ClairCity: Citizen-led air pollution reduction in cities

Deliverable 5.7: City Impact Analysis Report – Aveiro Region

February 2020 (revised version May 2020)

Document Details

Authors	Vera Rodrigues, Myriam Lopes, Sandra Rafael, Sílvia Coelho, Kevin Oliveira, Ana Patrícia Fernandes (UAVR) Kris Vanherle, Peter Papics (TML) Iason Daifas (PBL) Angreine Kewo (DTU) Carlo Trozzi, Enzo Piscitello (Techne Consulting) Joana Soares (NILU)
Contact	kris.vanherle@tmleuven.be vera.rodrigues@ua.pt
Creation Date	08/05/2019
Date of Last Revision	31/05/2020
Description	The Deliverable 5.7 collects all results of the full impact analysis, methodological approach and data sources. This report describes the full impact analysis for Aveiro Region.

Version History

Version	Updated By	Date	Changes / Comments
V1.0	Kris Vanherle	08/05/2019	Outline
V1.1	Kris Vanherle	12/11/2019	Added content by Peter (TML) and An (DTU)
V2.0	Kris Vanherle	13/01/2020	Incorporation of inputs TECHNE, DTU, PBL
V2.1	Kris Vanherle	18/02/2020	Updated inputs Aveiro and updated as stand-alone document
V2.2	Vera Rodrigues	25/05/2020	Updated inputs from TML, DTU, TECHNE, PBL, UAVR, NILU and updated as stand-alone document. Completed for Aveiro Region.

Contributions and Acknowledgements

The authors would like to thank the following people for their important contributions used in the preparation of this final document.

Quality Assurance	Enda Hayes (UWE)
Native Language Check	Enda Hayes (UWE)
Project internal comments	Enda Hayes (UWE) Irati Artola (Trinomics)

Table of Content

Document Details 2

Version History 2

Contributions and Acknowledgements 3

1 Methodological particularities 5

1.1 Transport: activity data 5

1.2 Transport: Mode choice model 8

1.3 Air quality modelling 9

2 Description and modelling of the scenario's 11

2.1 Transport 12

2.2 Industrial, Residential, Commercial & Institutional (IRCI) 16

2.3 Carbon footprint 23

3 Results 30

3.1 Transport 30

3.2 Spatial-temporal 41

3.3 IRCI 41

3.4 Carbon footprint 49

3.5 Air quality impacts 64

3.6 Health impacts 92

4 Conclusions 97

In this document, we elaborate into the methodology and results of the modelling for the Aveiro Region case. We first elaborate on any methodological particularity [1] and then report on the specific assumptions, translating the scenarios to model input [2] and report on the results of the modelling [3]. The impact assessment data illustrating the work undertaken can be found on the ClairCity Data Portal, as follow: https://claircitydata.cbs.nl/dataset/d5-5d-assessment-of-impacts-cira. Access can be arranged upon request. Furthermore, it was created a ClairCity community on Zenodo.org, where the full dataset was uploaded from the ClairCity Data Portal to Zenodo. The comunity is available on the link: https://zenodo.org/communities/claircity.

1 Methodological particularities

1.1 Transport: activity data

Detailed transport activity data was lacking for the Aveiro area and/or a transport model estimating transport volumes was unavailable. As such, we use a different approach to estimate the transport volumes in following steps:

- Road network generation
- Production & Attraction for demand generation
- Mode choice
- Assignment
- Post-processing - Scaling with local traffic data on highway's

Secondly, the Aveiro domain was too big to handle as a single region for the assignment algorithm to converge within acceptable time constraints. We opted to split the process and first do the assignment for the core area and apply traffic flow rates using road characteristics (i.e. primary/secondary/tertiary roads as flagged in OpenStreetMaps).

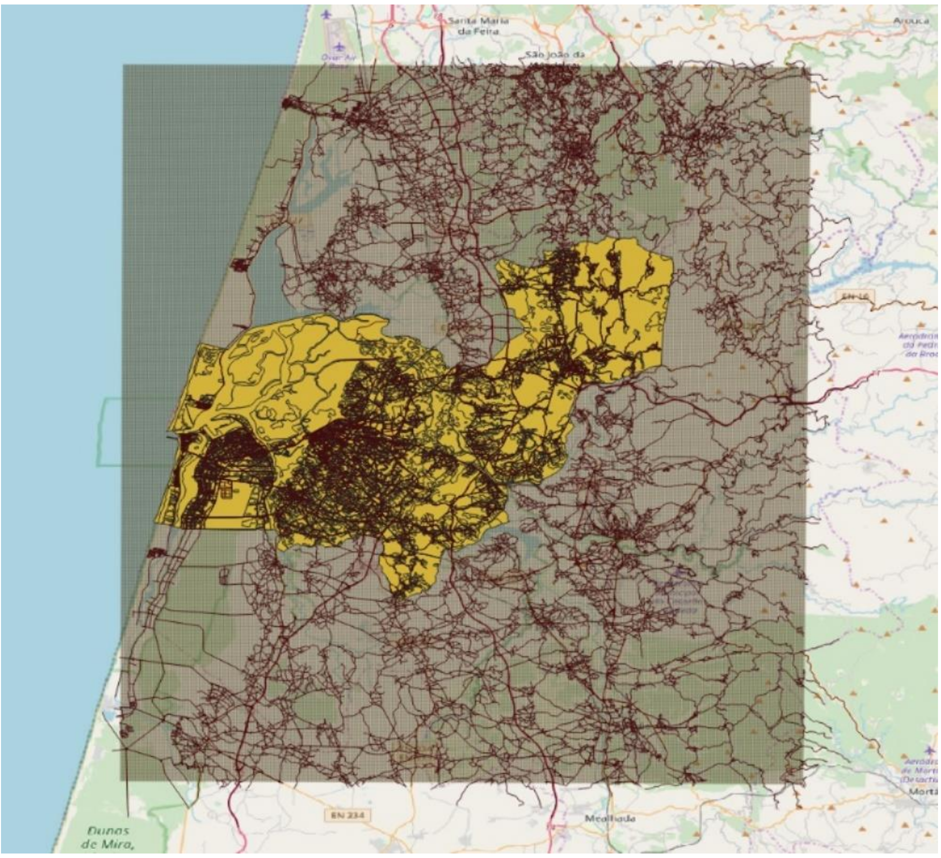


Figure 1-1: Core domain (yellow) and outer region (gridded)

Road network generation

We use OpenStreetMaps[1] to generate a noded network.

Demand generation

Production factors define the generation of demand for a zone. The factors feed into a function that describes the total amount of trips being generated in a zone. In most cases the trip generation function is a multi-variable regression model based on socio-economic variables such as population density, age distribution, income levels, etc...

The attractiveness of a zone as a trip end is mostly defined by infrastructural/spatial characteristics. The total amount of trips that dissipate in a zone is also described by multi-variable regression model based on number of available workplaces, schools, quantity and quality of shopping locations, availability of leisure activities, etc…

[1] https://www.openstreetmap.org/#map=13/50.2741/19.1064&layers=T

We use the land-use data from the integrated model for demand generation.

Mode choice

We rely on local data as well as EU-data from the TRANSPHORM city database for the modal shares (walk/bike/car/PT/freight)

Assignment

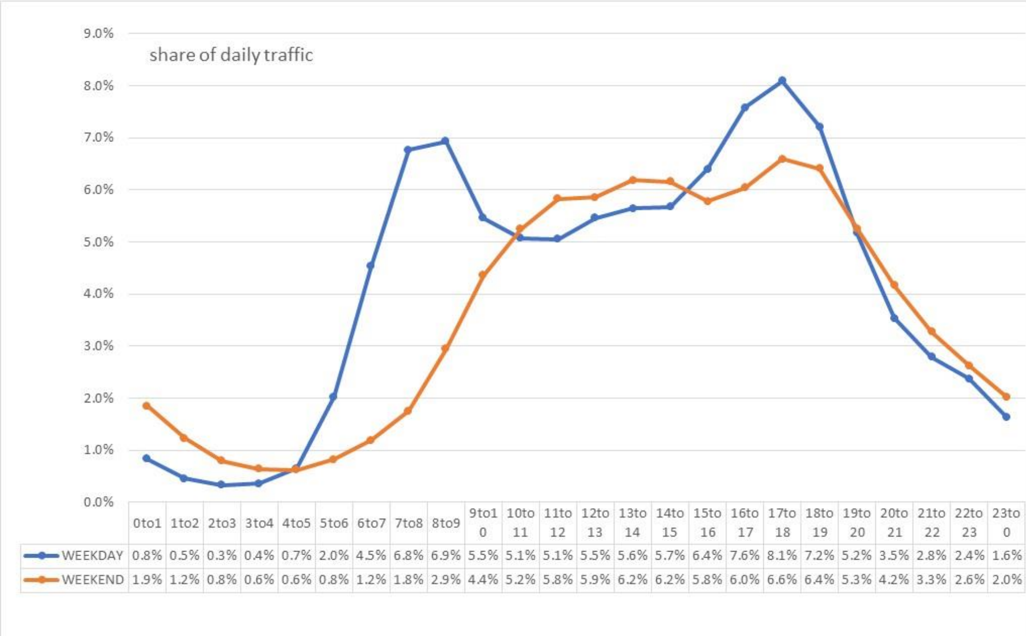
The main idea of assigning demand to the network is based on equilibrium principles. These state that drivers will keep on looking for shorter routes until all drivers unilateral perceive the least resistance. We incorporate a first calibration, scaling the generated demand in such a way the traffic volumes on key roads matches the data. In Aveiro, only for highways, traffic volume data could be used.

The assignment is for a full day. Capacities are adjusted accordingly. It is assumed that the maximum hourly road capacity is adjust to a full day and that this factor is a parameter to control for responsiveness of drivers with respect to busy roads. The factor is set to 10 which introduces mild responsiveness and a quick convergence of the algorithm.

Post-processing

The initial demand generation and assignment need further refinement. This includes, for Aveiro specifically: **OD matrix corrections scaling**: For all of the origin or destinations in the network a straightforward correction can be applied to be in line with counting data that was available at highway level. All the highest OSM class roads that cut the cordon around the case-study area are origins and destinations in the final trip matrix. We apply a single factor per origin row or destination column to match the total sum of a row / column with observed averages volumes per day.

Finally, as volumes are estimated for daily totals, a final step is needed to distribute intensity by time of day. This is fairly trivial and can be done using various data that is specific for the local situation. In table and figure below, the estimates we've used, based on observed highway traffic intensity (a good proxy for all roads), making a distinction between weekday and weekend. Note that the sum over all hours is 1 for weekday, but lower for weekend, as traffic generation an assignment is assumed for a weekday with typical peak-profiles.



	0to1	1to2	2to3	3to4	4to5	5to6	6to7	7to8	8to9	9to10	10to11	11to12	12to13	13to14	14to15	15to16	16to17	17to18	18to19	19to20	20to21	21to22	22to23	23to0
WEEKDAY	0.8%	0.5%	0.3%	0.4%	0.7%	2.0%	4.5%	6.8%	6.9%	5.5%	5.1%	5.1%	5.5%	5.6%	5.7%	6.4%	7.6%	8.1%	7.2%	5.2%	3.5%	2.8%	2.4%	1.6%
WEEKEND	1.9%	1.2%	0.8%	0.6%	0.6%	0.8%	1.2%	1.8%	2.9%	4.4%	5.2%	5.8%	5.9%	6.2%	6.2%	5.8%	6.0%	6.6%	6.4%	5.3%	4.2%	3.3%	2.6%	2.0%

Figure 1-2: Share of daily traffic by type of day, compared to a typical weekday

The approach chosen in Sosnowiec, Ljubljana, Aveiro and Liguria is the backbone of the transport module in the generic model. For more information on the methodology, we refer to *Deliverable 5.4: Generic city model*

1.2 Transport: Mode choice model

Since the present modal split in Aveiro urban area's and Bristol is very similar (with all modes within a few percent's margin), we used the mode choice model built for Bristol as is for Aveiro. In the Final Scenario and the remaining three cities we went a step further and manually calibrated the model using the ASC values to create an even better match with the current observed modal split.

1.3 Air quality modelling

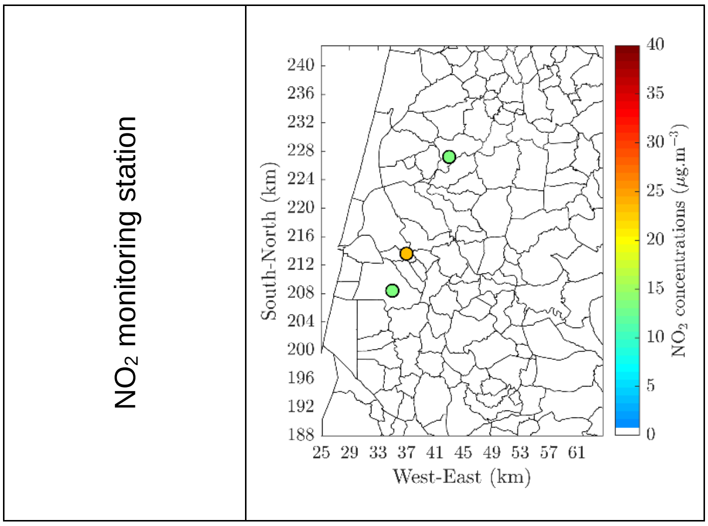
1.3.1 Background concentrations

Based on the source apportionment analysis obtained from the WRF-CAMx and the PSAT tool, it is expected an underestimation of the URBAIR concentrations comparing to measured data results due to the lack of other emission sources contributing to the concentrations within the area, as well as the background concentrations. Therefore, based on the SA, a concentration value for the background concentrations and other sources was used to be added on the whole domain. For NO_2 the background added was 0.1 µg.m^{-3}, for PM_{10} was 9.8 µg.m^{-3} and for $PM_{2.5}$ was 9.3 µg.m^{-3}.

1.3.2 Summary of measuring data

In order to compare and calibrate the modelling results for the year of 2015, for NO_2 and PM_{10} concentrations the modelling results could be compared with 2 suburban background monitoring station and 1 urban traffic monitoring station. For $PM_{2.5}$, the modelling results could only be compared with 1 urban background station.

Figure 1-3 shows the location of the monitoring stations and the annual mean concentration for 2015 for NO_2, PM_{10} and $PM_{2.5}$.



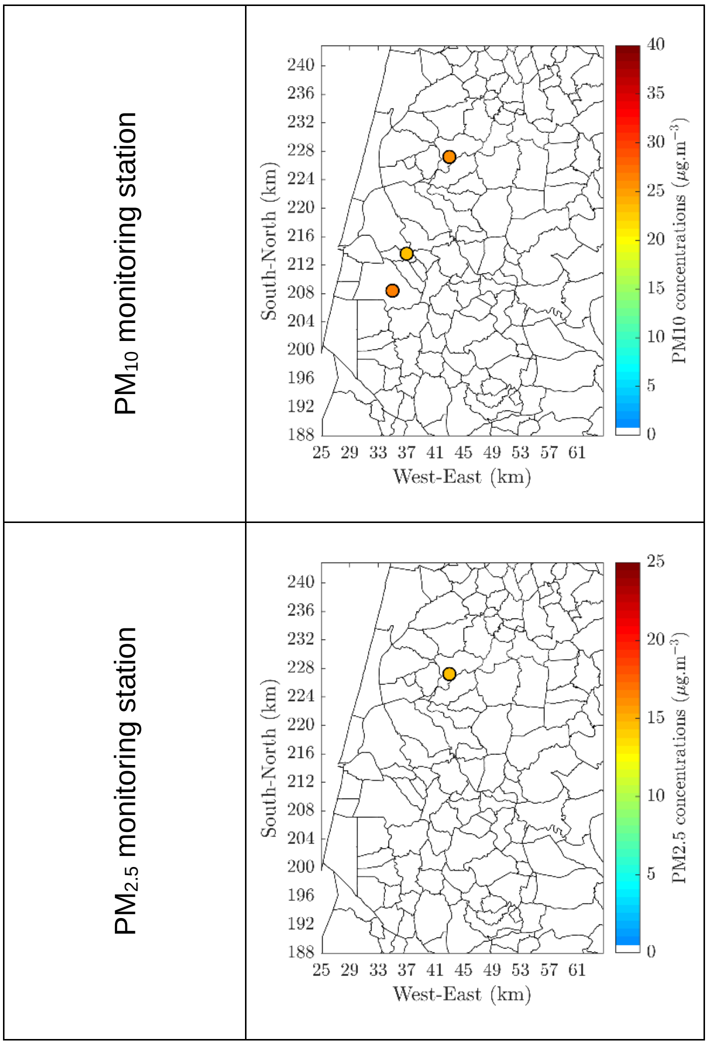


Figure 1-3: Summary data for 2015 with the location of the monitoring stations and respective annual mean concentration for each pollutant in μg.m^{-3}.

1.3.3 Adjustment procedure

The adjustment procedure is based on the linear regression between the measurements and the simulated concentrations obtained within the cells corresponding to the location of the measurement points. The slope from the linear regression is applied as an adjustment factor over the entire domain. For NO_2 concentrations, the slope obtained from the linear regression is equal to 2.2. For PM_{10} concentrations the resulting slope is equal to 1.4 and for $PM_{2.5}$ the slope is 0.5.

2 Description and modelling of the scenario's

In ClairCity, we do the quantification of the emissions and air quality in 4 sequential steps:

- **The baseline**: the emissions, air quality and carbon footprint in our reference year: 2015. These results can be verified with observations and serve as a calibration of the tools.
- **The business as usual scenario (BAU)**: the emissions, air quality and carbon footprint are estimated for selected future years: 2025, 2035, 2050. This takes into account the effect of existing measures (e.g. natural fleet renewal in transport)
- **The Stakeholder Dialogue Workshop scenario's (SDW)**: the emissions, air quality and carbon footprint in future years, compared to BAU, including the measures in the scenario's established in the stakeholder workshops.
- **The final unified scenario (UPS)**: the emissions, air quality and carbon footprint in future years, compared to BAU, in the single selected scenario, established in the policy workshop

This section mainly describes the assumption made in the modelling to estimate the scenarios. An overview of the initial definition of the individual policies and their timelines are given in the table below.

Table 2-1: Overview of the measures in the Aveiro Region SDW and final scenario

Policy	Low Scenario	High Scenario	Final Scenario
Build segregated urban cycle lanes and create secure cycle storage/parking	150 km of new urban cycle lanes and 100 number of new cycle parking spaces by 2025	300 km of new urban cycle lanes and 200 number of new cycle parking spaces by 2035	High option
Create school and workplace travel plans to increase uptake of active travel and public transport	50% modal shift from private cars to active travel and public transport by 2025	50% modal shift from private cars to active travel and public transport by 2025	High option (High and Low were the same)
Reallocate road space to pedestrians and improve safety	50 km of new/renewed pedestrian routes by 2025	100 km of new/renewed pedestrian routes by 2025	High option
Ban diesel cars/HGVs in urban centres	10% ban on diesel cars and 25% HGVs in urban centres by 2025	100% ban on diesel cars and HGVs in urban centres by 2030	Low option
Allow free parking for electric vehicles only	Switch 25% parking spaces into free parking for EVs only by 2035	Switch 100% parking spaces into free parking for EVs only by 2035	High option
Promote working from home	5% commuters work from home 1 day a week by 2030	10% commuters work from home 1 day a week by 2030	High option
Impose stricter regulation on polluting industries	Reduce industrial emissions by 15% by 2030	Reduce industrial emissions by 45% by 2030	Low option
Encourage replacement of older public transport fleet	Replace 15% public transport fleet with zero-emission vehicles by 2030	Replace 60% public transport fleet with zero-emission vehicles by 2030	Low option
Subsidise public transport tickets	Public transport fares reduced by 50% by 2021	Public transport fares reduced by 75% by 2025	Low option
Increase provision and reliability of public transport services	100% public transport journeys on schedule with all urban areas catered for by 2025	100% public transport journeys on schedule with all urban areas catered for by 2025	High option (High and Low were the same)

2.1 Transport

2.1.1 Baseline and BAU

The baseline modal split (trip share) is as follows:

- Walk 16%
- Bike 4%
- Car/van 74%
- Public transport 5%
- Other 1%

To calibrate the Bristol model to the trip shares of Aveiro, here are the changes in the ASC values that we derived:

ASC_1 = ASC_1-0.5
ASC_2 = ASC_2+1
ASC_3 = ASC_3+1
ASC_4 = ASC_4-0.4

The baseline passenger vehicle stock and its fleet evolution is according to our modified and updated MOVEET model (see further notes under Sosnowiec). The calibrated technology time shift for Portugal (describing the penetration timeline of xEV vehicles) is 2 years.

To scale the number of cars from Portugal to the region and city in question we simply scaled the numbers according to the population of the city/region relative to the population of Portugal (assuming that the car ownership rates in Portugal, the city, and the region are the same). We calculated with the following numbers: Portugal has a population of 10570000, Aveiro has a population of 78455, and the Região de Aveiro has a total population of 370394, translating to 291939 without the city itself.

2.1.2 Proposed SDW scenario's

As earlier, we only discuss policies here that were translated into our models. Some policies, for example "*Build segregated urban cycle lanes and create secure cycle storage/parking*", are not modelled separately, but are considered to be supporting policies of other modelled measures (e.g., in this example, the modal shift from private cars to active modes).

Subsidise public transport tickets: as earlier, we model this by assuming that local public transport prices drop by 50% (in the Low Scenario, by 2021) or 75% (in the High Scenario, by 2025), and let the mode choice model calculate the induced modal shift. As the first reporting year is 2025, we have always modelled this together with the next measure.

