

Figure 7.7 shows that the daily deposited dose of PM10 ranged from 135.5 µg (pre-school children) to 339.5 µg (students) on weekdays while on weekends the daily deposited dose ranged from 68.9 µg (pre-school children) to 210.4 µg (working adults). In addition, higher deposited dose was observed on weekdays than on weekends. Finally, the daily deposited was higher in the ET1 and ET2 region on both weekdays and weekends for all population groups.

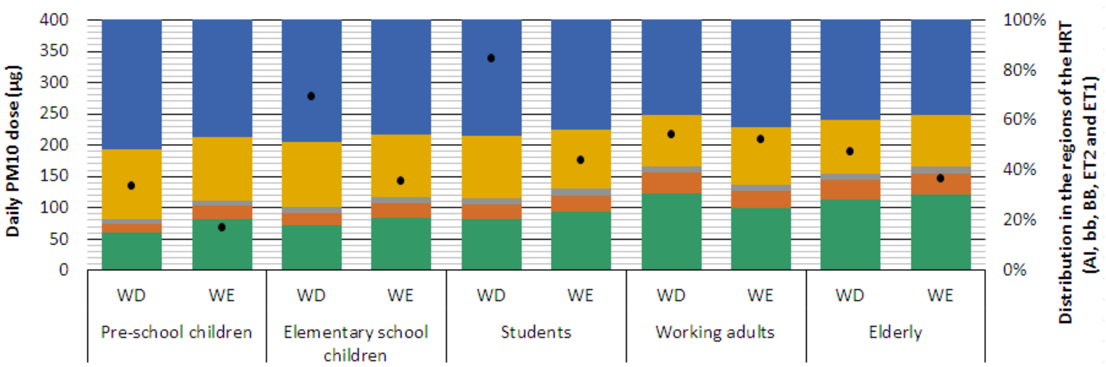
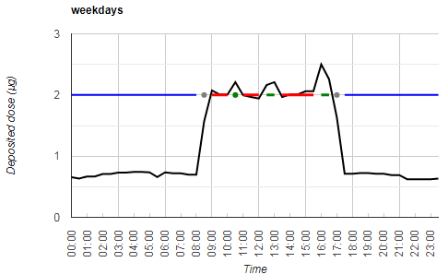


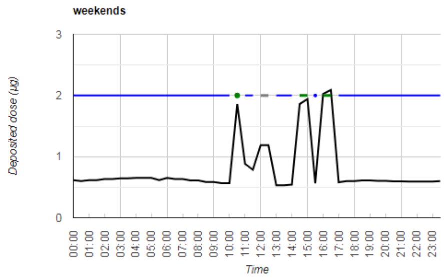
Figure 7.7 – Daily cumulative dose for PM10 (µg) and its distribution in the different regions of the HRT for each population group in Treviso metropolitan area.

PM2.5

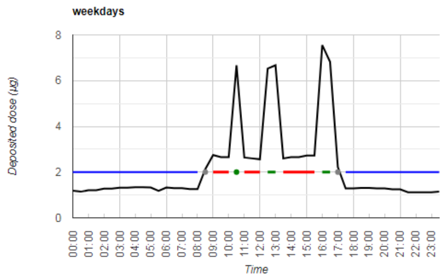
DD Home Commuting School/Work Outdoors Indoors-Other

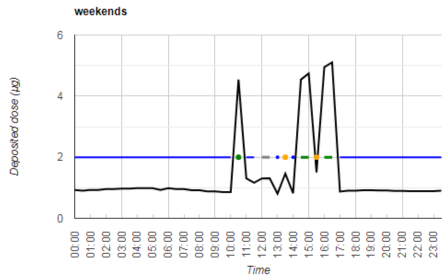
Pre-school children (ages 0 – 4)