Create school and workplace travel plans to increase uptake of active travel and public transport: in terms of modal shift, we model this by enforcing the mode choice model to shift 50% of those car trips that have the motive of work or education to active modes such as walking and cycling. We achieve this by modifying the ASC value of car in a negative direction until we arrive to the aimed -50% car share for trips with work and education motive. The resulting model parameters (together with the reduced PT prices) are the following:

- In Low Model:
  - StageCost_4 = data['StageCost_4'] * 0.5
  - ASC_1 = ASC_1-0.5
  - ASC_2 = ASC_2+1
  - ASC_3 = ASC_3-0.9
  - ASC_4 = ASC_4-0.4

- In High Model:
  - StageCost_4 = data['StageCost_4'] * 0.25
  - ASC_1 = ASC_1-0.5
  - ASC_2 = ASC_2+1
  - ASC_3 = ASC_3-0.85
  - ASC_4 = ASC_4-0.4

Ban diesel cars/HGVs in urban centres: this measure provides the largest differentiation between the High and Low scenario, and between the models that describe the city of Aveiro and the region outside of the city. We constructed the following four fleet models to describe the changes given in the scenarios' overview table:

- LOW_City: the only change in fleet model is a step-by-step banning of old diesel cars from the urban centers, that by definition leads to the ban of ~10% of diesel cars by 2025, and although it is not specified, we continue with stricter and stricter bans further on (until there is only Euro 6 left). Important, that we do at no point ban the sale of new, modern diesel cars. To do this, we need to scrap all diesel cars at the end of 2024 that are older than Age25.
  - We follow the same step by step approach that we did in other cities starting with scrapping Age24 and older cars in 2024 (meaning scrapping around 10% of the diesel stock), going until scrapping Age15 and older in 2030 (as the oldest Euro 6 in 2030 is Age14 this lines up nicely with the goal of keeping only these in the fleet).
  - This needs to be balanced with modifying the growth rates too. When scrapping Age_n car in year_n, then the growth rates in year_n+1 need to be zero for Age_n+1 cars and beyond (so no used car import in the age category that was scrapped already earlier).
  - Then just like we did in the Sosnowiec case, the sum of the remaining non zero growth rates is noted down for correction. However, since in Portugal the used import car market is assumed to be basically negligible, in the worst year this is not less than 0.992, so there is no need for the sale share corrections as it was for Poland. (No matter how negligible an effect it is, we still carried out the whole correction calculation as it was explained under Sosnowiec.)
- HIGH_City: we apply the same step by step banning approach as above, but starting the scrappage at the end of 2019 with the Age14 cars (newest Euro 3 vintage), and achieving the full scrap at the end of 2029. As above, growth rates are also adjusted and set to 0 for all vintages starting at 2030.
  - While adjusting the sale shares we took into account that a) the average age of diesel cars was 12 years at the beginning, b) as we get closer to the full ban, people are less inclined to buy a diesel car (compared to what the forecast diesel sale shares would be without an approaching full diesel ban). We assume that x years before the ban the original sale shares need to be adjusted with a x/12 multiplier (so, e.g., 5 years before the sale the actual sale shares are the forecast sale shares * 5/12). The deficit caused by the reduced

diesel sales is filled up by using a correction factor for the market shares of other fuel/drivetrain types (the same constant for all of these).

- LOW_Region: there are no measures changing the fleet composition outside the urban centres, so this is the same as the BAU.
- HIGH_Region: even though there are no measures active outside of the urban centres that would influence the fleet composition, we try to approximate the effect of a ban becoming and then being active in Aveiro itself, which is likely to cause the drop of diesel sales also outside of the city, since people can not use these cars to commute into the city anymore, etc. We assume a 1/3 drop in diesel sales, building up step by step as we get closer to the 2030 horizon. E.g., one year before the horizon the sale share multiplier is = 1-(11/12)*(1/3), and beyond the horizon it is kept constant at 1-1/3. This process starts in 2020 (multiplier =1-(2/12)*(1/3)), which is the first ban year in the city. As before the reduced diesel sales are balanced by applying a constant multiplier on the market share of other propulsion types.

Allow free parking for electric vehicles: We include the effect of this policy in two ways in our models. Firs of all, we have chosen a high xEV uptake scenario for the vehicle fleet, reflecting the positive effects of an electric vehicle promoting policy package. Moreover, we include the monetary cost savings in the mode choice model by estimating how much an average driver saves per car trip based on the calculated xEV fleet shares in a given model year, and the assumption that 25% or 100% of all parking spaces are free for xEV users in the Low and High scenarios, respectively.

- In the Low model:
  - 2035: by 2035 19.6% of the fleet is xEV. The average car trip price (we are working with the mode choice model of Bristol, so most values are in GBP or converted to GBP for the calculations) is 3.25 GBP, the parking price in Aveiro is maximum 2 EUR/day and/or 0.8EUR/hour (https://www.cm-aveiro.pt/visitantes/estacionamento). Assuming a typical parking related cost of 1 EUR per trip (0.89 GBP), if 25% of parking for xEVs are free, then 0.196*25=4.9% of all parking is free. For trips with a free parking there is a drop in cost of 0.89 GBP, so on average, there is a drop of 0.049*0.89 GBP = 0.04361 GBP for car trips overall. This means that parameters in the mode choice model are modified as follows (2nd line is included to avoid having negative consts for very short trips including parking cost savings):
    - StageCost_3 = data['StageCost_3'] - 0.04361
    - StageCost_3[StageCost_3<0] = 0
    - StageCost_4 = data['StageCost_4'] * 0.5
    - ASC_1 = ASC_1-0.5
    - ASC_2 = ASC_2+1
    - ASC_3 = ASC_3-0.9
    - ASC_4 = ASC_4-0.4
  - 2050: the calculation process is the same, but done for the 2050 share of xEV vehicles of 50.5%, resulting in an average saving per trip of 0.112 GBP.

- In the High model: The calculation process is the same, but we assume that all parking is free for xEV owners and of course that the fleet composition is slightly different, resulting in savings of 0.341 and 0.619 GBP (calculating with xEV shares of 38.3% and 69.5%) for 2035 and 2050, respectively.

Promote working from home: The basic assumption is that 5% or 10% of commuters (in the Low and High Scenarios, respectively) works from home on 1 day per week from 2030. We model this by removing the mileage from the model that would be travelled by these people (so a percentage of the total commuting trips). This is actually a very small percentage, as in the Low scenario we need to remove (1/5)*0.05 the total commuting mileage (1/5 because it is only one day of the working week, and 0.05 as only 5% of people will work from home), which results in a 1% mileage reduction (and 2% in the High scenario). This is such a small change, that actually the small car mileage growth caused by the free parking for xEV vehicles completely annihilates its aimed traffic dampening effect.

2.1.3 Final Scenario

For the Final Scenario we use a mix of the aforementioned considerations and techniques, according to the final choices made for each policy, as they are listed in the overview table above. For this final model, we use the fleet model of the initial Low Scenario.

The final mode choice model is basically the same as the High Scenario, except for the public transport pricing which is the same as the Low was before, and the parking price calculations that had to use the shares from the Low background scenario.

2.2 Industrial, Residential, Commercial & Institutional (IRCI)

2.2.1 Baseline

In the following the data collection and evaluation procedures in the baseline are detailed for Aveiro Region.

The following tables document the methodology and data used for:

- Industrial sources (Table 2-2);
- Residential and commercial sources (Table 2-3);
- Freguesia disaggregation variables (Table 2-4).

Note that we use Freguesia subdivision at time of 2011 census

Table 2-2: Methodology and source of data for Aveiro Region fuel consumptions/emissions evaluation - Industrial sources

Activity	Data availability	Source	Publication	Reference	Note	Disaggregation variable
Industrial sector point sources	Single facility	EEA	European Pollutant Release and Transfer Register (E-PRTR)	https://prtr.eea.europa.eu/#/facilitylevels		None (Point sources)
Industrial sector – point and area sources	Single facility	PACOPAR	Painel Consultivo Comunitário do Programa Atuação Responsável® de Estarreja		Source with emissions less than 100 Mg allocated to 1kmx1km grid	None (Point sources)
Industrial sector – area sources	Gridded	University of Aveiro (UA)			Data elaborated by UA using national inventory and land use	Corine land cover

Table 2-3: Methodology and source of data for Aveiro Region consumptions evaluation - Residential and commercial sources

Activity	Energy vector	Data availability	Source	Publication	Reference	Note	Disaggregation variable
Residential sector	Natural Gas	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Dwelling total area (Table 2-4)

	Wood	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Dwelling total area (Table 2-4)
	LPG	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Dwelling total area (Table 2-4)
	Gasoil	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Dwelling total area (Table 2-4)
	Charcoal	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Dwelling total area (Table 2-4)
Service sector	Natural Gas	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Employees (Table 2-4)
	Wood	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Employees (Table 2-4)
	LPG	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Employees (Table 2-4)
	Gasoil	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Employees (Table 2-4)

Table 2-4: Methodology and source of data for Aveiro Region level 3 fuel consumptions evaluation

Variable	Data availability	Sources	Publication	Reference	Fields
Dwelling numbers and area	Level 3 (Freguesia)	Instituto Nacional de Estatistica	Censos 2011	https://censos.ine.pt/xportal/xmain	Number of dwelling by fuel and technology*Average area of dwelling For wood combustion technologies the following association was defined: *Aquecimento central* with *boiler*, *Aquecimento nao central - lareira aberta* with *conventional fireplaces*, *Aquecimento nao central - recuperador de calor* with *advanced stoves*, *Aquecimento nao central* with *conventional stoves*
Service sector employees	Level 3 (Freguesia)	Instituto Nacional de Estatistica	Censos 2011	https://censos.ine.pt/xportal/xmain	

2.2.2 BAU

Business as Usual (BAU) scenario takes into consideration national and city level measures already defined/decided.

National BAU scenario evaluates national emission reduction starting from Portugal official projections.

The scenario was built in two steps using:

- the projections of greenhouse gas emissions and energy demand from the 7th national communication to UNFCCC[2] using scenario with additional measures (WAM);
- the national measures defined in the 'with measures' (adopted measures) projection in the frame of NECD[3].

In the first step the fuel consumption was varied following the energy demand projection with socioeconomic drivers, in the second step the emissions were varied to meet the NECD emissions considering technological drivers.

The **Aveiro Region** BAU projections consider:

Regarding industrial emissions from main point source, at the Aveiro Navigator Company Industrial Complex (Fabrica de Cacia)[4], a sleeve filters system was planned to be fitted on the biomass boiler in the first quarter of 2019 with reduction in particle emissions by 2020 of 90% on limit value and an effective reduction of 77% on 2015 PM_{10} emissions.

The Navigator Company also has a commitment to minimizing the use of fossil fuels in industrial processes by 2035, leading the Company to be a Carbon Neutral Company by 2035.

Regarding Residential, Commercial and Institutional sources the measures included are only the national ones, as the measures adopted by the municipalities of the Aveiro Region for residential and commercial sectors in the frame of Covenant of Mayors, such as the replacement of street light bulbs for LED lighting and the installation of PV panels in public buildings (e.g. municipal swimming pools), don't seems to give supplemental reduction in addition to national measures.

Point sources drivers' definition is reported in Table 2-5 while technological drivers' definition is reported in Table 2-6.

[2] Portuguese Environment Agency, 7th National Communication to the United Nations Framework Convention on Climate Change
[3] National emission ceilings (NEC Directive 2001/81/EC), 2015 submission on NECD, Annex IV Projections reporting
[4] The Navigator Company, Sustainability Report 2018

Table 2-5: Aveiro: Point source technological drivers used to project emissions in industrial, residential and commercial sector

Code	Name	Domain
SFS	Sleeve Filters System	Fábrica de Cacia (Portucel)

For drivers coming from EU NEC "with measures" data, as it's impossible to derive from available information the split between socio-economic measures, such as for example fuel consumptions reductions, and technological measures, such as for example advanced combustion technology, all the measures are valuated as technological. As the NEC projections are lower than emissions resulting from application of measures of UNFCCC NC ones and there is no specification about reductions by fuel in UNFCCC NC only NEC measures are taken into consideration.

Table 2-6: Aveiro: Technological drivers used to project emissions in industrial, residential and commercial sector

Code	Name	Domain
AVE_NECB_NOx	Aveiro NEC Building NOx	all Aveiro Freguesia
AVE_NECB_PM	Aveiro NEC Building PM	all Aveiro Freguesia
AVE_NECI_NOx	Aveiro NEC Industry NOx	all Aveiro Freguesia
AVE_NECI_PM	Aveiro NEC Industry PM	all Aveiro Freguesia

2.2.3 SDW scenarios

Scenarios from the Stakeholder dialog workshop (SWD) includes the measures of Table 2-7 relating to the IRCI sector (the codes are defined in this report).

Table 2-7: Aveiro: Measures coming from the Stakeholder dialog workshop

Code	Description	Scenario
AVE_I-15%PM	Aveiro Reduce PM industrial emissions by 15% on 2025	Low
AVE_I-45%PM	Aveiro Reduce PM industrial emissions by 45% on 2025	High
AVE_I-45%NOX	Aveiro Reduce NO_x industrial emissions by 45% on 2025	High

The following assumptions apply to the simulations:

- No measures for residential and commercial sector were proposed by SWD;
- The industrial measures are considered as complementary to national NECD ones;
- Regarding NO_x emissions, the reduction by SWD measures in the low scenario are lower than national NECD ones; no supplemental driver was introduced for NO_x in this scenario.

2.2.4 Unified Policy Scenario

The final Unified Policy Scenario includes the measures of Table 2-8 relating to the IRCI sector (the codes are defined in this report).

Table 2-8: Aveiro Region: Measures for the Unified Policy Scenario

Code	Description
AVE_I-15%PM	Aveiro Reduce PM industrial emissions by 15% on 2025

2.3 Carbon footprint

2.3.1 Baseline

The following tables document the methodology and data used for:

- Industrial sources (Table 2-2);
- Residential and commercial sources (Table 2-3);
- Freguesia disaggregation variables (Table 2-4).

Note that we use Freguesia subdivision at time of 2011 census.

Table 2-9: Methodology and source of data for Aveiro Region fuel consumptions/emissions evaluation - Industrial sources

Activity	Energy vector	Data availability	Source	Publication	Reference	Note	Disaggregation variable
Industrial sector	Natural Gas	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal. Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Employees (Table 2-4)
	Coal	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal. Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Employees (Table 2-4)
	LPG	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal. Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Employees (Table 2-4)
	Gasoil	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal. Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Employees (Table 2-4)
	Fuel oil	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal. Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Employees (Table 2-4)
	Wood	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal. Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Employees (Table 2-4)
	Biogas	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal. Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Employees (Table 2-4)

	Electricity	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal. Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Employees (Table 2-4)

Table 2-10: Methodology and source of data for Aveiro Region consumptions evaluation - Residential and commercial sources

Activity	Energy vector	Data availability	Source	Publication	Reference	Note	Disaggregation variable
Residential sector	Natural Gas	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal.Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Dwelling total area (Table 2-4)
	Wood	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal. Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Dwelling total area (Table 2-4)
	LPG	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal. Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Dwelling total area (Table 2-4)
	Gasoil	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal. Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Dwelling total area (Table 2-4)
	Charcoal	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal. Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Dwelling total area (Table 2-4)
	Electricity	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal. Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Dwelling total area (Table 2-4)

Service sector	Natural Gas	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal. Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Employees (Table 2-4)
	Wood	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal. Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Employees (Table 2-4)
	LPG	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal. Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Employees (Table 2-4)
	Gasoil	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal. Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Employees (Table 2-4)
	Electricity	Level 1 (National)	Direção-Geral de Energia e Geologia	ENERGIA em Portugal. Versão 06-03-2017	http://www.dgeg.gov.pt?cr=15697		Employees (Table 2-4)

Table 2-11: Methodology and source of data for Aveiro Region level 3 fuel consumptions evaluation

Variable	Data availability	Sources	Publication	Reference	Fields
Dwelling numbers and area	Level 3 (Freguesia)	Instituto Nacional de Estatistica	Censos 2011	https://censos.ine.pt/xportal/xmain	Number of dwelling by fuel and technology*Average area of dwelling For wood combustion technologies the following association was defined: *Aquecimento central* with *boiler*, *Aquecimento nao central - lareira aberta* with *conventional fireplaces*, *Aquecimento nao central - recuperador de calor* with *advanced stoves*, *Aquecimento nao central* with *conventional stoves*
Service sector employees	Level 3 (Freguesia)	Instituto Nacional de Estatistica	Censos 2011	https://censos.ine.pt/xportal/xmain	

2.3.2 BAU

Business as Usual (BAU) scenario takes into consideration national and city level measures already defined/decided. As a general input to the projection model, results from IRCI and Traffic models have been assumed for fuel consumptions.

For electricity emission factors an additional driver was introduced to take into consideration the evolution of carbon footprint from electricity generation. The driver is defined using the projections of greenhouse gas emissions and energy demand from the 7th national communication to UNFCCC[5] using scenario with additional measures (WAM) and the Roteiro para a Neutralidade Carbónica 2050 of July 2019[6]. The evolution of use of fuels in the industrial, residential and commercial sectors is derived from the information in the quoted documents using as a reference the global reductions of final use of different fuels.

2.3.3 SDW Scenarios

Scenario projections take into consideration city level additional measures from Stakeholder dialog workshop (SWD). Also, in this case as a general input to the projection model, results from IRCI and Traffic models have been assumed for fuel consumptions.

2.3.4 Final Unified Policy Scenario

Also, for the final Unified Policy Scenario as a general input to the projection model, results from IRCI and Traffic models have been assumed for fuel consumptions.

[5]

[6] Presidência do Conselho de Ministros, Roteiro para a Neutralidade Carbónica 2050, julho 2019

3 Results

In this section, we elaborate on the results of the simulations. We report on a sector by sector basis, first reporting on transport, as most of the policy measures focus on transport and secondly on the other sectors (IRCI) combined.

In transport, we first report the (passenger) mode choice changes and secondly on the fleet/emissions impact.

Emissions for other sectors are reported in the section on the IRCI-module results.

Carbon footprint, air quality and consequent health impacts are reported in separate sections as well.

3.1 Transport

3.1.1 Mode choice changes

We present here the tables containing the relative mileage changes (compared to the Baseline) and the resulting modal split (where technically feasible) for various reporting years in each scenario. For the Final scenario we also present the calibrated baseline.

Mode	Mileage change	Trip share (%)
1|Walk	▲ 2.096	29.2
2|Bicycle	▲ 2.649	7.5
3|Car/van	▼ 0.742	44.0
4|Bus/metro	▲ 3.079	11.7
5|Train/surface rail	▲ 2.205	3.5
6|Taxi	▲ 2.752	1.9
7|Other (incl. motorbike)	▲ 2.351	2.2

Figure 3-1: Scenario Low (2025)

Mode	Mileage change
1|Walk	▲ 2.080
2|Bicycle	▲ 2.648
3|Car/van	▼ 0.743
4|Bus/metro	▲ 3.066
5|Train/surface rail	▲ 2.143
6|Taxi	▲ 2.793
7|Other (incl. motorbike)	▲ 2.400

Figure 3-2: Scenario Low (2035)

Mode	Mileage change
1|Walk	▲ 2.085
2|Bicycle	▲ 2.662
3|Car/van	▼ 0.742
4|Bus/metro	▲ 3.062
5|Train/surface rail	▲ 2.166
6|Taxi	▲ 2.823
7|Other (incl. motorbike)	▲ 2.353

Figure 3-3: Scenario Low (2050)

Mode	Mileage change	Trip share (%)
1|Walk	▲ 2.040	28.5
2|Bicycle	▲ 2.487	7.3
3|Car/van	▼ 0.731	44.2
4|Bus/metro	▲ 3.998	12.7
5|Train/surface rail	▲ 2.051	3.3
6|Taxi	▲ 2.698	1.9
7|Other (incl. motorbike)	▲ 2.175	2.1

Figure 3-4: Scenario High (2025)

Mode	Mileage change
1|Walk	2.013
2|Bicycle	2.435
3|Car/van	0.733
4|Bus/metro	3.975
5|Train/surface rail	2.015
6|Taxi	2.565
7|Other (incl. motorbike)	2.135

Figure 3-5: Scenario High (2035)

Mode	Mileage change
1|Walk	1.997
2|Bicycle	2.414
3|Car/van	0.735
4|Bus/metro	3.932
5|Train/surface rail	2.000
6|Taxi	2.604
7|Other (incl. motorbike)	2.176

Figure 3-6: Scenario High (2050)

Mode	Trip share (%)
1|Walk	15.86
2|Bicycle	3.41
3|Car/van	73.01
4|Bus/metro	4.55
5|Train/surface rail	1.45
6|Taxi	0.83
7|Other (incl. motorbike)	0.90

Figure 3-7: Trip shares in the calibrated mode choice model for the Baseline of the Final Scenario

Mode	Mileage change	Trip share (%)
1|Walk	2.096	29.2
2|Bicycle	2.649	7.5
3|Car/van	0.742	44.0
4|Bus/metro	3.079	11.7
5|Train/surface rail	2.205	3.5
6|Taxi	2.752	1.9
7|Other (incl. motorbike)	2.351	2.2

Figure 3-8: Final Scenario (2025)

Mode	Mileage change
1|Walk	▲ 2.069
2|Bicycle	▲ 2.644
3|Car/van	▼ 0.743
4|Bus/metro	▲ 3.030
5|Train/surface rail	▲ 2.172
6|Taxi	▲ 2.820
7|Other (incl. motorbike)	▲ 2.276

Figure 3-9: Final Scenario (2035)

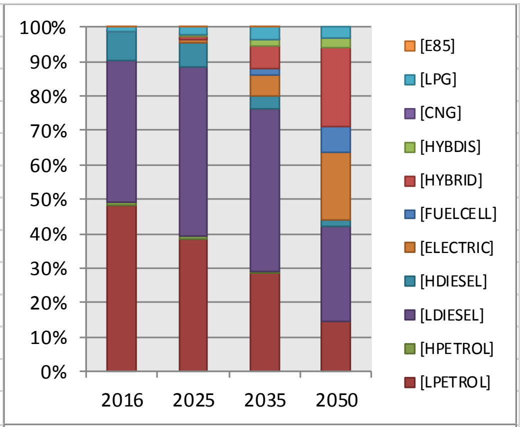
Mode	Mileage change
1|Walk	▲ 2.064
2|Bicycle	▲ 2.577
3|Car/van	▼ 0.745
4|Bus/metro	▲ 3.030
5|Train/surface rail	▲ 2.158
6|Taxi	▲ 2.730
7|Other (incl. motorbike)	▲ 2.325

Figure 3-10: Final Scenario (2050)

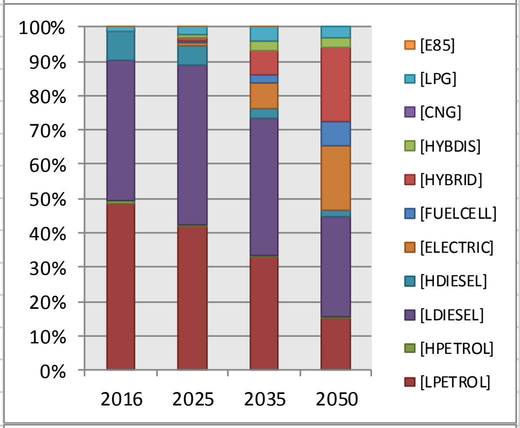
3.1.2 Fleet and Emissions

We present here the fleet compositions for each reporting year within each scenario, and the final emission calculation tables.

VENSIM model in percentage of total fleet per reporting year				
BAU	2016	2025	2035	2050
[LPETROL]	48.28%	38.63%	28.57%	14.47%
[HPETROL]	0.91%	0.58%	0.39%	0.20%
[LDIESEL]	41.09%	49.05%	47.23%	27.43%
[HDIESEL]	8.52%	6.99%	3.71%	1.79%
[ELECTRIC]	0.06%	1.03%	6.23%	19.92%
[FUELCELL]	0.00%	0.19%	1.99%	7.43%
[HYBRID]	0.03%	0.91%	6.25%	22.77%
[HYBDIS]	0.00%	0.50%	2.06%	3.07%
[CNG]	0.00%	0.00%	0.00%	0.00%
[LPG]	1.10%	2.12%	3.56%	2.92%
[E85]	0.00%	0.00%	0.00%	0.00%



VENSIM model in percentage of total fleet per reporting year				
LOW	2016	2025	2035	2050
[LPETROL]	48.28%	41.94%	32.85%	15.30%
[HPETROL]	0.91%	0.63%	0.45%	0.21%
[LDIESEL]	41.09%	46.15%	40.20%	28.99%
[HDIESEL]	8.52%	5.55%	2.63%	1.90%
[ELECTRIC]	0.06%	1.30%	7.42%	18.98%
[FUELCELL]	0.00%	0.26%	2.34%	7.02%
[HYBRID]	0.03%	1.13%	7.34%	21.51%
[HYBDIS]	0.00%	0.61%	2.49%	3.02%
[CNG]	0.00%	0.00%	0.00%	0.00%
[LPG]	1.10%	2.42%	4.28%	3.07%
[E85]	0.00%	0.00%	0.00%	0.00%



VENSIM model in percentage of total fleet per reporting year				
HIGH	2016	2025	2035	2050
[LPETROL]	48.28%	56.33%	61.50%	30.63%
[HPETROL]	0.91%	0.83%	0.84%	0.42%
[LDIESEL]	41.09%	23.99%	0.00%	0.00%
[HDIESEL]	8.52%	1.57%	0.00%	0.00%
[ELECTRIC]	0.06%	2.66%	14.54%	26.15%
[FUELCELL]	0.00%	0.51%	4.42%	9.42%
[HYBRID]	0.03%	2.39%	14.11%	28.91%
[HYBDIS]	0.00%	1.37%	5.19%	5.04%
[CNG]	0.00%	0.00%	0.01%	0.00%
[LPG]	1.10%	4.54%	9.28%	5.78%
[E85]	0.00%	0.00%	0.00%	0.00%

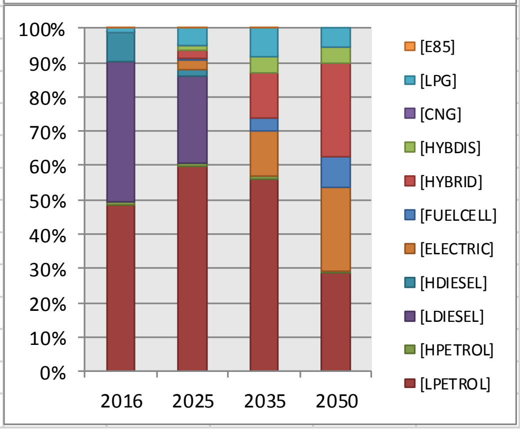
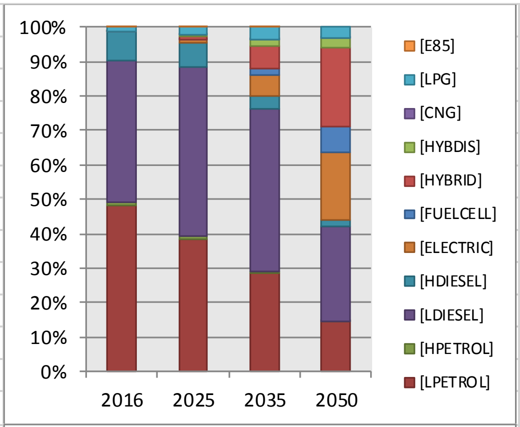
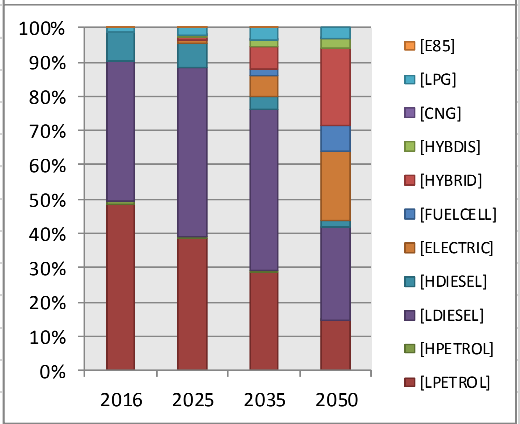


Figure 3-11: Passenger car fleet composition in the BAU, the Low, and High Scenarios in the City.

	VENSIM model in percentage of total fleet per reporting year			
BAU	2016	2025	2035	2050
[LPETROL]	48.28%	38.63%	28.57%	14.47%
[HPETROL]	0.91%	0.58%	0.39%	0.20%
[LDIESEL]	41.09%	49.05%	47.23%	27.43%
[HDIESEL]	8.52%	6.99%	3.71%	1.79%
[ELECTRIC]	0.06%	1.03%	6.23%	19.92%
[FUELCELL]	0.00%	0.19%	1.99%	7.43%
[HYBRID]	0.03%	0.91%	6.25%	22.77%
[HYBDIS]	0.00%	0.50%	2.06%	3.07%
[CNG]	0.00%	0.00%	0.00%	0.00%
[LPG]	1.10%	2.12%	3.56%	2.92%
[E85]	0.00%	0.00%	0.00%	0.00%



	VENSIM model in percentage of total fleet per reporting year			
LOW	2016	2025	2035	2050
[LPETROL]	48.28%	38.63%	28.57%	14.47%
[HPETROL]	0.91%	0.58%	0.39%	0.20%
[LDIESEL]	41.09%	49.05%	47.23%	27.43%
[HDIESEL]	8.52%	6.99%	3.71%	1.79%
[ELECTRIC]	0.06%	1.03%	6.23%	19.92%
[FUELCELL]	0.00%	0.19%	1.99%	7.43%
[HYBRID]	0.03%	0.91%	6.25%	22.77%
[HYBDIS]	0.00%	0.50%	2.06%	3.07%
[CNG]	0.00%	0.00%	0.00%	0.00%
[LPG]	1.10%	2.12%	3.56%	2.92%
[E85]	0.00%	0.00%	0.00%	0.00%



	VENSIM model in percentage of total fleet per reporting year			
HIGH	2016	2025	2035	2050
[LPETROL]	48.28%	39.97%	32.02%	17.22%
[HPETROL]	0.91%	0.60%	0.44%	0.24%
[LDIESEL]	41.09%	47.54%	41.01%	20.05%
[HDIESEL]	8.52%	6.89%	3.31%	1.31%
[ELECTRIC]	0.06%	1.22%	7.62%	22.00%
[FUELCELL]	0.00%	0.23%	2.43%	8.18%
[HYBRID]	0.03%	1.07%	7.62%	25.03%
[HYBDIS]	0.00%	0.59%	2.52%	3.56%
[CNG]	0.00%	0.00%	0.00%	0.00%
[LPG]	1.10%	2.33%	4.23%	3.47%
[E85]	0.00%	0.00%	0.00%	0.00%

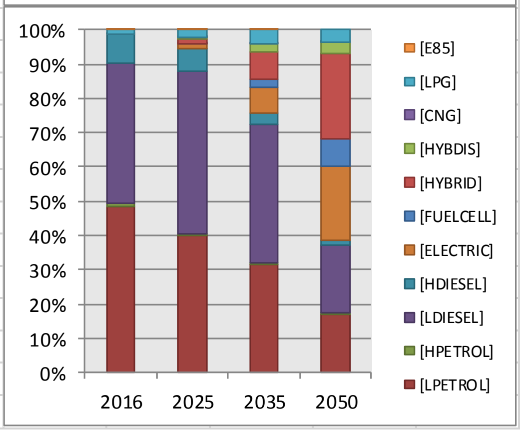


Figure 3-12: Passenger car fleet composition in the BAU, the Low, and High Scenarios in the Region.

VENSIM model in percentage of total fleet per reporting year				
FINAL	2016	2025	2035	2050
[LPETROL]	48.28%	41.94%	32.85%	15.30%
[HPETROL]	0.91%	0.63%	0.45%	0.21%
[LDIESEL]	41.09%	46.15%	40.20%	28.99%
[HDIESEL]	8.52%	5.55%	2.63%	1.90%
[ELECTRIC]	0.06%	1.30%	7.42%	18.98%
[FUELCELL]	0.00%	0.26%	2.34%	7.02%
[HYBRID]	0.03%	1.13%	7.34%	21.51%
[HYBDIS]	0.00%	0.61%	2.49%	3.02%
[CNG]	0.00%	0.00%	0.00%	0.00%
[LPG]	1.10%	2.42%	4.28%	3.07%
[E85]	0.00%	0.00%	0.00%	0.00%

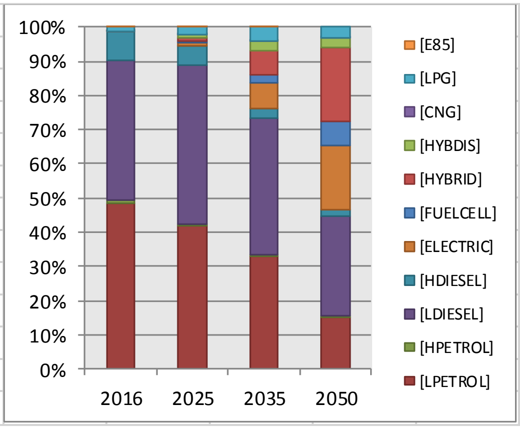


Figure 3-13: Passenger car fleet composition in the Final Scenario in the City.

VENSIM model in percentage of total fleet per reporting year				
FINAL	2016	2025	2035	2050
[LPETROL]	48.28%	38.63%	28.57%	14.47%
[HPETROL]	0.91%	0.58%	0.39%	0.20%
[LDIESEL]	41.09%	49.05%	47.23%	27.43%
[HDIESEL]	8.52%	6.99%	3.71%	1.79%
[ELECTRIC]	0.06%	1.03%	6.23%	19.92%
[FUELCELL]	0.00%	0.19%	1.99%	7.43%
[HYBRID]	0.03%	0.91%	6.25%	22.77%
[HYBDIS]	0.00%	0.50%	2.06%	3.07%
[CNG]	0.00%	0.00%	0.00%	0.00%
[LPG]	1.10%	2.12%	3.56%	2.92%
[E85]	0.00%	0.00%	0.00%	0.00%

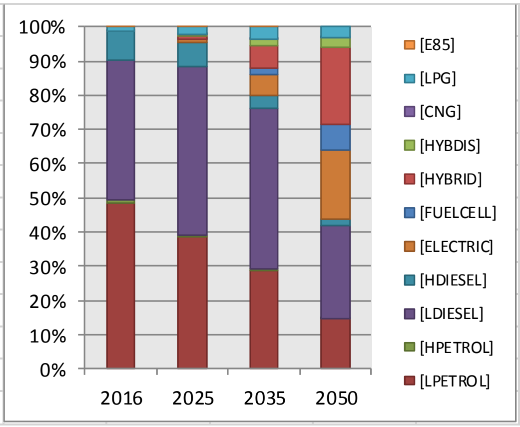


Figure 3-14: Passenger car fleet composition in the Final Scenario in the Region.

Because the policy package differs between city area’s and non-urban area’s, results are presented in 4 groups of tables:

1. SDW-scenario results for the city-area
2. UPS-scenario results for the city-area
3. SDW-scenario results for the wider region
4. UPS-scenario results for the wider region

Table 3-1: Relative emissions in the BAU and SDW scenario for the Aveiro city area's

MIDZWVR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	40.87%	24.36%	10.84%
LOW		24.80%	23.54%	10.84%
HIGH		24.80%	0.00%	0.00%

PM

Year	2015	2025	2035	2050
BAU	100.00%	29.03%	16.12%	12.39%
LOW		13.81%	15.27%	12.39%
HIGH		13.81%	0.00%	0.00%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	111.01%	123.23%	144.14%
LOW		111.01%	123.23%	144.14%
HIGH		111.01%	0.00%	0.00%

MOTO

Nox

Year	2015	2025	2035	2050
BAU	100.00%	116.60%	87.58%	38.66%
LOW		116.60%	87.58%	38.66%
HIGH		116.60%	87.58%	38.66%

PM

Year	2015	2025	2035	2050
BAU	100.00%	73.30%	40.52%	31.37%
LOW		73.30%	40.52%	31.37%
HIGH		73.30%	40.52%	31.37%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	110.46%	122.02%	141.66%
LOW		110.46%	122.02%	141.66%
HIGH		110.46%	122.02%	141.66%

ZWVR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	30.44%	13.28%	5.82%
LOW		23.42%	13.25%	5.82%
HIGH		23.42%	0.00%	0.00%

PM

Year	2015	2025	2035	2050
BAU	100.00%	35.73%	18.08%	13.89%
LOW		28.61%	18.05%	13.89%
HIGH		28.61%	0.00%	0.00%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	109.92%	120.82%	139.23%
LOW		109.92%	120.82%	139.23%
HIGH		109.92%	0.00%	0.00%

CAR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	58.92%	27.77%	7.37%
LOW		37.80%	10.62%	5.70%
HIGH		11.26%	2.26%	1.21%

PM

Year	2015	2025	2035	2050
BAU	100.00%	44.19%	12.60%	7.82%
LOW		21.51%	7.29%	5.91%
HIGH		6.83%	5.42%	4.57%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	107.24%	117.68%	127.78%
LOW		79.53%	87.40%	94.76%
HIGH		78.39%	86.24%	93.94%

BUS

Nox

Year	2015	2025	2035	2050
BAU	100.00%	35.62%	19.65%	8.67%
LOW		98.70%	48.19%	17.27%
HIGH		85.44%	15.62%	0.00%

PM

Year	2015	2025	2035	2050
BAU	100.00%	41.59%	22.78%	17.63%
LOW		115.24%	55.86%	35.09%
HIGH		89.78%	14.49%	0.00%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	110.46%	122.02%	141.66%
LOW		340.11%	374.08%	433.80%
HIGH		441.62%	485.01%	556.99%

VAN

Nox

Year	2015	2025	2035	2050
BAU	100.00%	49.89%	26.06%	9.10%
LOW		31.30%	17.08%	8.27%
HIGH		18.03%	12.90%	6.03%

PM

Year	2015	2025	2035	2050
BAU	100.00%	36.61%	14.36%	10.11%
LOW		17.66%	11.28%	9.15%
HIGH		10.32%	10.35%	8.48%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	109.12%	120.46%	135.96%
LOW		95.27%	105.32%	119.45%
HIGH		94.70%	104.74%	119.04%

Table 3-2: Relative emissions in the BAU and UPS scenario for the Aveiro city area's

MIDZWVR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	40.87%	24.36%	10.84%
UPS		24.80%	23.54%	10.84%

PM

Year	2015	2025	2035	2050
BAU	100.00%	29.03%	16.12%	12.39%
UPS		13.81%	15.27%	12.39%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	111.01%	123.23%	144.14%
UPS		111.01%	123.23%	144.14%

MOTO

Nox

Year	2015	2025	2035	2050
BAU	100.00%	116.60%	87.58%	38.66%
UPS		116.60%	87.58%	38.66%

PM

Year	2015	2025	2035	2050
BAU	100.00%	73.30%	40.52%	31.37%
UPS		73.30%	40.52%	31.37%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	110.46%	122.02%	141.66%
UPS		110.46%	122.02%	141.66%

ZWVR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	30.44%	13.28%	5.82%
UPS		23.42%	13.25%	5.82%

PM

Year	2015	2025	2035	2050
BAU	100.00%	35.73%	18.08%	13.89%
UPS		28.61%	18.05%	13.89%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	109.92%	120.82%	139.23%
UPS		109.92%	120.82%	139.23%

CAR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	58.92%	27.77%	7.37%
UPS		37.80%	10.62%	5.72%

PM

Year	2015	2025	2035	2050
BAU	100.00%	44.19%	12.60%	7.82%
UPS		21.51%	7.29%	5.93%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	107.24%	117.68%	127.78%
UPS		79.53%	87.38%	95.17%

BUS

Nox

Year	2015	2025	2035	2050
BAU	100.00%	35.62%	19.65%	8.67%
UPS		98.70%	47.63%	17.09%

PM

Year	2015	2025	2035	2050
BAU	100.00%	41.59%	22.78%	17.63%
UPS		115.24%	55.21%	34.73%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	110.46%	122.02%	141.66%
UPS		340.11%	369.70%	429.27%

VAN

Nox

Year	2015	2025	2035	2050
BAU	100.00%	49.89%	26.06%	9.10%
UPS		31.30%	17.08%	8.28%

PM

Year	2015	2025	2035	2050
BAU	100.00%	36.61%	14.36%	10.11%
UPS		17.66%	11.28%	9.16%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	109.12%	120.46%	135.96%
UPS		95.27%	105.31%	119.65%

Table 3-3: Relative emissions in the BAU and SDW scenario for the Aveiro region

MIDZWVR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	40.87%	24.36%	10.84%
LOW		40.87%	24.36%	10.84%
HIGH		40.87%	24.36%	10.84%

PM

Year	2015	2025	2035	2050
BAU	100.00%	29.03%	16.12%	12.39%
LOW		29.03%	16.12%	12.39%
HIGH		29.03%	16.12%	12.39%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	111.01%	123.23%	144.14%
LOW		111.01%	123.23%	144.14%
HIGH		111.01%	123.23%	144.14%

MOTO

Nox

Year	2015	2025	2035	2050
BAU	100.00%	116.60%	87.58%	38.66%
LOW		116.60%	87.58%	38.66%
HIGH		116.60%	87.58%	38.66%

PM

Year	2015	2025	2035	2050
BAU	100.00%	73.30%	40.52%	31.37%
LOW		73.30%	40.52%	31.37%
HIGH		73.30%	40.52%	31.37%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	110.46%	122.02%	141.66%
LOW		110.46%	122.02%	141.66%
HIGH		110.46%	122.02%	141.66%

ZWVR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	30.44%	13.28%	5.82%
LOW		30.44%	13.28%	5.82%
HIGH		30.44%	13.28%	5.82%

PM

Year	2015	2025	2035	2050
BAU	100.00%	35.73%	18.08%	13.89%
LOW		35.73%	18.08%	13.89%
HIGH		35.73%	18.08%	13.89%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	109.92%	120.82%	139.23%
LOW		109.92%	120.82%	139.23%
HIGH		109.92%	120.82%	139.23%

CAR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	58.92%	27.77%	7.37%
LOW		43.70%	20.62%	5.46%
HIGH		42.58%	18.91%	4.21%

PM

Year	2015	2025	2035	2050
BAU	100.00%	44.19%	12.60%	7.82%
LOW		32.77%	9.36%	5.80%
HIGH		32.20%	8.87%	5.37%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	107.24%	117.68%	127.78%
LOW		79.53%	87.40%	94.76%
HIGH		78.39%	86.24%	93.94%

BUS

Nox

Year	2015	2025	2035	2050
BAU	100.00%	35.62%	19.65%	8.67%
LOW		98.70%	48.19%	17.27%
HIGH		85.44%	15.62%	0.00%

PM

Year	2015	2025	2035	2050
BAU	100.00%	41.59%	22.78%	17.63%
LOW		115.24%	55.86%	35.09%
HIGH		89.78%	14.49%	0.00%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	110.46%	122.02%	141.66%
LOW		340.11%	374.08%	433.80%
HIGH		441.62%	485.01%	556.99%

VAN

Nox

Year	2015	2025	2035	2050
BAU	100.00%	49.89%	26.06%	9.10%
LOW		42.28%	22.49%	8.15%
HIGH		41.73%	21.64%	7.52%

PM

Year	2015	2025	2035	2050
BAU	100.00%	36.61%	14.36%	10.11%
LOW		30.90%	12.74%	9.10%
HIGH		30.62%	12.50%	8.88%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	109.12%	120.46%	135.96%
LOW		95.27%	105.32%	119.45%
HIGH		94.70%	104.74%	119.04%

Table 3-4: Relative emissions in the BAU and UPS scenario for the Aveiro region

MIDZWVR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	40.87%	24.36%	10.84%
UPS		40.87%	24.36%	10.84%

PM

Year	2015	2025	2035	2050
BAU	100.00%	29.03%	16.12%	12.39%
UPS		29.03%	16.12%	12.39%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	111.01%	123.23%	144.14%
UPS		111.01%	123.23%	144.14%

MOTO

Nox

Year	2015	2025	2035	2050
BAU	100.00%	116.60%	87.58%	38.66%
UPS		116.60%	87.58%	38.66%

PM

Year	2015	2025	2035	2050
BAU	100.00%	73.30%	40.52%	31.37%
UPS		73.30%	40.52%	31.37%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	110.46%	122.02%	141.66%
UPS		110.46%	122.02%	141.66%

ZWVR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	30.44%	13.28%	5.82%
UPS		30.44%	13.28%	5.82%

PM

Year	2015	2025	2035	2050
BAU	100.00%	35.73%	18.08%	13.89%
UPS		35.73%	18.08%	13.89%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	109.92%	120.82%	139.23%
UPS		109.92%	120.82%	139.23%

CAR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	58.92%	27.77%	7.37%
UPS		43.70%	20.62%	5.49%

PM

Year	2015	2025	2035	2050
BAU	100.00%	44.19%	12.60%	7.82%
UPS		32.77%	9.36%	5.83%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	107.24%	117.68%	127.78%
UPS		79.53%	87.38%	95.17%

BUS

Nox

Year	2015	2025	2035	2050
BAU	100.00%	35.62%	19.65%	8.67%
UPS		98.70%	47.63%	17.09%

PM

Year	2015	2025	2035	2050
BAU	100.00%	41.59%	22.78%	17.63%
UPS		115.24%	55.21%	34.73%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	110.46%	122.02%	141.66%
UPS		340.11%	369.70%	429.27%

VAN

Nox

Year	2015	2025	2035	2050
BAU	100.00%	49.89%	26.06%	9.10%
UPS		42.28%	22.49%	8.16%

PM

Year	2015	2025	2035	2050
BAU	100.00%	36.61%	14.36%	10.11%
UPS		30.90%	12.74%	9.11%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	109.12%	120.46%	135.96%
UPS		95.27%	105.31%	119.65%

3.2 Spatial-temporal

- Data pre-processing

Here we used the temperature dataset in ten-minute resolutions, which were shared by ClairCity's local partner in Aveiro, Portugal. The dataset is available in an .xlsx file and has three variables: date, time and temperature. The dates are from 2015, that is, 365 days from 1 January 2015 to 31 December 2015. The time variable shows the minute tenth of each hour, starting from hour zero: 00:00 to 11:50 in the evening or 23:50, representing the 24 hours in the day. Finally, the hourly temperature variable provides the values of hourly temperatures in Celsius to one decimal place. The data transformation from ten-minute resolution to daily average resolution was performed in Python.