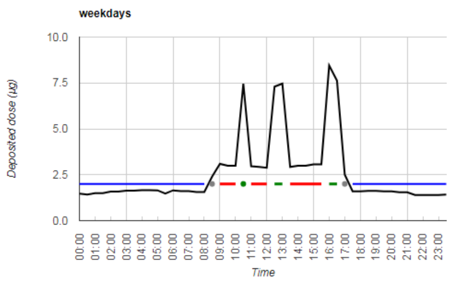


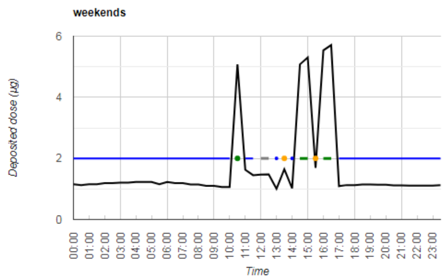
Elementary school children (ages 5 – 10)



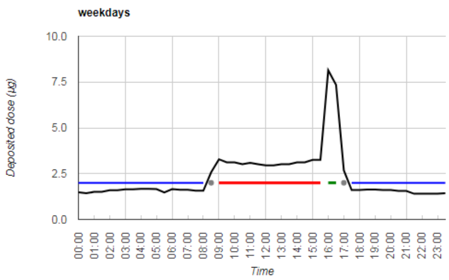


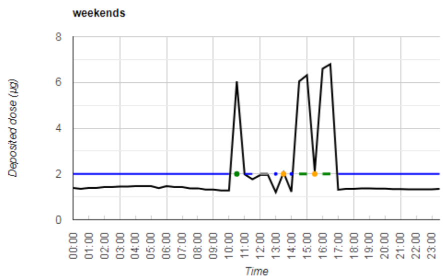
Students (ages 11 – 25)





Working adults (ages 26 – 65)





Elderly (ages > 65)

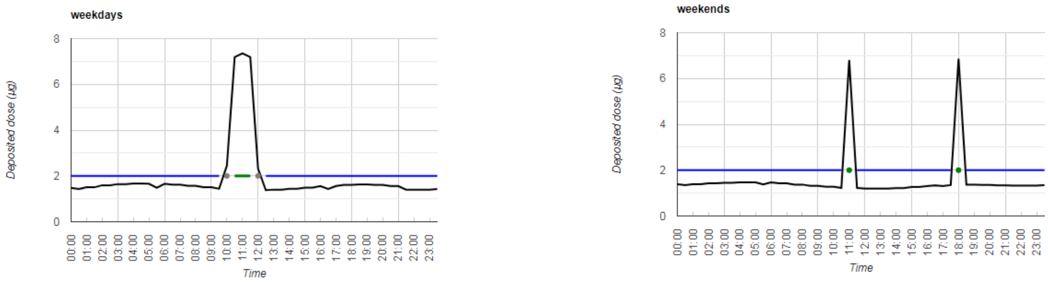


Figure 7.8 – PM2.5 deposited dose (in all regions) throughout the day for each population group in Treviso metropolitan area.

The daily deposited dose of PM2.5 ranged from 57.4 μg (pre-school children) to 122.6 μg (students) on weekdays. Regarding weekends the daily deposited dose in the human respiratory tract ranged from 37.4 μg (pre-school children) to 94.1 μg (working adults). In addition, higher deposited dose was observed on weekdays than on weekends. Finally, the daily deposited dose was higher in AI region on both weekdays and weekends.