Table 3-5: Resulting intra-day profiles

Typical days (TD)	Pattern (%)		
	Commercial	Residential	
	NOX and PM10	NOX	PM10
11-02-2015	0,322232267	0,327785069	0,335078442
15-02-2015	0,319974696	0,325488595	0,332730871
12-08-2015	0,259330379	0,256725091	0,253303155
16-08-2015	0,260684921	0,258066026	0,254626216

3.3 IRCI

3.3.1 Baseline

In the following maps the main results for NO_x and PM_{10} emissions are reported by freguesia. In detail are reported:

- Aveiro Region Residential, Commercial & Institutional NO_x emissions for all sectors and fuels (Figure 3-15)
- Aveiro Region Residential, Commercial & Institutional PM_{10} emissions for all sectors and fuels (Figure 3-16),
- Aveiro Region Residential, Commercial & Institutional PM_{10} emissions from solid biomass (Figure 3-17),
- Aveiro Region Industry NO_x point emissions (Figure 3-18),
- Aveiro Region Industry PM_{10} point emissions (Figure 3-19)
- Aveiro Region Industry NO_x diffuse area emissions (Figure 3-20),
- Aveiro Region Industry PM_{10} diffuse area emissions (Figure 3-21).

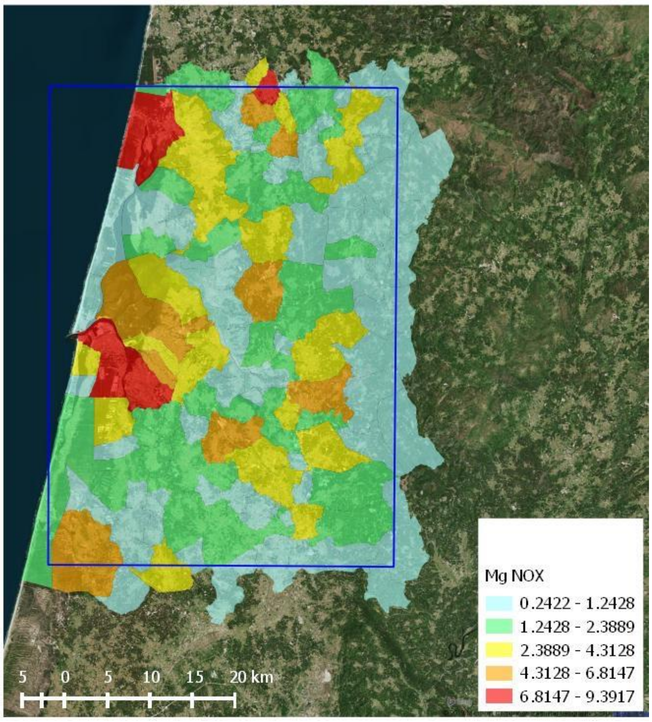


Figure 3-15: Aveiro Region Residential, Commercial & Institutional NOx emissions – all sectors and fuels

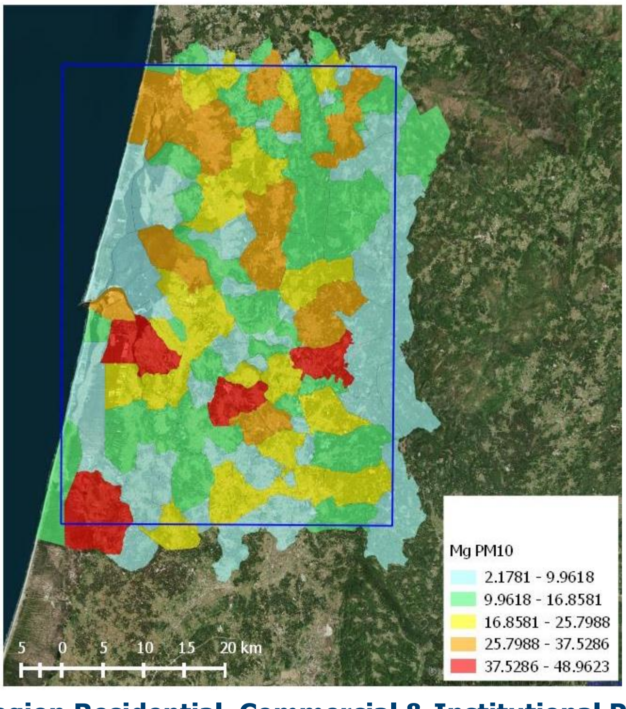


Figure 3-16: Aveiro Region Residential, Commercial & Institutional PM10 emissions – all sectors and fuels

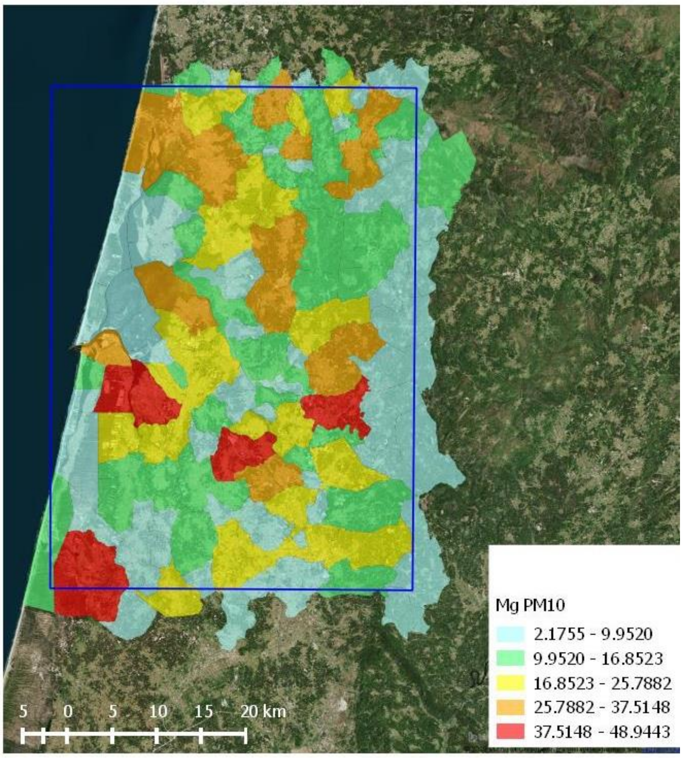


Figure 3-17: Aveiro Region Residential, Commercial & Institutional PM10 emissions – solid biomass

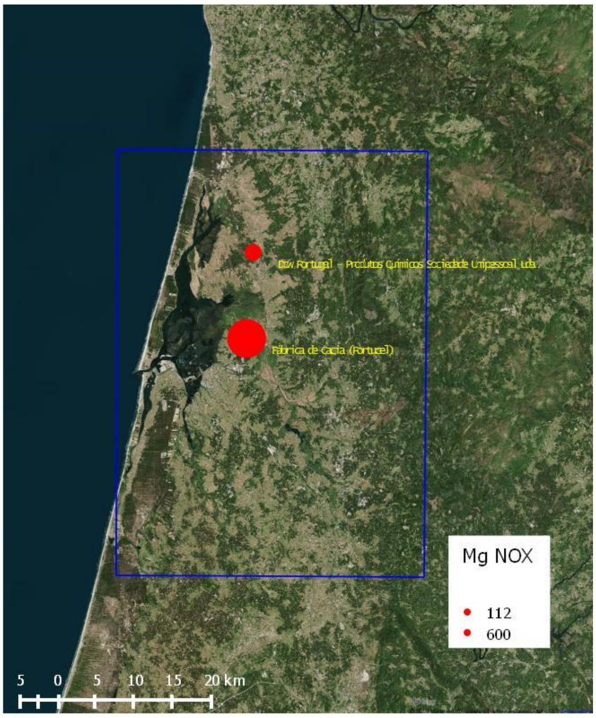


Figure 3-18: Aveiro Region Industry NOx point emissions

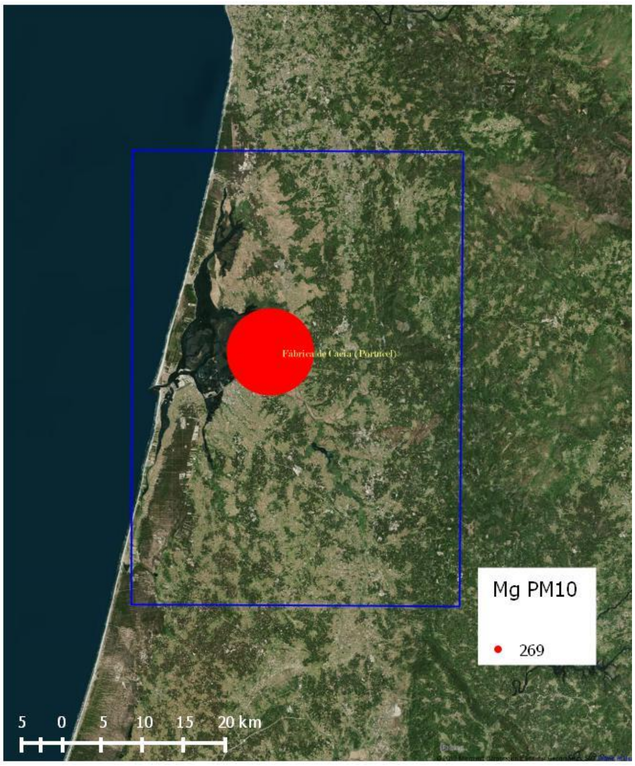


Figure 3-19: Aveiro Region Industry PM10 point emissions

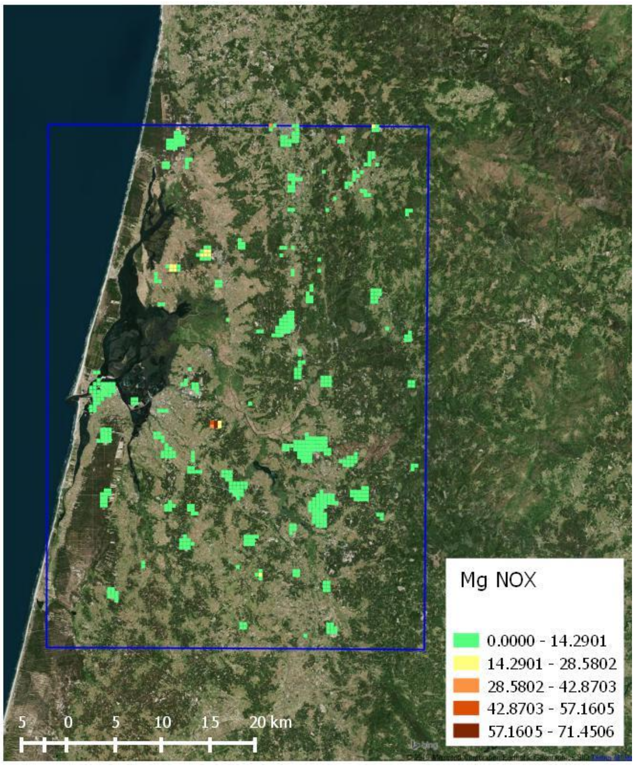


Figure 3-20: Aveiro Region Industry NOx diffuse area emissions

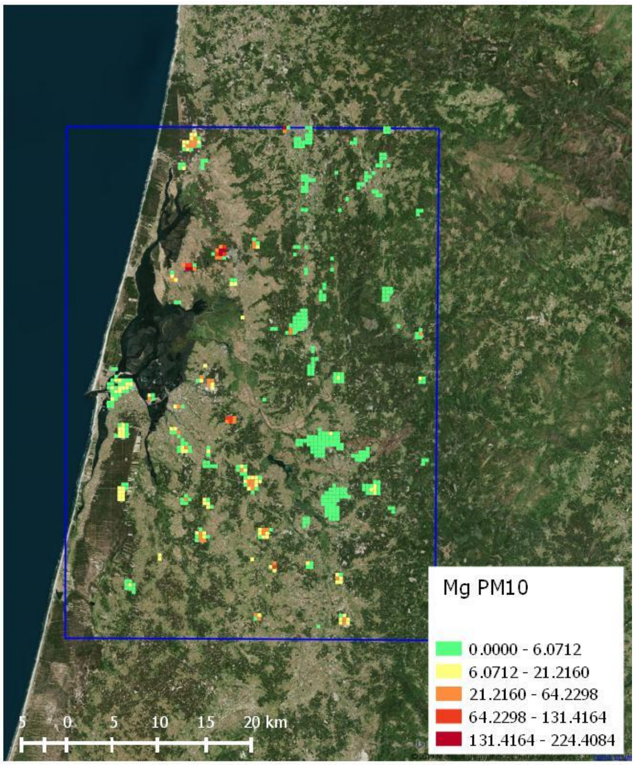


Figure 3-21: Aveiro Region Industry PM10 diffuse area emissions

Finally, in the following Figure 3-22 and Figure 3-23 the emissions for the different activities & fuels in the *Aveiro Region* are reported.

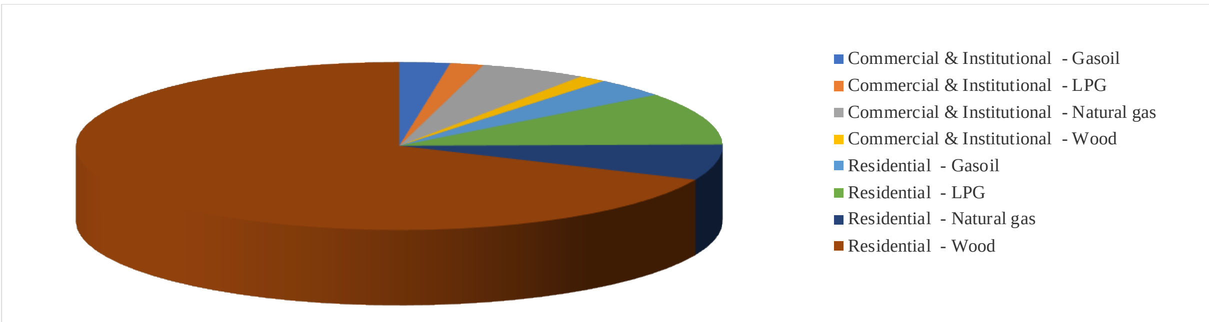


Figure 3-22: Aveiro Region Residential, Commercial & Institutional NOx emissions

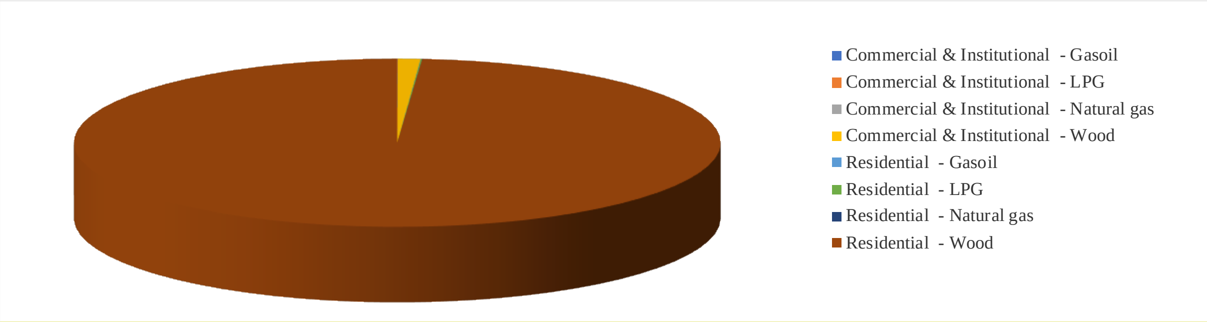


Figure 3-23: Aveiro Region Residential, Commercial & Institutional PM10 emissions

3.3.2 BAU

The evolutions of industrial emissions are reported in Figure 3-24 for nitrogen oxides (NO_x) and for suspended particles with diameter less than 10µ (PM_{10}).

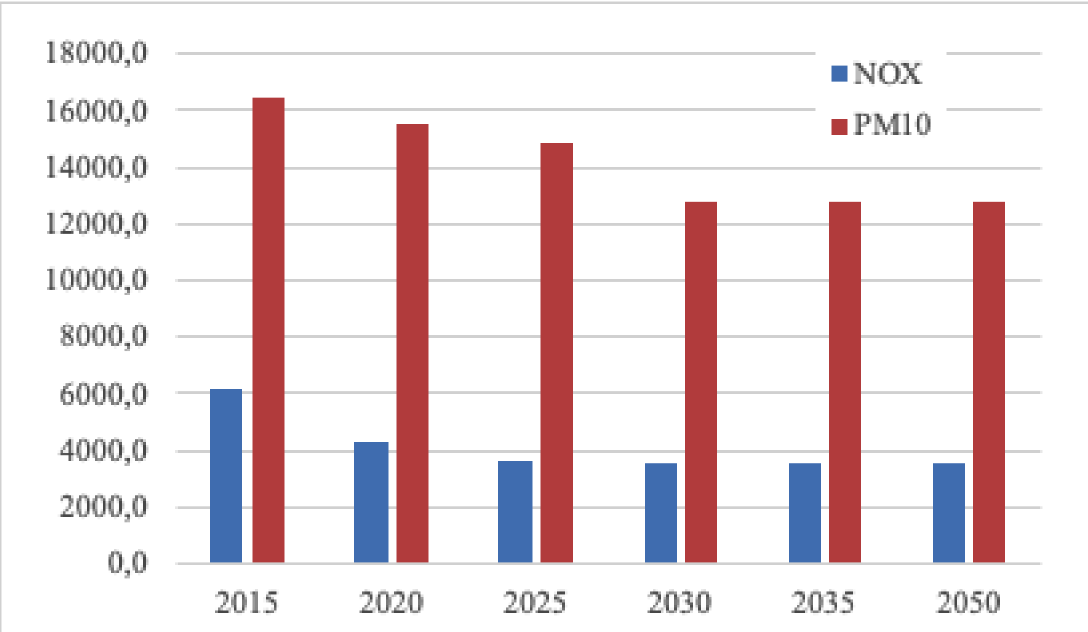


Figure 3-24: Aveiro BAU Industrial sources NOx and PM emissions

The evolution of residential, commercial and institutional emissions are reported in Figure 3-25 for nitrogen oxides (NO_x) and in Figure 3-26 for suspended particles with diameter less than 10µ (PM_{10}).

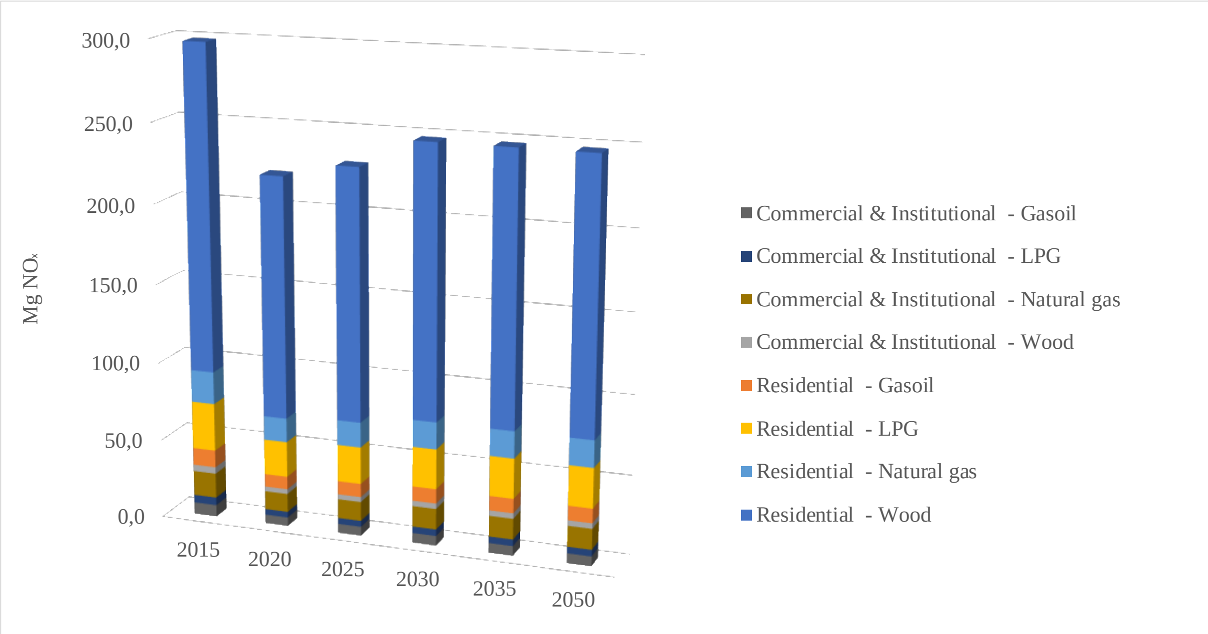


Figure 3-25: Aveiro BAU total Residential, Commercial & Institutional NOx emissions

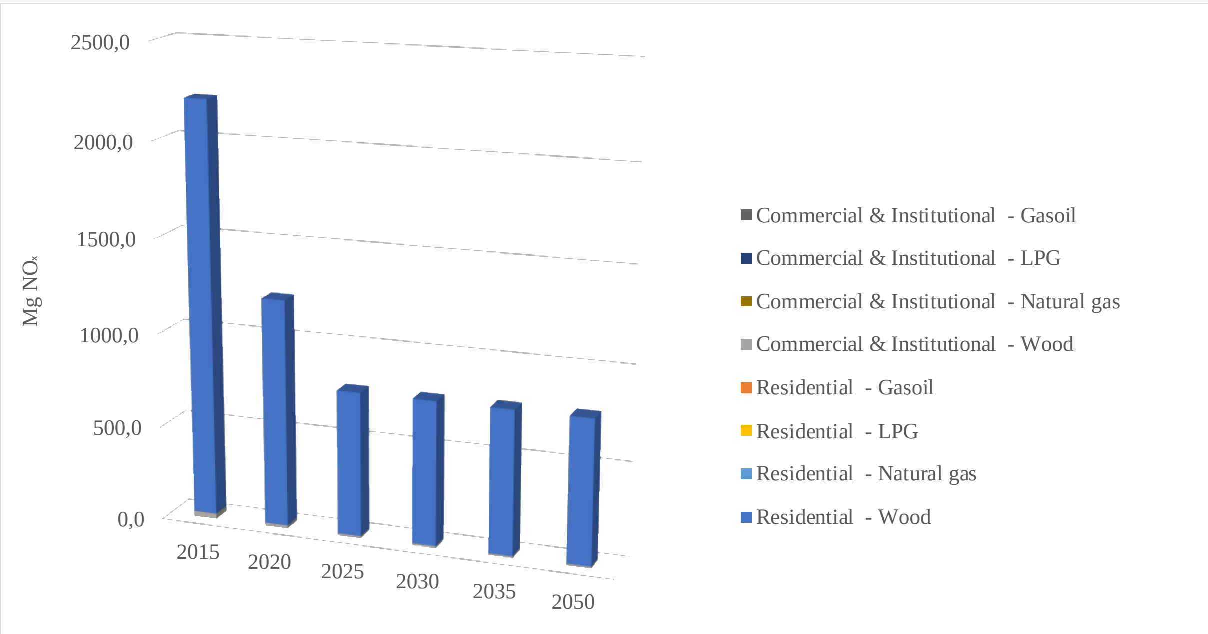


Figure 3-26: Aveiro BAU Residential, Commercial & Institutional PM10 emissions

3.3.3 Stakeholder dialog workshop Scenarios

Scenarios from the Stakeholder dialog workshop (SWD) includes no measures relating to the residential, commercial and institutional sector. While for the industrial:

In Figure 3-27 for nitrogen oxides (NO_x) and Figure 3-28 for suspended particles with diameter less than 10µ (PM_{10}) the trends of emissions in the different scenarios are reported.