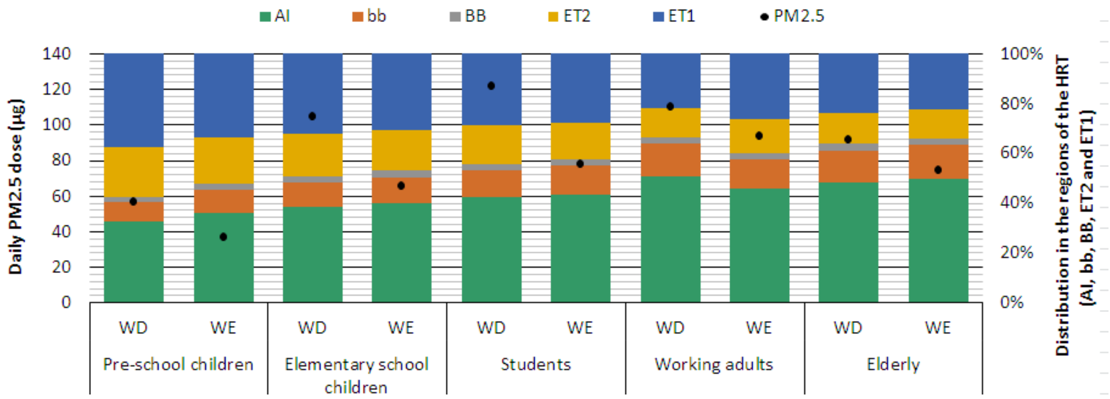


Figure 7.9 – Daily cumulative dose for PM2.5 (μg) and its distribution in the different regions of the HRT for each population group in Treviso metropolitan area.

Burden of Disease

Burden of Disease (BoD) is quantified based on Upper Respiratory Infections and Natural Mortality. Upper Respiratory Infections were used for the children population groups (pre-school children and elementary school children) while Natural Mortality was used for adults over 25 years old (working adults and elderly). BoD is measured in disability adjusted life years (DALY), which is calculated as the sum of years of life lost due to premature mortality (YLL) and disability weighted years lived with disabilities (YLD), and may be expressed in YLL, YLD, DALY, or in number of Deaths. Table 7.4 shows that DALY was equal to 0.83 and 35000 for children and adults, respectively. The YLL and YLD estimations for adults over 25 years old were 21000 and

13000, respectively. The corresponding values of children were 0 and 0.83 respectively. In total, 1400 premature deaths were attributed to PM2.5 exposure in 2015.

Table 7.4 – Upper respiratory infections and natural mortality per population sub-group in Treviso metropolitan area.

	Upper Respiratory Infections			Natural Mortality		
	Pre-school children	**Elementary school children**	**All groups**	**Working adults**	**Elderly**	**All groups**
DALY	0.40	0.43	0.83	14000	20000	35000
YLL	0.00	0.00	0.00	6400	15000	21000
YLD	0.40	0.43	0.83	8100	5400	13000
Deaths	0.00	0.00	0.00	180	1200	1400
Sick days (mild)	–	4400	–	–	–	–
Sick days (moderate)	–	2700	–	–	–	–
Sick days (severe)	–	55	–	–	–	–
Days of school absenteeism	–	1500	–	–	–	–
Total sick days	–	7200	–	–	–	–

Built-up of Policy Making Scenarios

The scenarios of Table 2.1 were implemented for Treviso municipality and other municipalities of the metropolitan area of Treviso. There are not cruise ships in Treviso and hence the scenarios of Cruise ships (S9 & S10) were not implemented.

PM Ambient Concentrations

Table 7.5 shows the relative changes (%) in PM concentrations for each scenario. Only scenarios S4, S7 and S8 achieve relative changes in annual PM concentrations. The scenarios of residential heating (S7 & S8) decrease PM concentrations by 2.5%-8.4% in Treviso municipality while in the other municipalities of the metropolitan area of Treviso led to a decrease in PM concentrations by 2.2%-6.4%.

Table 7.5 – Relative changes (%) in PM10 and PM2.5 concentrations between the reference case and the modified scenarios (S1 – S10) in Treviso.