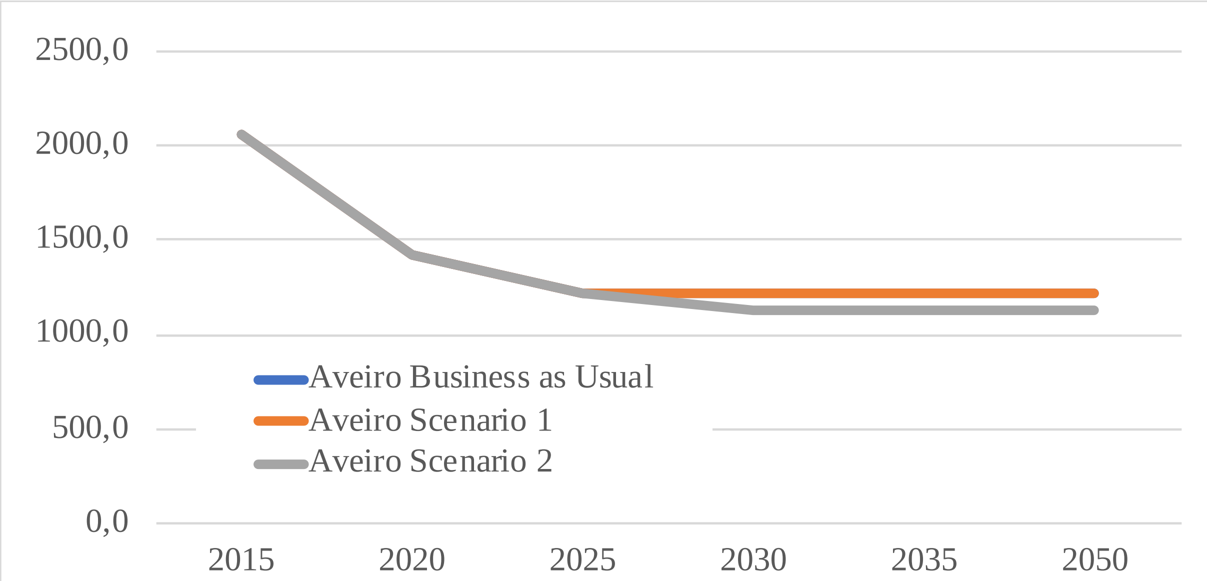


Figure 3-27: Aveiro Scenarios: Industrial sources NOx emissions

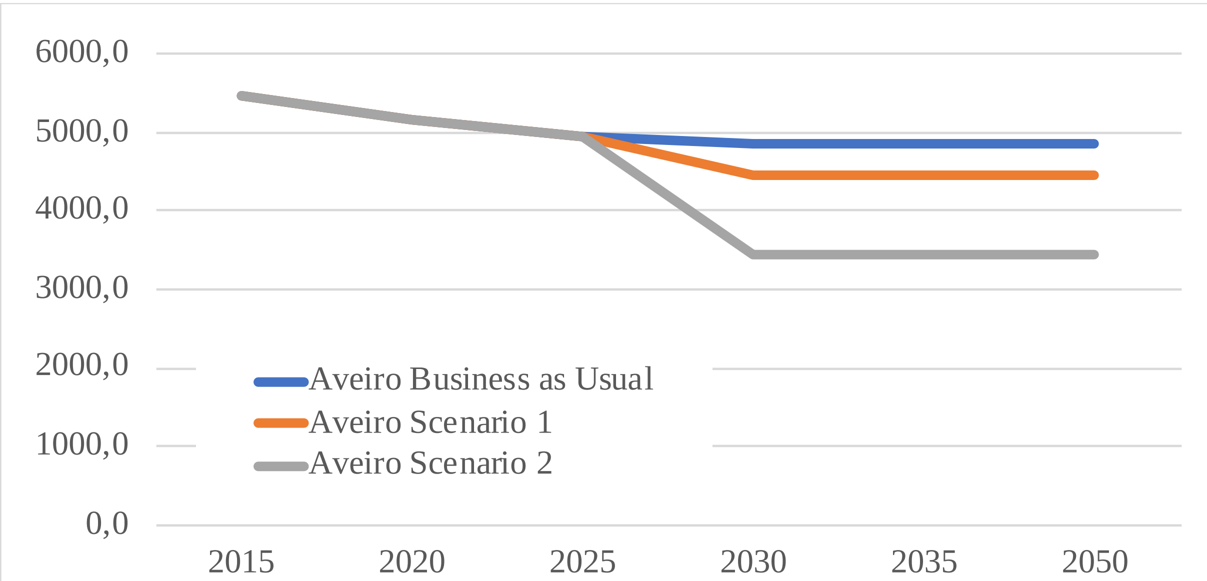


Figure 3-28: Aveiro Scenarios: Industrial sources PM10 emissions

3.3.4 Unified Policy Scenario

In Figure 3-29 for suspended particles with diameter less than 10µ (PM_{10}) the trends of emissions in the different scenarios are reported.

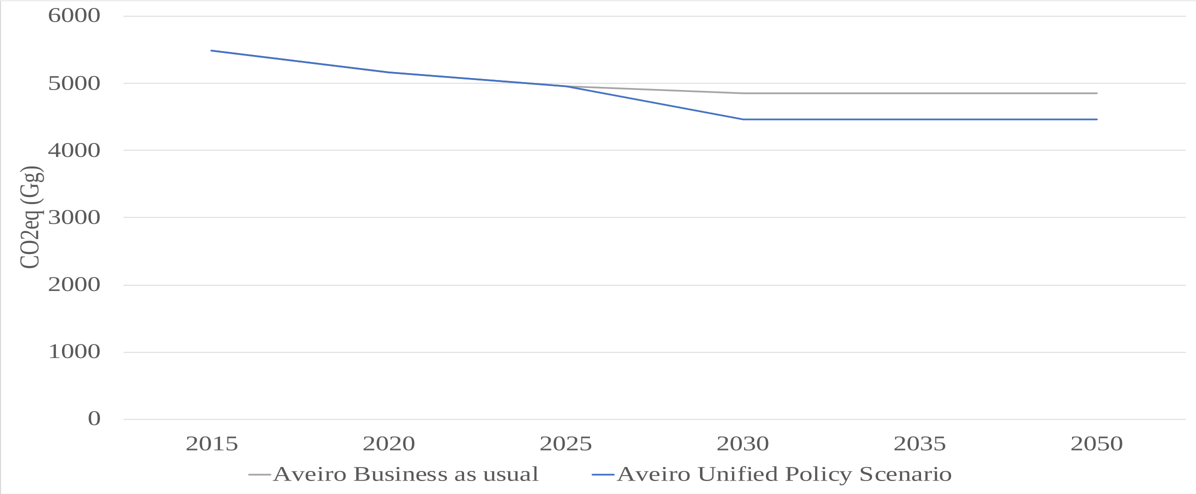


Figure 3-29: Aveiro BAU & Unified Policy Scenario comparison: Industrial sources PM10 emissions

Unified Policy Scenario includes no measures relating to the Residential, Commercial and Institutional sector and no additional reduction on BAU regarding NOx from industrial sources.

3.4 Carbon footprint

3.4.1 Baseline

In Table 3-6 Carbon Footprint by fuel is reported for Aveiro expressed as CO_2, CO_2 equivalent and CO_2 equivalent on Life Cycle.

Table 3-6: Aveiro Carbon Footprint by Fuel (Mg)

Energy Vector	CO_2	CO_{2eq}	$CO_{2eq,LCA}$
Biomass	-	6.330	15.659
Gasoil/diesel	999.419	1.002.113	1.144.887
Gasoline	518.717	520.216	653.644
LPG	72.948	72.948	90.290
Natural gas	320.152	320.152	380.644
Coal	950.909	957.452	1.114.483
Electricity	5.510	5.545	5.780
Total	**2.867.656**	**2.884.757**	**3.405.387**

In Figure 3-30 Carbon Footprint expressed as CO_2 equivalent on Life Cycle is reported by fuel and sector.

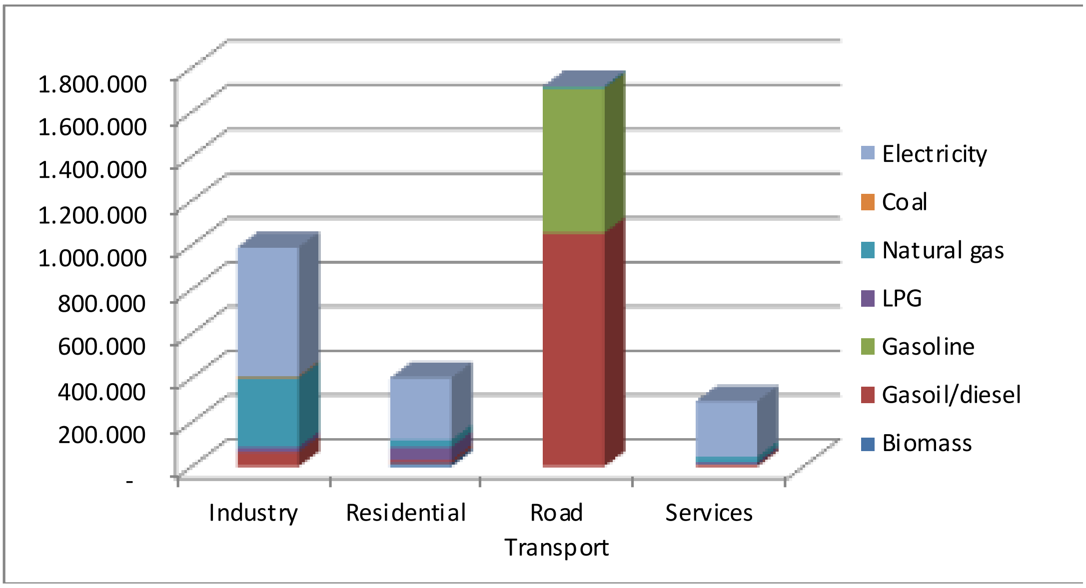


Figure 3-30: Aveiro Carbon Footprint (Mg CO_2 equivalent on Life Cycle)

In the following maps the results for sectors Carbon footprint are finally reported. In detail are reported:

- Aveiro Freguesia Carbon Footprint for all sectors and fuel (Figure 3-31),
- Aveiro Freguesia Carbon Footprint for Industrial sector (Figure 3-34);
- Aveiro Freguesia Carbon Footprint for Residential sector (Figure 3-33);
- Aveiro Freguesia Carbon Footprint for Services sector (Figure 3-32);
- Aveiro Freguesia Carbon Footprint for Transport sector (Figure 3-35).

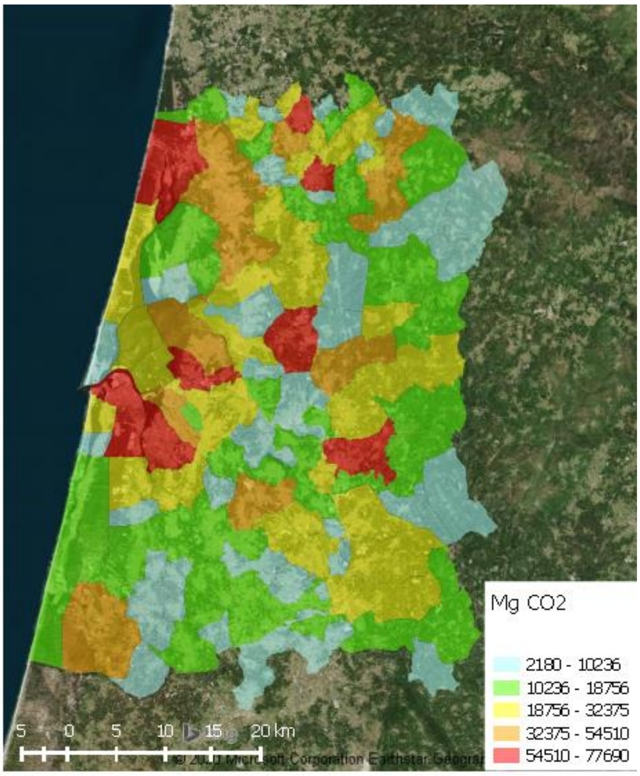


Figure 3-31: Aveiro Freguesia Carbon Footprint – all sectors

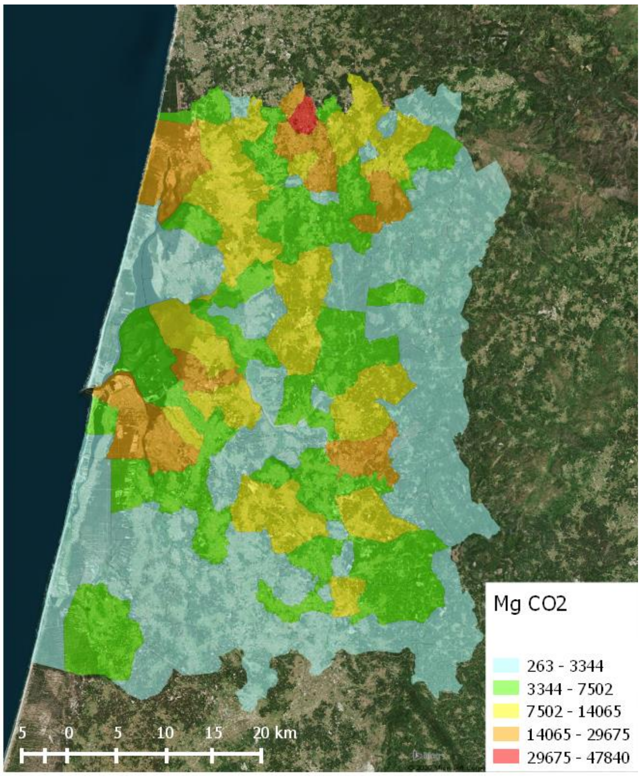


Figure 3-32: Aveiro Freguesia Carbon Footprint – industry sector

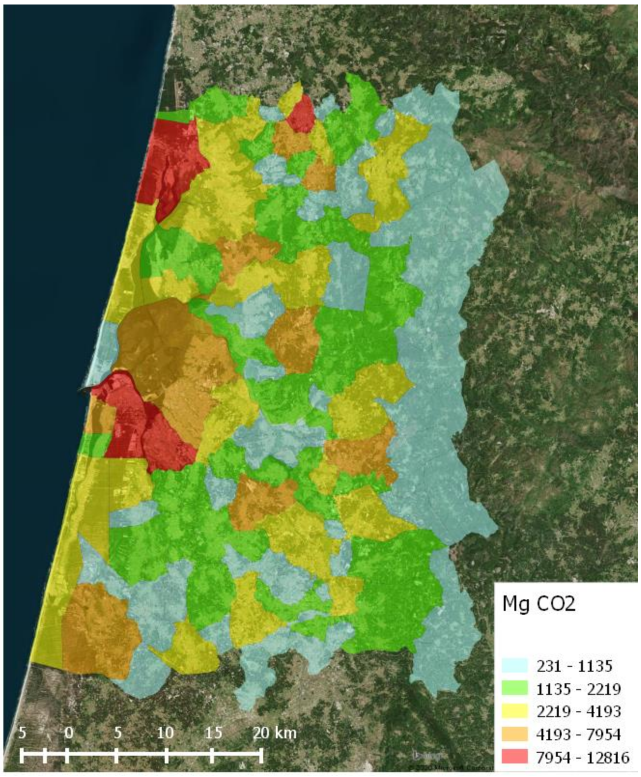


Figure 3-33: Aveiro Freguesia Carbon Footprint – residential sector

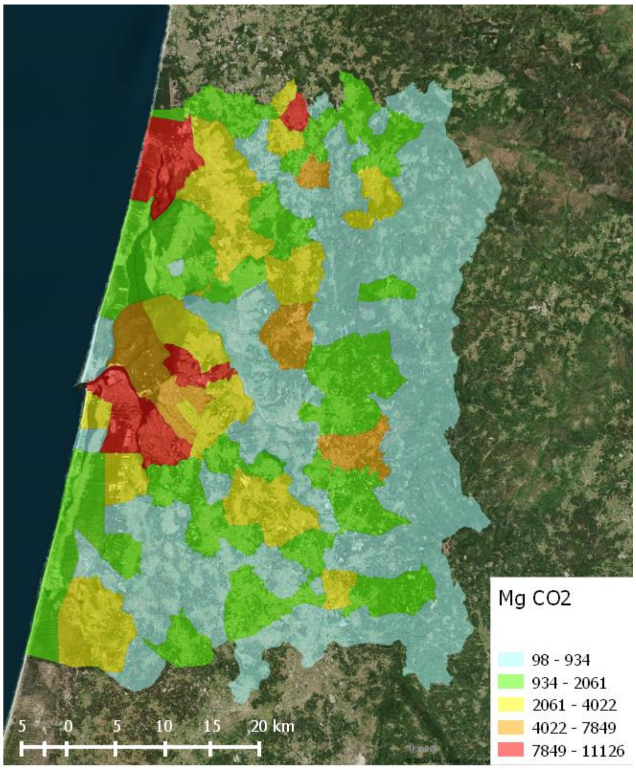


Figure 3-34: Aveiro Freguesia Carbon Footprint – services sector

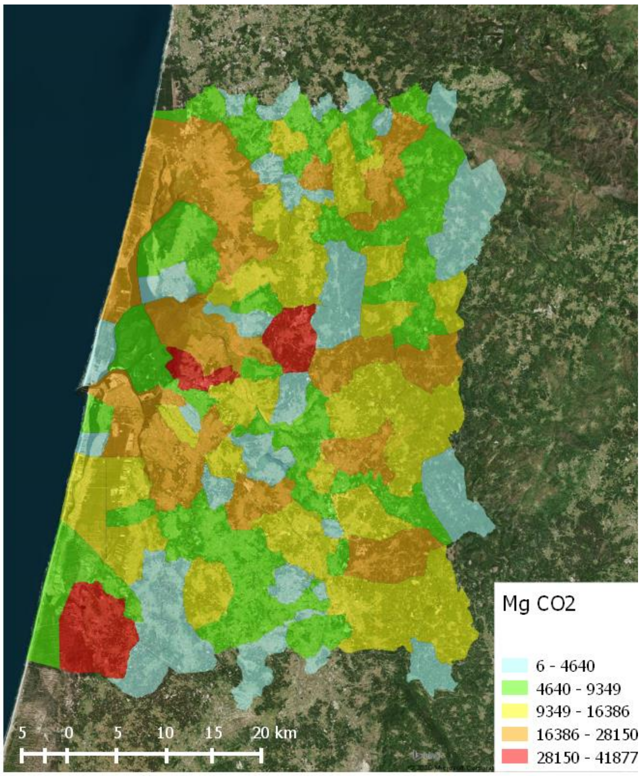


Figure 3-35: Aveiro Freguesia Carbon Footprint – road transport

3.4.2 BAU

In Table 3-7 Carbon Footprint by sector is reported for Aveiro BAU expressed as CO_2, CO_2 equivalent and CO_2 equivalent on Life Cycle. In Table 3-8 CO_2 equivalent on Life Cycle reductions on 2015 are reported.

Table 3-7: Aveiro BAU Carbon Footprint by Sector (Gg)

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide (CO_2)						
Residential	326,4	343,6	293,3	101,6	60,5	19,3
Services	251,8	266,6	228,2	63,1	35,1	13,1
Transport	1.447,2	1.395,1	1.333,2	1.234,8	1.134,3	772,9
Industry	842,2	917,3	847,1	483,8	350,4	139,8
Total	***2.867,7***	***2.922,6***	***2.701,8***	***1.883,3***	***1.580,3***	***945,1***
Carbon dioxide equivalent (CO_{2eq})						

Industry	334,4	351,3	301,5	109,3	67,1	21,8
Services	253,3	268,2	229,5	63,3	35,1	13,1
Transport	1.451,2	1.399,0	1.336,9	1.238,1	1.137,3	775,0
Residential	845,8	921,1	850,2	484,3	350,6	139,9
Total	***2.884,8***	***2.939,5***	***2.718,0***	***1.895,0***	***1.590,1***	***949,7***
Carbon dioxide equivalent on life cycle (CO_{2eq})						
Residential	401,5	420,8	363,2	140,0	88,8	29,1
Services	295,8	313,2	268,2	74,7	41,6	15,5
Transport	1.717,6	1.652,1	1.574,8	1.456,3	1.335,3	909,8
Industry	990,4	1.079,3	997,6	572,5	415,0	165,3
Total	***3.405,4***	***3.465,4***	***3.203,9***	***2.243,5***	***1.880,7***	***1.119,7***

Table 3-8: Aveiro BAU Carbon Footprint by Sector: index (2015=100)

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide equivalent on life cycle (CO_{2eq})						
Residential	100	105	90	35	22	7
Services	100	106	91	25	14	5
Transport	100	96	92	85	78	53
Industry	100	109	101	58	42	17
Total	***100***	***102***	***94***	***66***	***55***	***33***

Carbon Footprint, expressed as CO_2 equivalent on Life Cycle, is reported in Figure 3-36 by sector and in Figure 3-37 by fuel. The graphs highlight the largely dominant contribution of the residential and service sectors as described above, from the point of view of energy carriers, natural gas and electricity.