		Base	Road traffic						Residential heating	
		Reference	S1	S2	S3	S4	S5	S6	S7	S8
		μg/m³	Relative changes (%) in PM concentrations							
TREVISO MUNICIPALITY										
PM10	Annual	39	*	*	*	*	*	*	-7.9	-2.6
	Winter	122	*	*	*	*	*	*	-7.9	-2.5
	Summer	11	*	*	*	*	*	*	-7.9	-2.6
	Spring	33	*	*	*	*	*	*	-7.9	-2.6
	Autumn	34	*	*	*	*	*	*	-7.9	-2.5
PM2.5	Annual	27	*	*	*	*	*	*	-8.3	-3.0
	Winter	85	*	*	*	*	*	*	-8.4	-3.0
	Summer	8	*	*	*	*	*	*	-8.3	-2.9
	Spring	22	*	*	*	*	*	*	-8.4	-3.0
	Autumn	23	*	*	*	*	*	*	-8.3	-3.0
OTHER MUNICIPALITIES OF THE METROPOLITAN AREA OF TREVISO										
PM10	Annual	40	*	*	*	-4.6	*	*	-6.4	-3.9
	Winter	124	*	*	*	-4.6	*	*	-6.4	-3.9
	Summer	11	*	*	*	-4.6	*	*	-6.4	-3.9
	Spring	33	*	*	*	-4.7	*	*	-6.3	-3.9
	Autumn	35	*	*	*	-4.6	*	*	-6.4	-3.9
PM2.5	Annual	27	*	*	*	*	*	*	-6.4	-2.3
	Winter	85	*	*	*	*	*	*	-6.4	-2.3
	Summer	8	*	*	*	*	*	*	-6.3	-2.2
	Spring	22	*	*	*	*	*	*	-6.4	-2.2
	Autumn	23	*	*	*	*	*	*	-6.4	-2.3

* Value is within the range of uncertainty of the Tool (± 2%).

Population Exposure

The relative changes (%) of population exposure for each scenario was presented in Table 7.6. The highest reduction was observed for residential heating scenarios (S7 & S8). Specifically, the reduction in PM population exposure ranged from 2.0%-14.3 % and 2.4%-7.7% in Treviso municipality and the other municipalities of the metropolitan area of Treviso, respectively.

Additionally, highest reduction in PM population exposure was observed for elementary school children.

Table 7.6 – Relative changes (%) in PM10 and PM2.5 population exposure between the reference case and the modified scenarios (S1 – S10) in Treviso.

		Base	Road traffic						Residential heating	
		Reference	S1	S2	S3	S4	S5	S6	S7	S8
		μg/m³ · nop	Relative changes (%) in PM population exposure							
TREVISO MUNICIPALITY										
PM10	All groups	34500	*	*	*	-2.9	*	*	-11.4	-5.7
	Pre-school children	1300	*	*	*	*	*	*	-7.7	*
	Elementary school children	1400	*	*	*	-7.1	*	*	-14.3	-7.1
	Students	4650	*	*	2.2	-2.2	2.2	*	-10.6	-4.3
	Working adults	19000	*	*	*	*	*	*	-10.5	*
	Elderly	7550	*	*	*	-2.7	*	*	-11.8	-3.9
PM2.5	All groups	25000	*	*	*	*	*	*	-4.0	*
	Pre-school children	910	*	*	*	*	*	*	-6.6	-2.2
	Elementary school children	980	*	*	*	*	*	*	-7.1	-2.0
	Students	3300	*	*	*	*	*	*	-6.1	-3.0
	Working adults	14000	*	*	7.1	*	*	*	-7.1	*
	Elderly	5900	*	*	*	*	*	*	-6.8	-3.4
OTHER MUNICIPALITIES OF THE METROPOLITAN AREA OF TREVISO										
PM10	All groups	17000	*	*	*	*	*	*	-5.9	*
	Pre-school children	855	*	*	*	-2.3	-2.3	*	-3.5	-3.5
	Elementary school children	580	*	*	*	*	*	*	-6.9	*
	Students	2200	*	*	*	*	*	*	-4.5	*
	Working adults	9950	*	*	*	*	*	*	-5.1	*
	Elderly	3450	*	*	*	-2.9	-2.9	*	-5.9	*
PM2.5	All groups	13000	*	*	*	*	*	*	-7.7	*
	Pre-school children	600	*	*	*	*	*	*	-5.0	*
	Elementary school children	420	*	*	*	-2.4	*	*	-4.8	-2.4
	Students	1600	*	*	*	*	*	*	-6.3	*
	Working adults	7600	*	*	*	*	*	*	-6.6	-2.6
	Elderly	2700	*	*	3.7	*	*	*	-3.7	*

* Value is within the range of uncertainty of the Tool (± 2%).