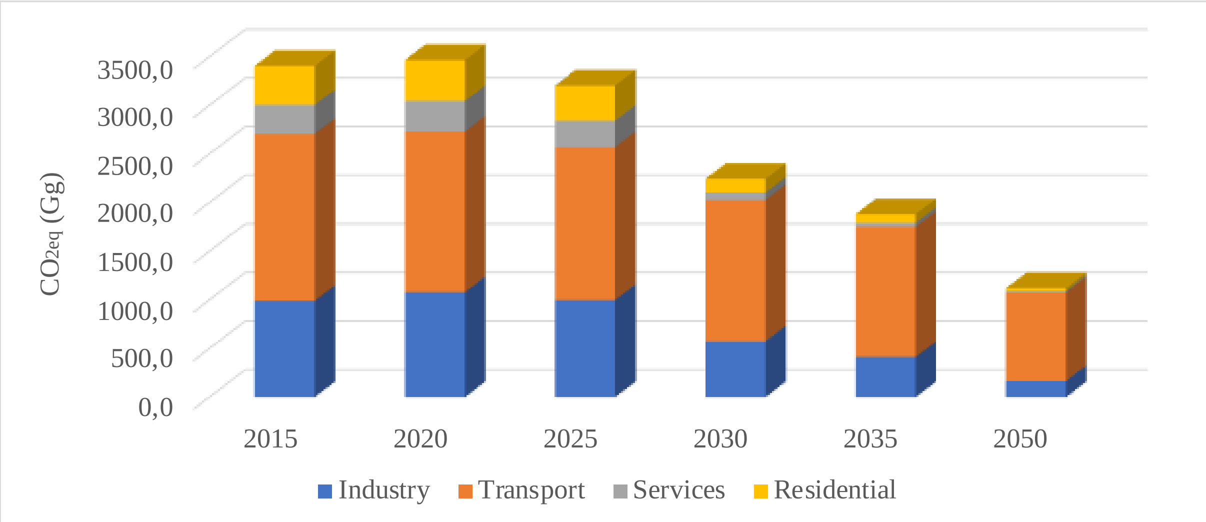


Figure 3-36: Aveiro BAU Carbon Footprint by sector (Gg CO2 equivalent on Life Cycle)

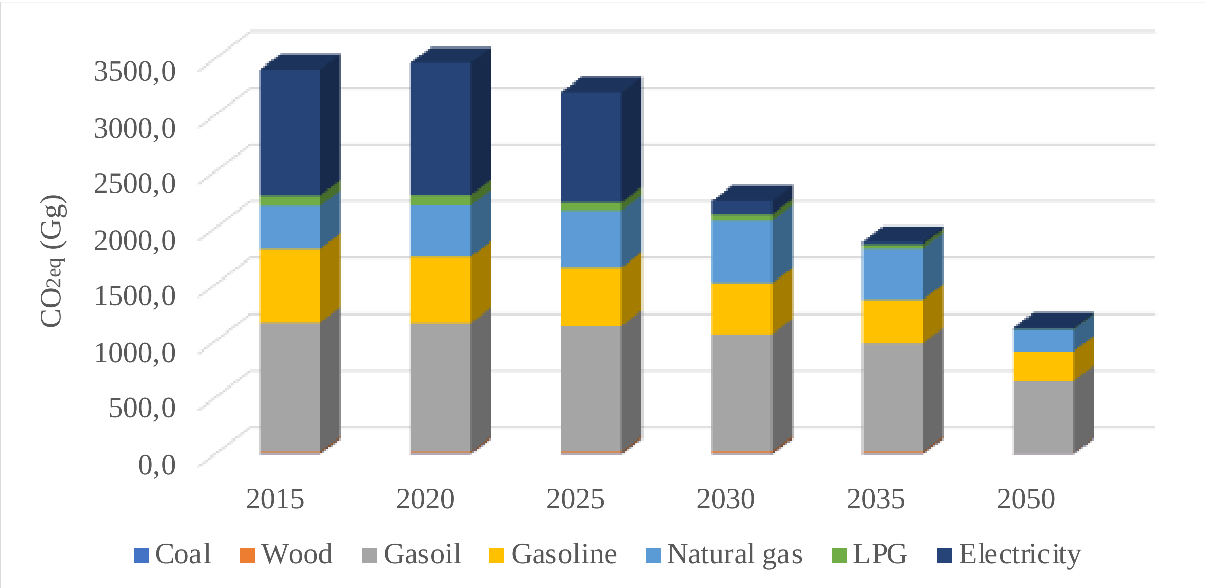


Figure 3-37: Aveiro BAU Carbon Footprint by fuel (Gg CO2 equivalent on Life Cycle)

3.4.3 Stakeholder dialog workshop Scenarios

In Table 3-9 CO_2 equivalent on Life Cycle reductions on 2015 are reported. In Table 3-10 Carbon Footprint by sector is reported for Aveiro Scenario *low* expressed as CO_2, CO_2 equivalent and CO_2 equivalent on Life Cycle.

Table 3-9: Aveiro Scenario low Carbon Footprint by Sector (Gg)

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide (CO_2)						
Residential	326,4	343,6	293,3	101,6	60,5	19,3
Services	251,8	266,6	228,2	63,1	35,1	13,1
Transport	1.447,2	1.297,2	1.147,9	1.049,4	949,6	674,4
Industry	842,2	917,3	847,1	483,8	350,4	139,8
Total	***2.867,7***	***2.824,7***	***2.516,5***	***1.698,0***	***1.395,6***	***846,6***
Carbon dioxide equivalent (CO_{2eq})						
Residential	334,4	351,3	301,5	109,3	67,1	21,8
Services	253,3	268,2	229,5	63,3	35,1	13,1
Transport	1.451,2	1.300,8	1.151,0	1.052,3	952,2	676,2
Industry	845,8	921,1	850,2	484,3	350,6	139,9
Total	***2.884,8***	***2.841,3***	***2.532,2***	***1.709,1***	***1.404,9***	***851,0***
Carbon dioxide equivalent on life cycle (CO_{2eq})						
Residential	401,5	420,8	363,2	140,0	88,8	29,1
Services	295,8	313,2	268,2	74,7	41,6	15,5
Transport	1.717,6	1.535,2	1.353,5	1.236,7	1.118,4	790,9
Industry	990,4	1.079,3	997,6	572,5	415,0	165,3
Total	***3.405,4***	***3.348,4***	***2.982,6***	***2.023,9***	***1.663,7***	***1.000,8***

Table 3-10: Aveiro Scenario low Carbon Footprint by Sector: index (2015=100)

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide equivalent on life cycle (CO_{2eq})						
Residential	100	100	105	90	35	22
Services	100	100	106	91	25	14
Transport	100	100	89	79	72	65
Industry	100	100	109	101	58	42
Total	***100***	***100***	***98***	***88***	***59***	***49***

For the Scenario *low*, Carbon Footprint, expressed as CO_2 equivalent on Life Cycle, is reported in Figure 3-38 by sector and in Figure 3-39 by fuel.

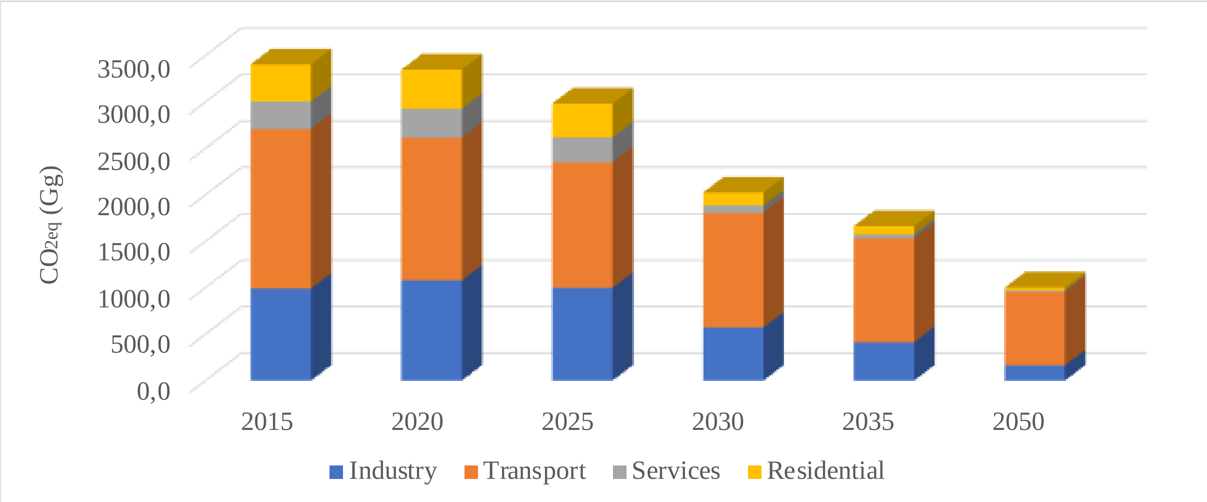


Figure 3-38: Aveiro Scenario low Carbon Footprint by sector (Gg CO_2 equivalent on Life Cycle)

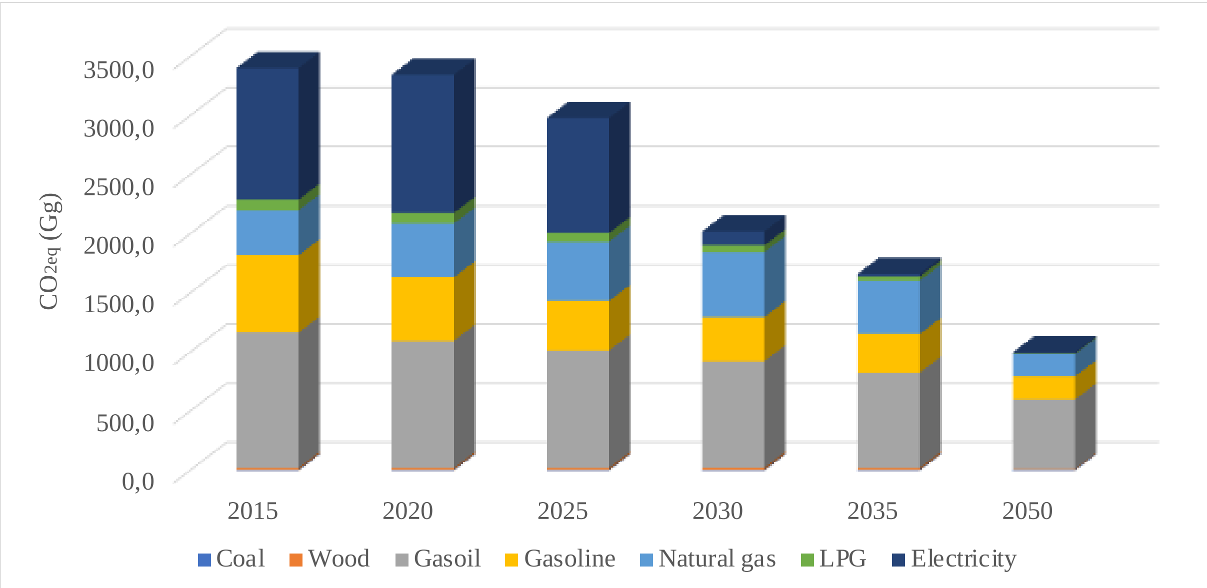


Figure 3-39: Aveiro Scenario low Carbon Footprint by fuel (Gg CO_2 equivalent on Life Cycle)

In Table 3-11 Carbon Footprint by sector is reported for Aveiro Scenario *high* expressed as CO_2, CO_2 equivalent and CO_2 equivalent on Life Cycle. In

Table 3-12 CO_2 equivalent on Life Cycle reductions on 2015 are reported.

Table 3-11: Aveiro Scenario high Carbon Footprint by Sector (Gg)

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide (CO_2)						
Residential	326,4	343,6	293,3	101,6	60,5	19,3
Services	251,8	266,6	228,2	63,1	35,1	13,1
Transport	1.447,2	1.229,4	1.019,4	886,3	751,2	491,7
Industry	842,2	917,3	847,1	483,8	350,4	139,8
Total	***2.867,7***	***2.756,9***	***2.388,0***	***1.534,9***	***1.197,2***	***663,9***
Carbon dioxide equivalent (CO_{2eq})						
Residential	334,4	351,3	301,5	109,3	67,1	21,8
Services	253,3	268,2	229,5	63,3	35,1	13,1
Transport	1.451,2	1.232,8	1.022,2	888,7	753,2	493,1
Industry	845,8	921,1	850,2	484,3	350,6	139,9
Total	***2.884,8***	***2.773,3***	***2.403,4***	***1.545,6***	***1.205,9***	***667,8***
Carbon dioxide equivalent on life cycle (CO_{2eq})						
Residential	401,5	420,8	363,2	140,0	88,8	29,1
Services	295,8	313,2	268,2	74,7	41,6	15,5
Transport	1.717,6	1.463,6	1.219,2	1.068,9	916,3	593,9
Industry	990,4	1.079,3	997,6	572,5	415,0	165,3
Total	***3.405,4***	***3.276,9***	***2.848,3***	***1.856,1***	***1.461,6***	***803,8***

Table 3-12: Aveiro Scenario high Carbon Footprint by Sector: index (2015=100)

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide equivalent on life cycle (CO_{2eq})						
Residential	100	105	90	35	22	7
Services	100	106	91	25	14	5
Transport	100	85	71	62	53	35
Industry	100	109	101	58	42	17
Total	***100***	***96***	***84***	***55***	***43***	***24***

For the Scenario *high*, Carbon Footprint, expressed as CO_2 equivalent on Life Cycle, is reported in Figure 3-40 by sector and in Figure 3-41 by fuel.

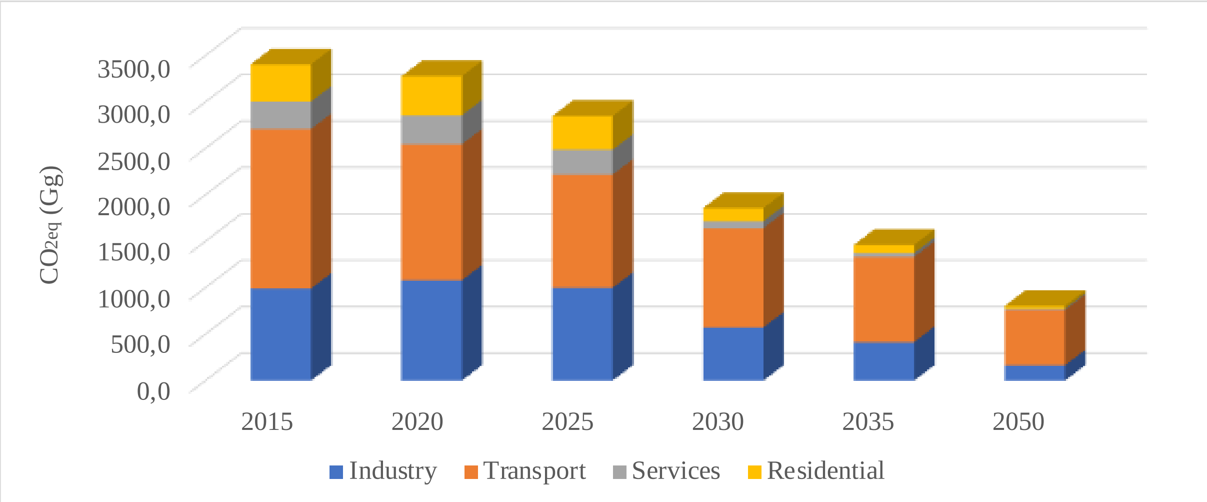


Figure 3-40: Aveiro Scenario high Carbon Footprint by sector (Gg CO_2 equivalent on Life Cycle)

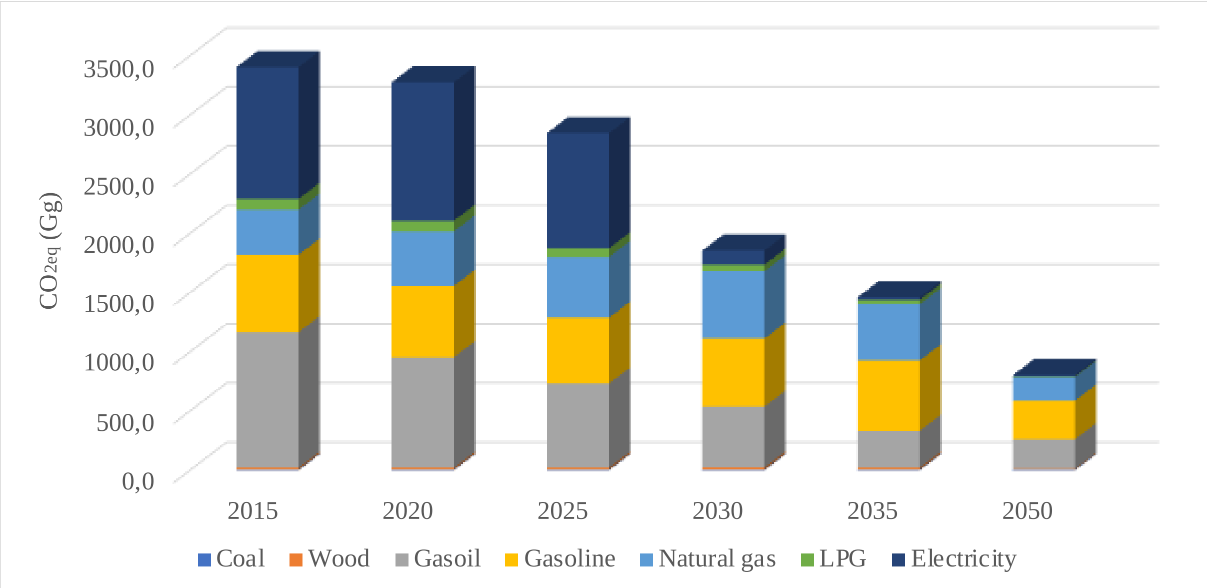


Figure 3-41: Aveiro Scenario high Carbon Footprint by fuel (Gg CO_2 equivalent on Life Cycle)

Total Carbon Footprint in the different scenarios is compared in Figure 3-42 expressed as CO_2 equivalent on Life Cycle.

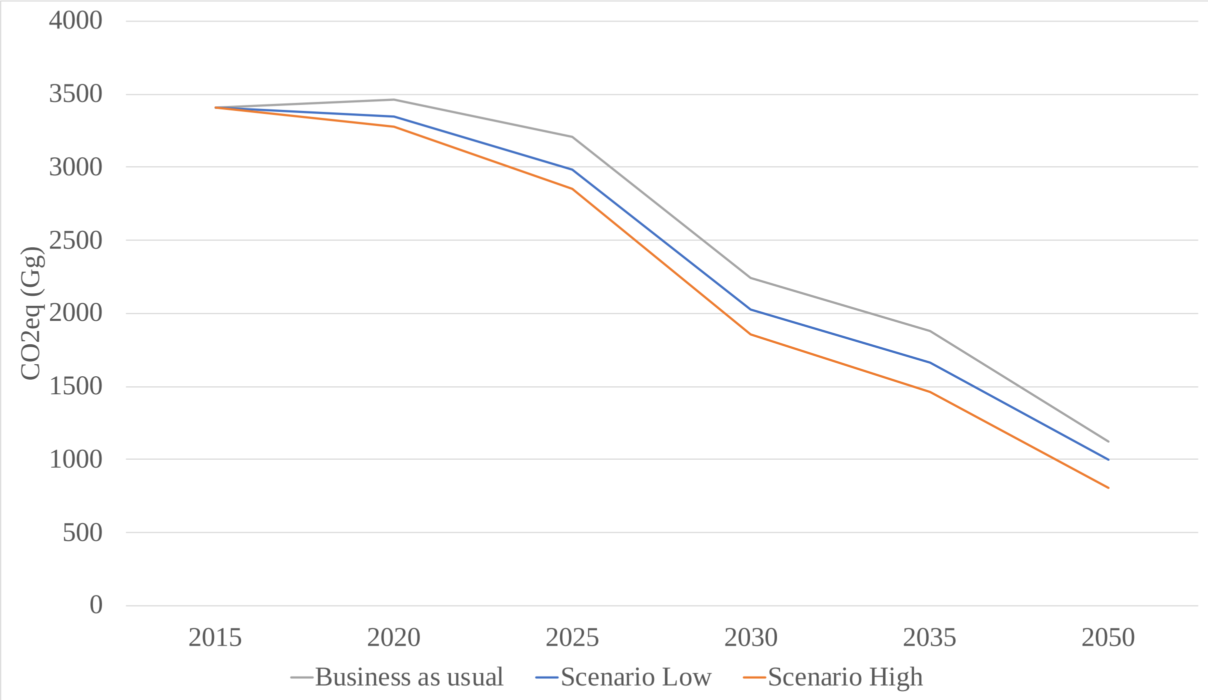


Figure 3-42: Aveiro Carbon Footprint (Mg CO_2 equivalent on Life cycle) by scenario

3.4.4 Unified Policy Scenario

In Table 3-13 Carbon Footprint by sector is reported for Aveiro Unified Policy Scenario expressed as CO_2, CO_2 equivalent and CO_2 equivalent on Life Cycle. In

Table **3-14** CO_2 equivalent on Life Cycle reductions on 2015 are reported.

Table 3-13: Aveiro Unified Policy Scenario Carbon Footprint by Sector (Gg)

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide (CO_2)						
Residential	326,4	343,6	293,3	101,6	60,5	19,3
Services	251,8	266,6	228,2	63,1	35,1	13,1
Transport	1.447,2	1.296,8	1.157,6	1.057,8	972,3	619,3
Industry	842,2	917,3	847,1	483,8	350,4	139,8
Total	***2.867,7***	***2.824,3***	***2.526,2***	***1.706,4***	***1.418,3***	***791,5***
Carbon dioxide equivalent (CO_{2eq})						
Residential	334,4	351,3	301,5	109,3	67,1	21,8
Services	253,3	268,2	229,5	63,3	35,1	13,1
Transport	1.451,2	1.300,4	1.160,8	1.060,7	974,9	621,0
Industry	845,8	921,1	850,2	484,3	350,6	139,9

Year	2015	2020	2025	2030	2035	2050
Total	***2.884,8***	***2.840,9***	***2.542,0***	***1.717,6***	***1.427,7***	***795,7***
Carbon dioxide equivalent on life cycle (CO_{2eq})						
Residential	401,5	420,8	363,2	140,0	88,8	29,1
Services	295,8	313,2	268,2	74,7	41,6	15,5
Transport	1.717,6	1.532,9	1.361,6	1.242,6	1.140,7	725,3
Industry	990,4	1.079,3	997,6	572,5	415,0	165,3
Total	***3.405,4***	***3.346,2***	***2.990,7***	***2.029,8***	***1.686,0***	***935,2***

Table 3-14: Aveiro Unified Policy Scenario Carbon Footprint by Sector: index (2015=100)

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide equivalent on life cycle (CO_{2eq})						
Residential	100	105	90	35	22	7
Services	100	106	91	25	14	5
Transport	100	89	79	72	66	42
Industry	100	109	101	58	42	17
Total	***100***	***98***	***88***	***60***	***50***	***27***

For the Unified Policy Scenario, Carbon Footprint, expressed as CO_2 equivalent on Life Cycle, is reported in Figure 3-43 by sector and in Figure 3-44 by fuel.

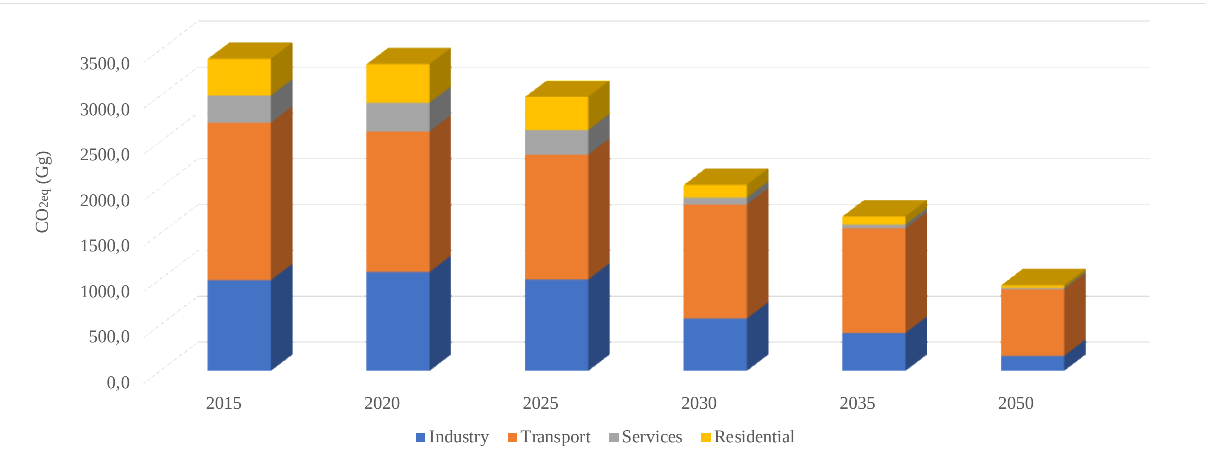


Figure 3-43: Aveiro Unified Policy Scenario Carbon Footprint by sector (Gg CO_2 equivalent on Life Cycle)

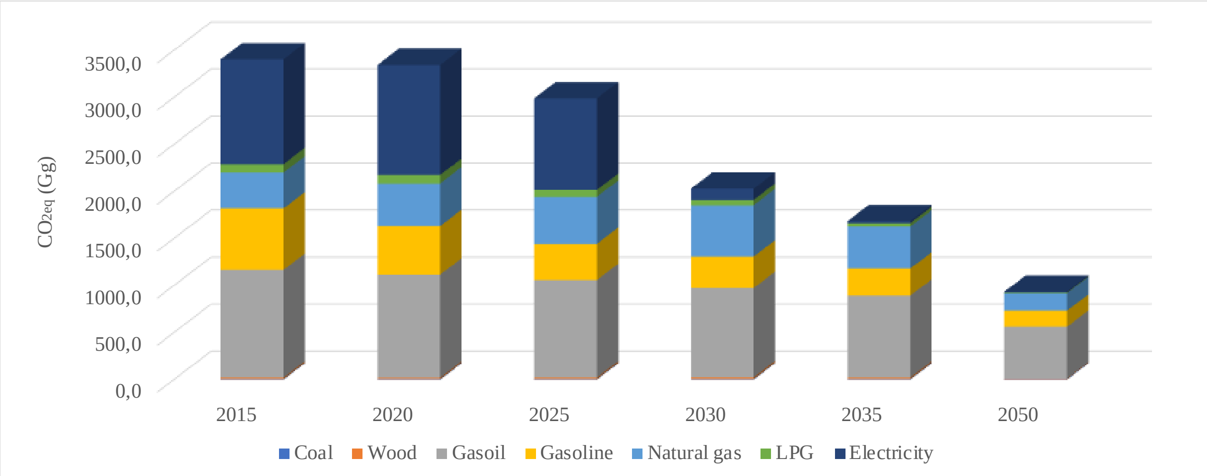


Figure 3-44: Aveiro Unified Policy Scenario Carbon Footprint by fuel (Gg CO_2 equivalent on Life Cycle)

Total Carbon Footprint in the business as usual (BAU) and unified policy scenario (UPS) is compared in Figure 3-45 expressed as CO_2 equivalent on Life Cycle.

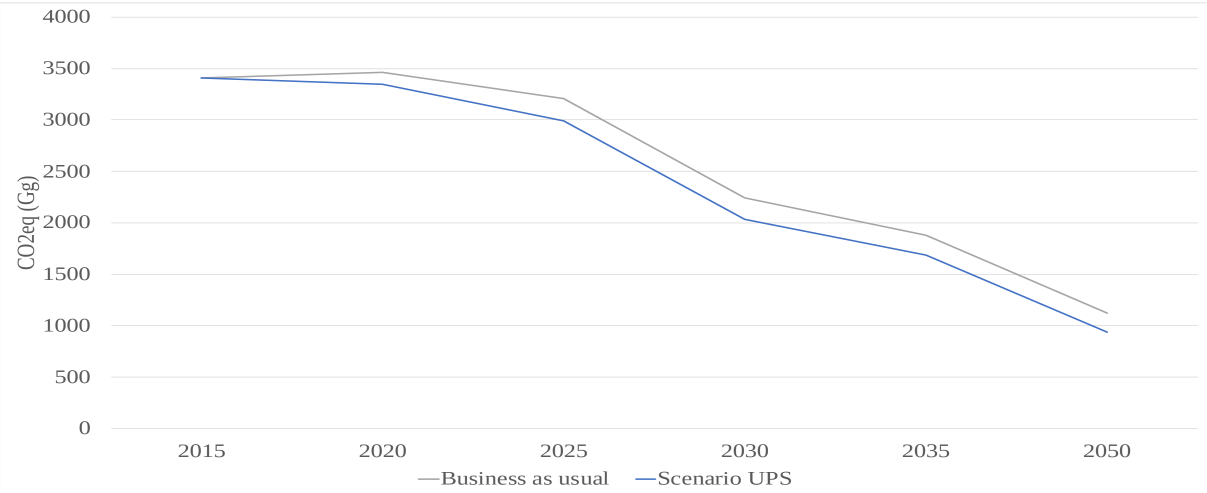


Figure 3-45: Aveiro Carbon Footprint (Mg CO_2 equivalent on Life cycle) by scenario

In Figure 3-46 results are reported by sector and in Figure 3-47 by sector and fuel. Finally, in Figure 3-48 Carbon Footprint on life cycle generated by citizens' activities is reported in BAU and UPS scenario.

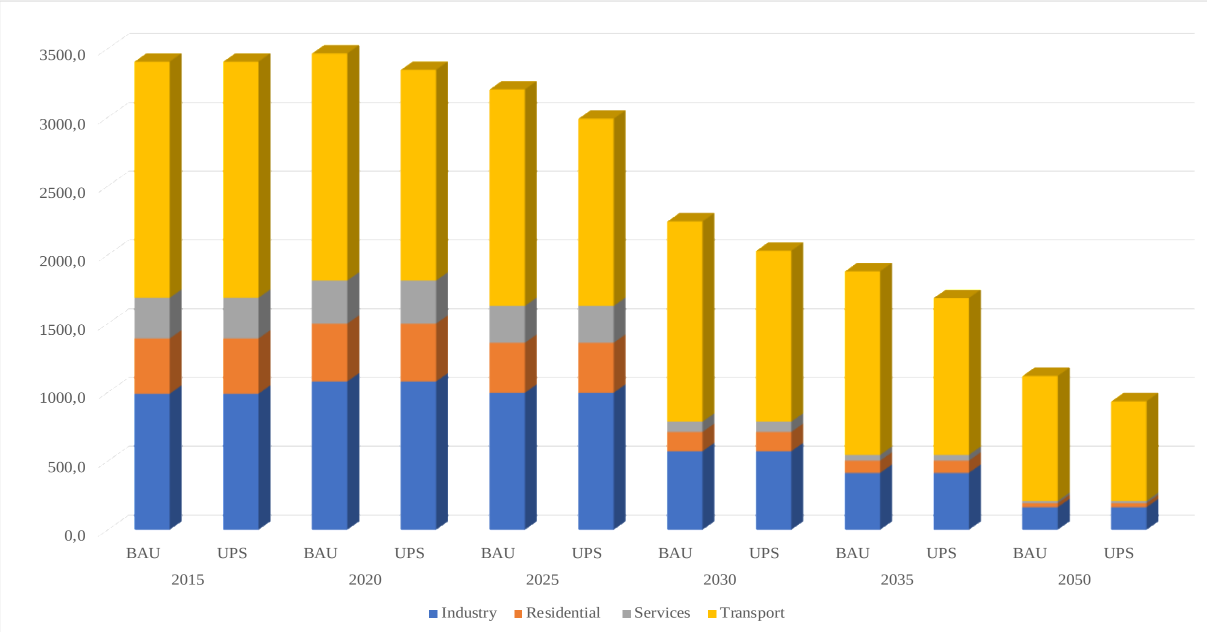


Figure 3-46: Aveiro Carbon Footprint on life cycle BAU and UPS comparison by sector (Mg CO_2 equivalent)

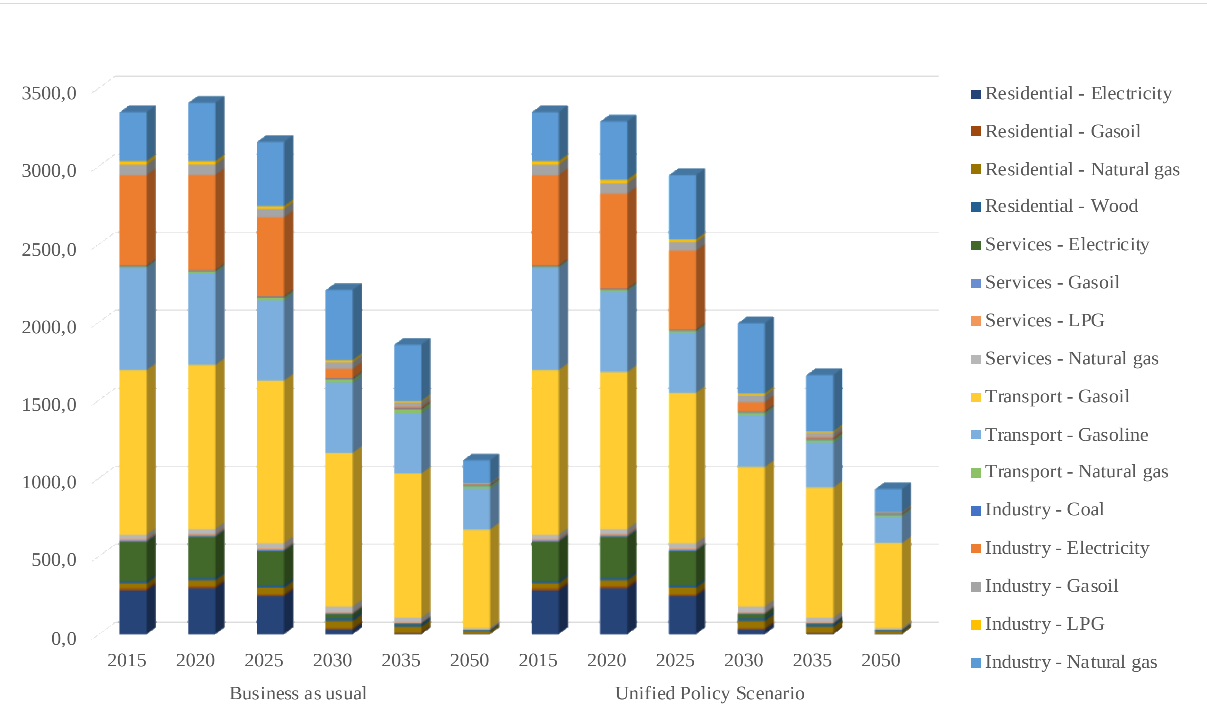


Figure 3-47: Aveiro Carbon Footprint on life cycle BAU and UPS comparison by sector and fuel (Mg CO_2 equivalent)

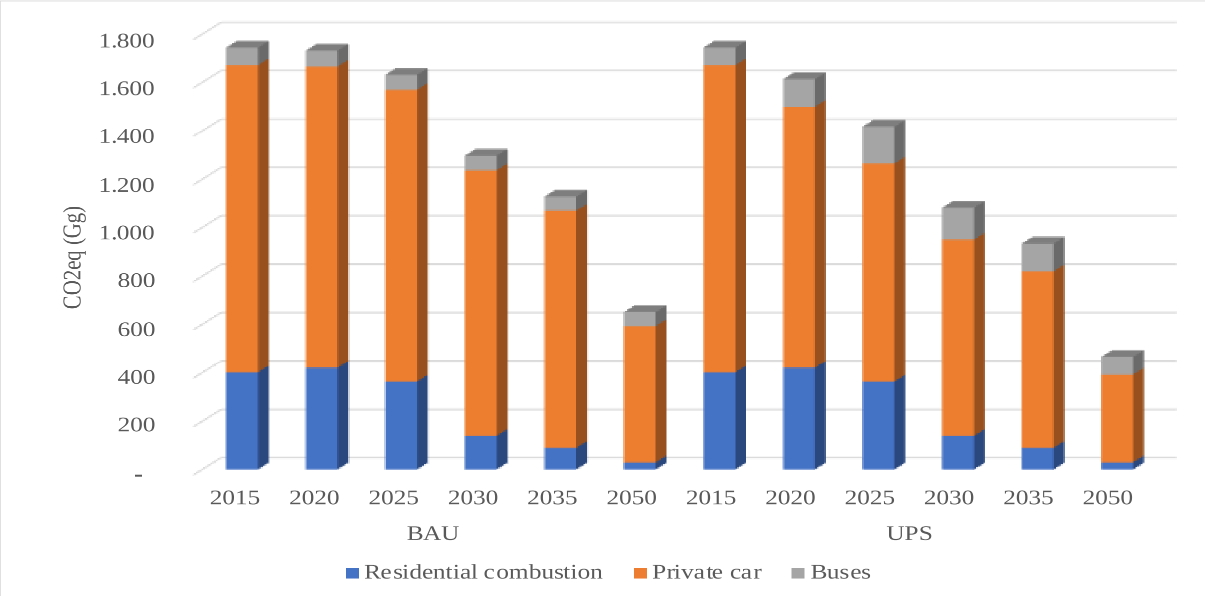
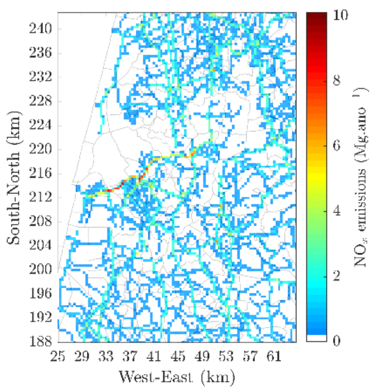
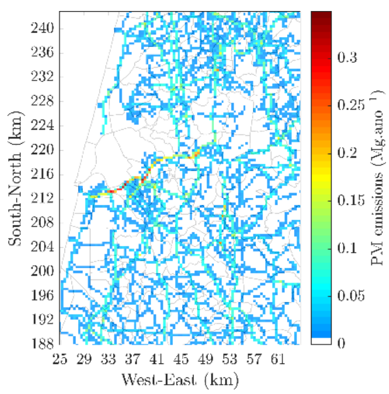


Figure 3-48: Aveiro Carbon Footprint on life cycle generated by citizens' activities in BAU and UPS scenario (Mg CO_2 equivalent)

3.5 Air quality impacts

3.5.1 Annual emissions input

Air quality simulations, start from the spatiotemporally distributed emissions from all the sources described in the previous section. Figure 3-49 shows the emission values for NO_x and PM in $Mg.year^{-1}$ for each sector.

	NOx	PM
Transport		

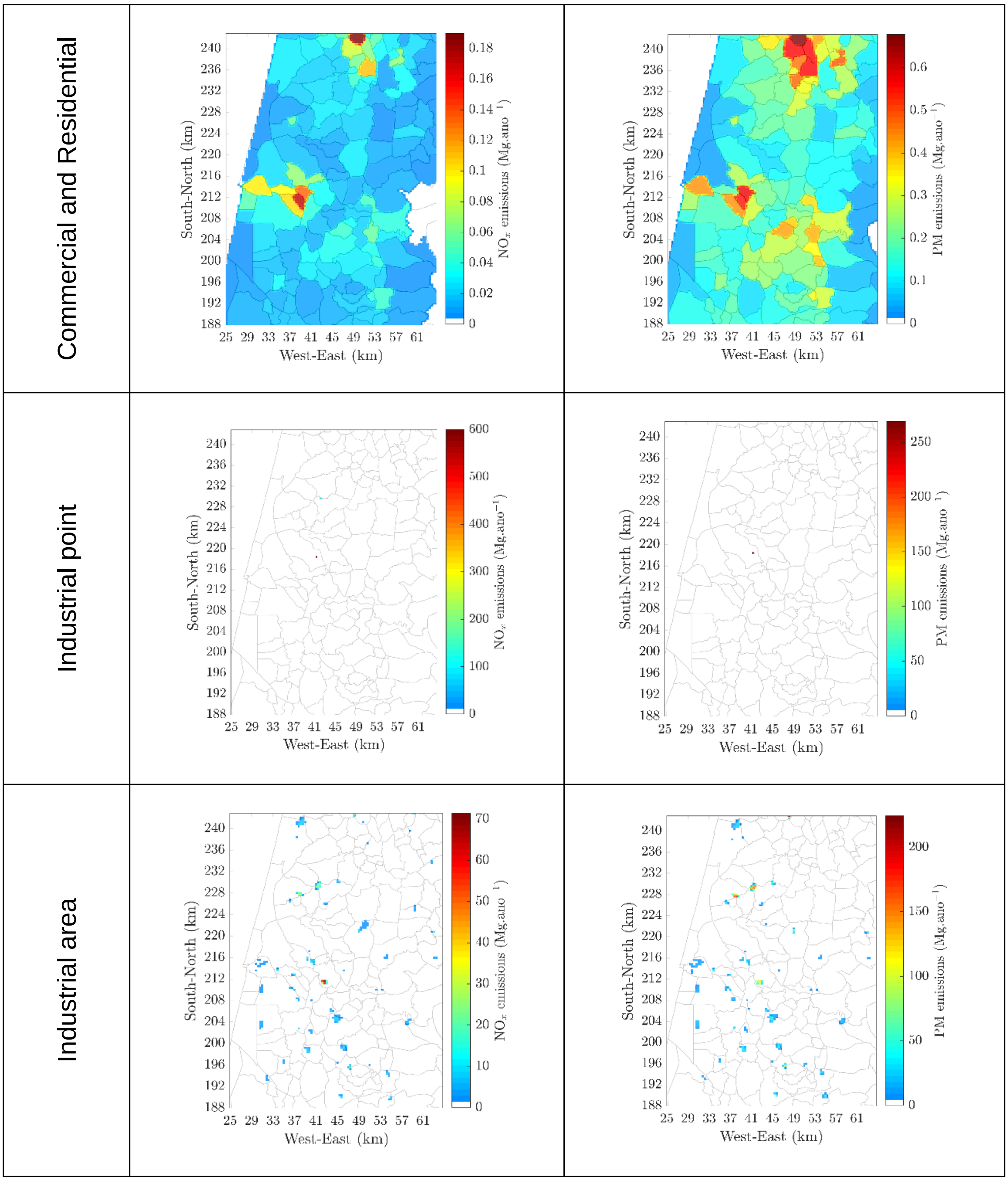


Figure 3-49: Emission values for NO_x and PM by sector, in $Mg.year^{-1}$

3.5.2 Assessment of air quality at mesoscale: baseline year

The meteorological characterization in the Aveiro Region, at the mesoscale, was based on the analysis of the spatial average of the following variables: temperature, precipitation and wind speed and direction. The mean air temperatures and accumulated temperature, for each month, are presented in Figure 3-50.

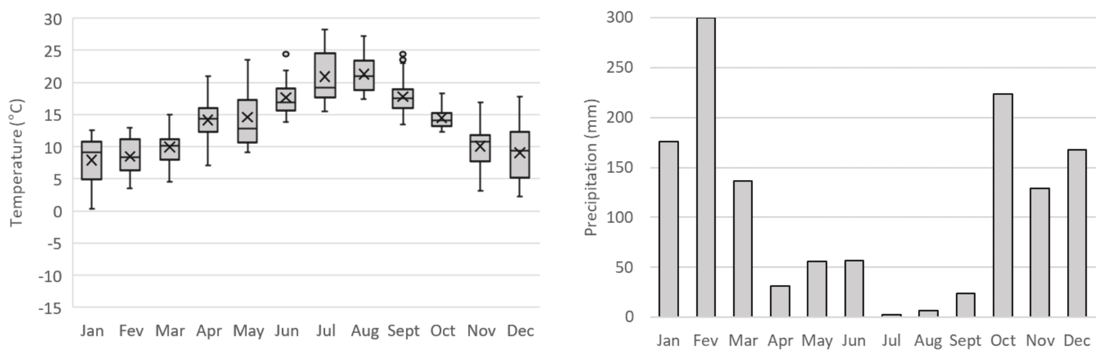


Figure 3-50: (Left) Box and whisker plot of temperature by month; boxes indicate the lower and upper quartile; horizontal line in each box represents the median temperature; the mean temperature for each month is indicated by a x; vertical lines extending from each box represent the minimum and maximum temperature recorded for that month. (Right) Column graph of total precipitation by month.

According to Figure 3-50, in Aveiro Region, the minimum mean temperatures are obtained in January and February, with 7.9°C and 8.5°C, respectively. The month where the highest mean temperature is recorded is August, with 21.3°C, followed by July, with 20.9°C. Regarding precipitation, the months with the highest accumulated precipitation go from October to March (with values up to 300mm), while the driest months are July and August with less than 6 mm. During almost the whole year, the wind blows predominantly from the 4th quadrant (NW), with a wind speed between 2 and 10 m.s^{-1}.