DEPOSITED DOSE

Table 7.7 presents the relative changes in PM deposited dose for each scenario. Only scenarios S4, S7 and S8 cause reduction in PM deposited dose. Scenario S7 achieves the highest reduction in PM deposited dose, followed by S8 and then S4. The values for the other scenarios are within the range of uncertainty of the Tool (± 2%). The scenario S4 decrease PM deposited dose by 2.5%-2.7% for both PM10 and PM2.5 while the scenarios of residential heating (S7 & S8) decrease PM deposited dose by 2.6%-6.5% for both PM10 and PM2.5.

Table 7.7 – The base scenario of PM dose (μg) in Treviso municipality and the reduction (%) of dose when road traffic (S1-S6) and residential heating scenarios (S7-S8) are applied.

		TREVISO METROPOLITAN AREA								
		Base	Road traffic						Residential heating	
		Reference	S1	S2	S3	S4	S5	S6	S7	S8
		μg	Relative changes (%) in PM deposited dose							
PM10	Pre-school children	41090	*	*	*	-2.4	*	*	-5.7	-2.6
	Elementary school children	76380	*	*	*	-2.5	*	*	-6.0	-2.7
	Students	93476	*	*	*	-2.5	*	*	-6.0	-2.7
	Working adults	79991	*	*	*	-2.7	*	*	-6.5	-2.9
	Elderly	64871	*	*	*	-2.6	*	*	-6.3	-2.9
PM2.5	Pre-school children	18530	*	*	*	-2.4	*	*	-5.9	-2.6
	Elementary school children	31162	*	*	*	-2.6	*	*	-6.2	-2.8
	Students	36604	*	*	*	-2.5	*	*	-6.1	-2.8
	Working adults	38816	*	*	*	-2.7	*	*	-6.5	-2.9
	Elderly	31873	*	*	*	-2.6	*	*	-6.2	-2.8

* Value is within the range of uncertainty of the Tool (± 2%).

BURDEN OF DISEASE

Finally, the relative changes (%) in health impacts due to exposure to PM2.5 for each scenario was presented in Table 7.8. The most important scenarios (with the highest reduction) for Treviso Metropolitan area are the residential heating scenarios (S7 & S8) while the impact/reduction of road traffic scenarios is negligible (the most values are within the range of uncertainty of the Tool (± 2%)). The highest reduction was observed for disability adjusted life years (DALY). Specifically, scenarios S7 and S8 decrease DALY by 11.1% and 5.6 %, respectively. Therefore, the most effective emission reduction measures are the residential heating scenarios (S7 & S8).

Table 7.8 – The base scenario of health impacts due to PM2.5 exposure (n) in Treviso municipality and the change (%) in health impacts when road traffic (S1-S6) and residential heating scenarios (S7-S8) are applied.

		TREVISO METROPOLITAN AREA								
		Base	Road traffic						Residential heating	
		Reference	S1	S2	S3	S4	S5	S6	S7	S8
		n	Relative changes (%) in PM deposited dose							
Upper respiratory infections - Elementary school children	Sick days (mild)	2300	*	*	*	-4.3	*	*	-8.7	-4.3
	Sick days (moderate)	1400	*	*	*	*	*	*	-7.1	*
	Sick days (severe)	29	*	*	3.6	*	*	*	-10.3	-3.4
	Days of school absenteeism	795	*	*	2.5	*	*	*	-8.8	-2.5
	Total sick days	3700	*	*	2.7	*	*	*	-8.1	-2.7
Natural Mortality - all groups	DALY	18000	*	*	*	*	*	*	-11.1	-5.6
	YLL	11000	*	*	*	*	*	*	-9.1	*
	YLD	7000	*	*	*	*	*	*	-8.6	-2.9
	Deaths	735	*	*	2.7	*	*	*	-9.5	-2.7

* Value is within the range of uncertainty of the Tool (± 2%).

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