The air quality characterization in Aveiro Region, at mesoscale, was based on spatial maps of concentrations and on a source contribution analysis. The spatial analysis was done for the average concentrations of NO_2, PM10 and PM2.5 for the following periods: (i) annual; (ii) a typical winter month (February); and (iii) a typical summer month (August) (Figure 3-51).

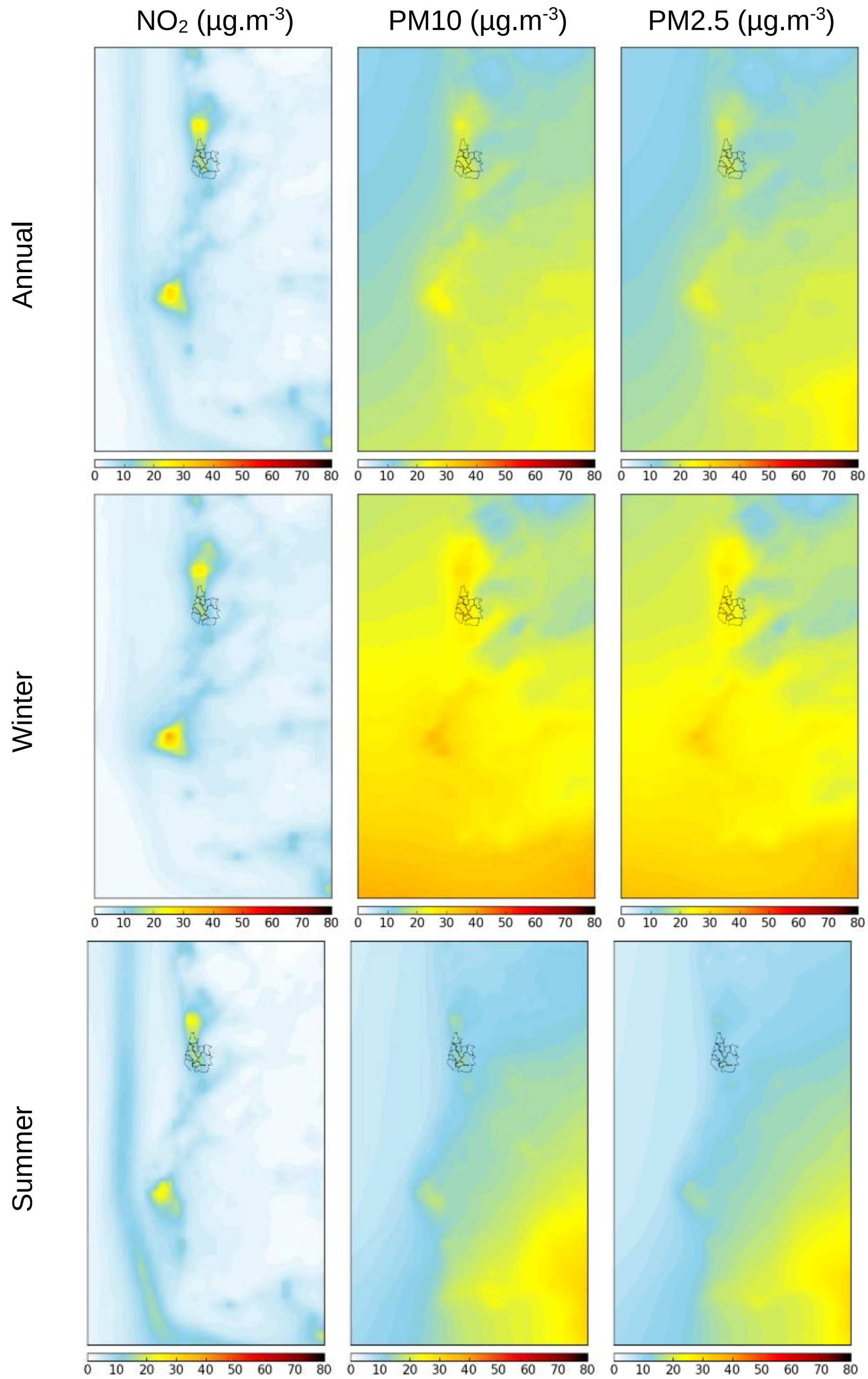


Figure 3-51: Spatial distribution of NO_2, PM10 and PM2.5 concentrations, for the different periods analysed (annual, winter and summer) in Aveiro Region.

For each pollutant, NO_2, PM10 and PM2.5, results presented in Figure 3-51 similar spatial patterns for the different periods analysed. For NO_2, the highest concentration values are found in Aveiro Region, in other urban areas like Porto (north of Aveiro) and Lisbon (south of Aveiro) and also in the Atlantic Ocean, on the ships routes. For PM10 and PM2.5, the concentration fields show a gradient decreasing from south to north.

Regarding the analysis of seasonal concentration fields, results show that, for all pollutants, the maximum values are found in winter, while the minimum values are recorded in summer. For NO_2, the highest concentration values, for annual, winter and summer periods are 33 µg.m^{-3}, 39 µg.m^{-3} and 25 µg.m^{-3}, respectively. For PM10, the maximum concentration values are close to 34 µg.m^{-3}, for the annual average, 39 µg.m^{-3} in winter and 35 µg.m^{-3} in summer. For PM2.5, the highest concentration values are 29 µg.m^{-3}, 37 µg.m^{-3} and 32 µg.m^{-3} for annual, winter and summer periods, respectively.

The source contribution analysis was provided to estimate the contribution to the modelled NO_2, PM10 and PM2.5 concentrations, from transboundary transport (TBD) and from specific source groups previously defined – residential and commercial combustion (RES), industrial combustion and processes (IND), road transport (TRP) and all the remaining sources (OTH). The results were analysed in terms of the relative contribution of those groups to the NO_2, PM10 and PM2.5 concentration simulated for the urban area of Aveiro, which was the receptor area defined in the PSAT application.

The contribution of each source group for NO_2, PM10 and PM2.5 concentrations, in the urban area of Aveiro for the three periods previously defined, are analysed in Figure 3-52.

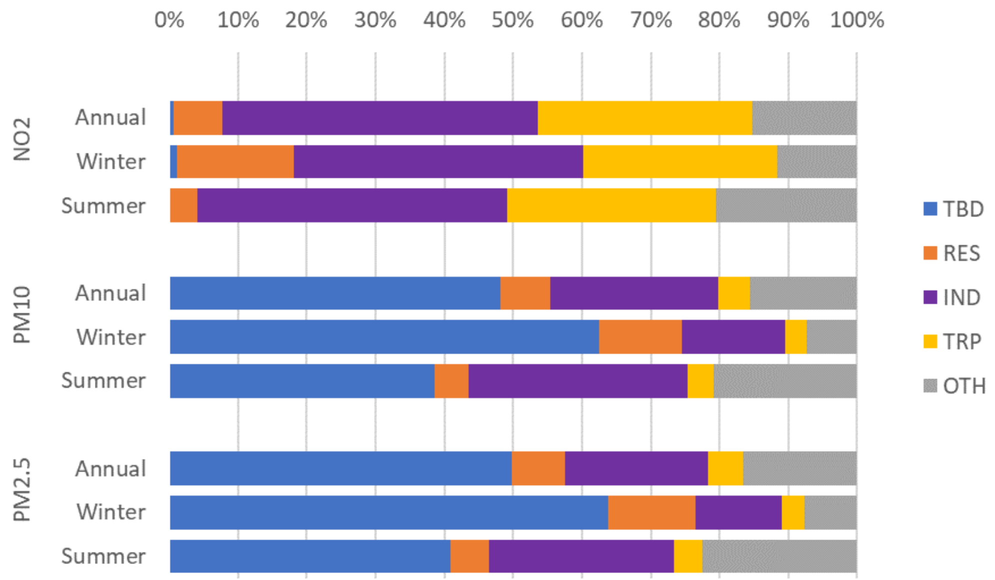


Figure 3-52: Annual, winter and summer averages contribution for each source group for NO_2, PM10 and PM2.5 concentrations, for Aveiro urban area; (TBD- transboundary transport, RES - residential and commercial combustion, IND - industrial combustion and processes, TRP - road transport and OTH - all the remaining sources).

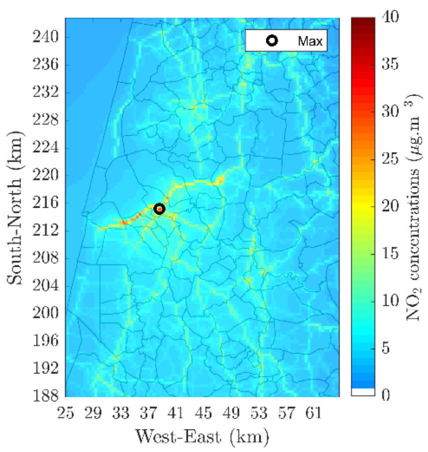
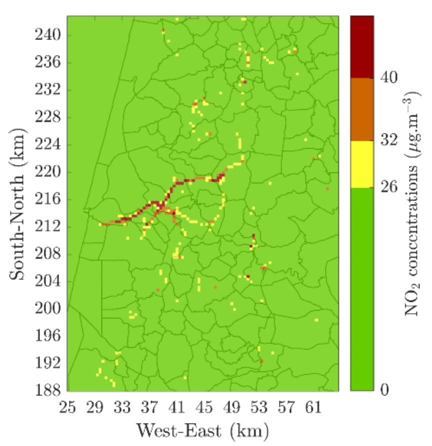
The average annual contributions of each source group reveal that, for NO_2, the largest contribution is from IND (about 45%), followed by TRP (about 30%).

For PM10, the annual average contributions of each source group reveal that one of the major contributions is from TBD (48%), highlighting the importance of long-range transport for the PM10 pollution in the study region. This transboundary effect is even more notorious in the summer period, with values of 63%. Source contribution results also point to a great influence of the contribution of different human activities, such as industrial combustion and processes and residential and commercial combustion, to the PM10 levels. For PM2.5, the analysis is similar to that of PM10.

Although the other sources (OTH) have a significant contribution for NO_2, PM10 and PM2.5 concentrations, in this analysis it is neglected, as it represents several groups, rather than a specific source group.

3.5.3 Assessment of air quality at urban scale: baseline year

Figure 3-53 shows, for the baseline year, the annual average of NO_2, PM_{10} and $PM_{2.5}$ concentrations simulated by the urban scale model URBAIR, including the background concentrations and the adjustment factor. For each pollutant two color scheme are presented, a) the standard ClairCity color scheme and b) a customized color scheme based on the EC assessment thresholds, which the EC directive EU/50/2008 establishes for each pollutant an upper and a lower assessment threshold. For NO_2 the lower assessment threshold (LAT) is 26 and the upper assessment threshold (UAT) is 32. For PM_{10} the LAT value is 20 and the UAT value is 28, and for $PM_{2.5}$ the LAT value is 12 and the UAT value is 17.

	a) Standard colour scheme	b) EC assessment thresholds
NO_2 concentrations		

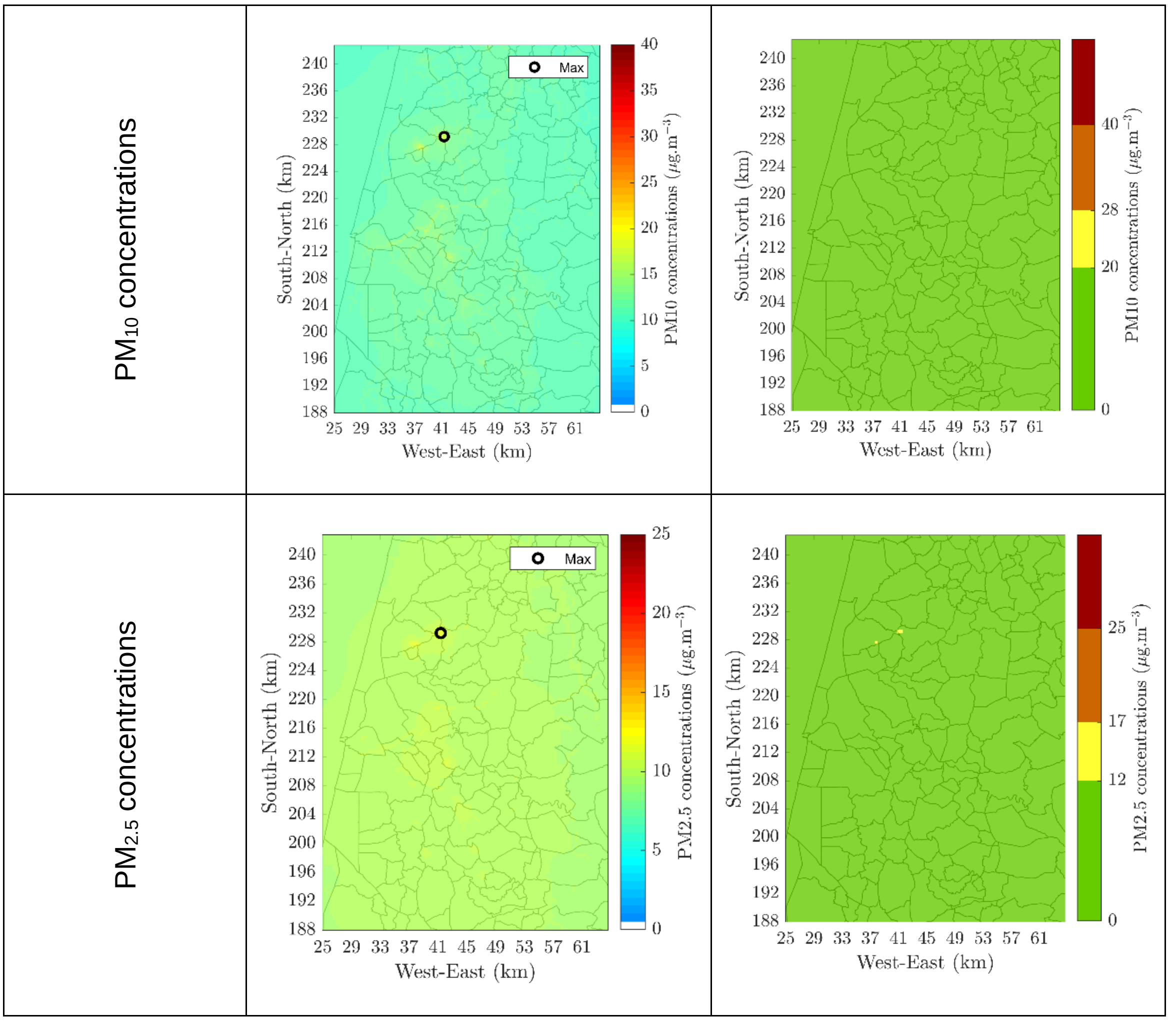


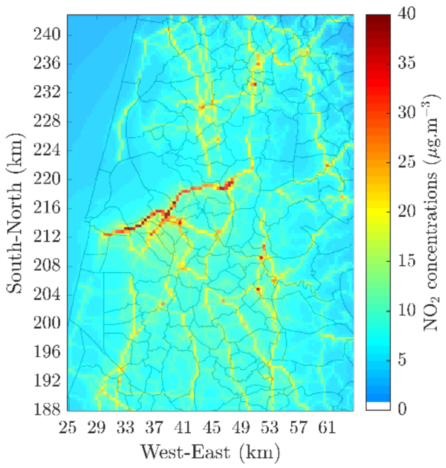
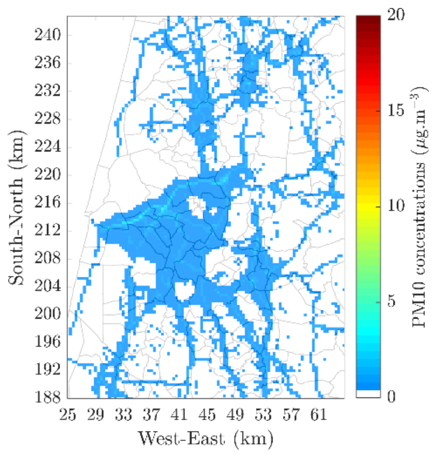
Figure 3-53: Annual average of the NO_2, PM10 and PM2.5 concentrations, including the background concentrations and the adjustment factor. a) using a standard color scheme, and b) using a customized color scheme based on the EC assessment thresholds

The maximum value of the annual NO_2 concentrations in 2015 is equal to 57.7 µg.m^{-3} and is located within the urban area (as indicated on the map). The main sector contributing to that maximum value is the road transport with a contribution of 95.1%. The average value of the NO_2 concentrations over the entire domain is equal to 15.9 µg.m^{-3} and the source apportionment analysis indicates that transport is contributing with 91.0%, industrial sector with 7.8% and the residential and commercial sector with 1.2% to the simulated concentrations.

The maximum value of the annual PM_{10} concentrations in 2015 is equal to 17.6 µg.m^{-3} and is located within the urban area (indicated on the map). A source apportionment analysis to the cell where the maximum annual value is simulated presents a contribution of 4.5% from transport sector, 85.9% from the industrial and 9.6% from the residential and commercial sector. The average value over the entire domain is equal to 11.5 µg.m^{-3}. For PM_{10} concentrations, average over the entire domain a source apportionment analysis allowed to determine the contribution of each sector, which indicates transport is contributing with 23.3%, industrial sector with 39.0% and the residential and commercial sector with 37.7%.

The maximum value of the annual $PM_{2.5}$ concentrations in 2015 is equal to 12.1 µg.m^{-3} and is located within the urban area (indicated on the map). A source apportionment analysis to the cell where the maximum annual value is simulated presents a contribution of 2.3% from transport sector, 87.9% from the industrial and 9.9% from the residential and commercial sector. The average value over the entire domain is equal to 9.8 µg.m^{-3}. For $PM_{2.5}$ concentrations, average over the entire domain a source apportionment analysis allowed to determine the contribution of each sector, which indicates transport is contributing with 13.3%, industrial sector with 44.1% and the residential and commercial sector with 42.6%.

In order to assess the impact of each sector on air quality, the concentration maps for each pollutant and for each sector are presented. Figure 3-54 shows the final adjusted concentration maps for each emission sector for NO_2 and PM_{10}, without adding the background. For each sector and pollutant the maximum simulated concentration is located on the map.

	NO_2 concentrations	PM_{10} concentrations
Transport sector		

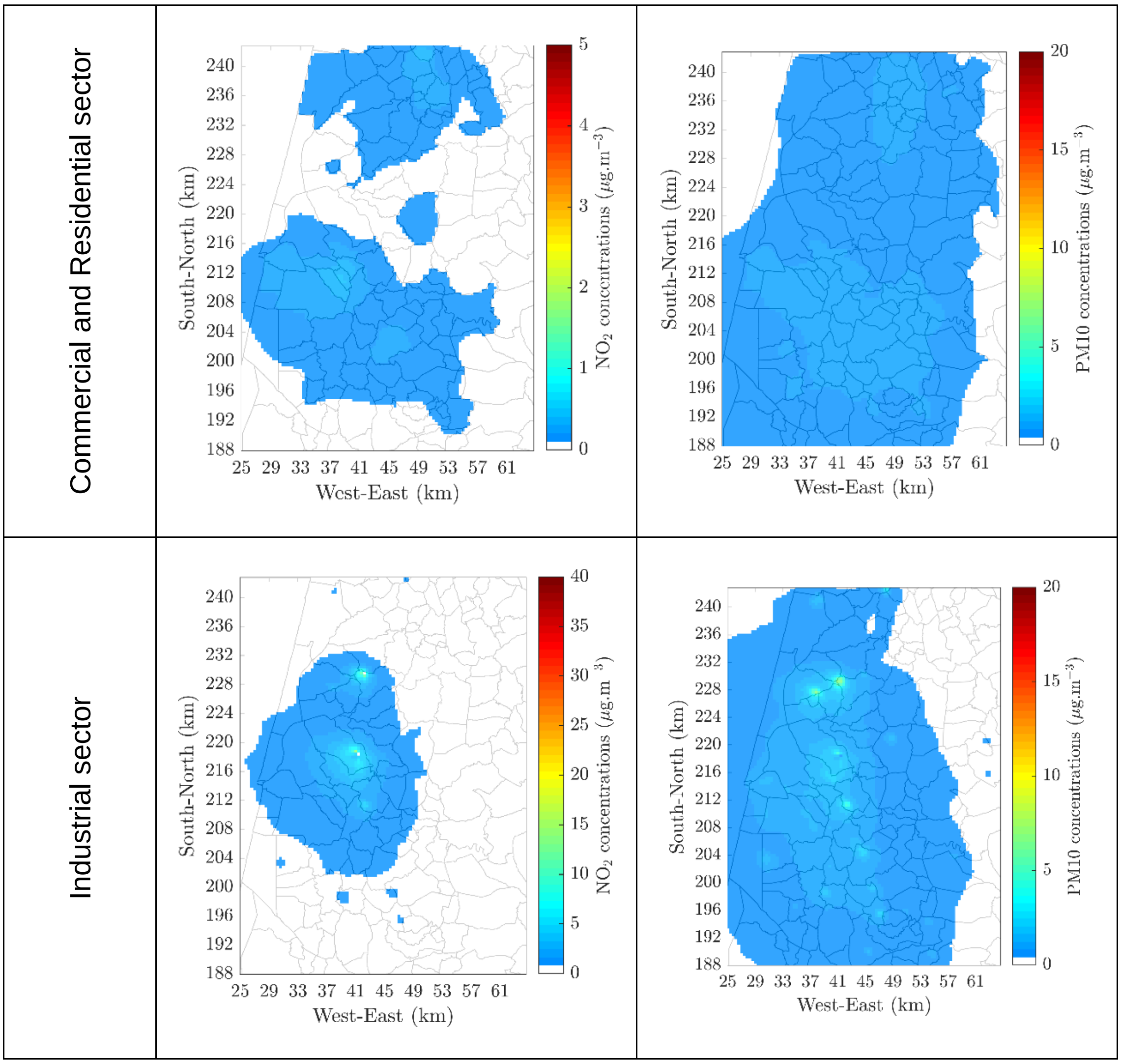


Figure 3-54: Air quality maps for NO_2 and PM adjusted concentrations by sector without the added background.

For the emission sectors considered, the emissions of particulate matter are assumed to be the same except for the transport sector, therefore, for industrial and commercial and residential sector the $PM_{2.5}$ concentrations maps will be the same as PM_{10} concentration maps. For transport, the emission are different due to different $PM_{10}/PM_{2.5}$ contribution from exhaust and non-exhaust emissions, as explained before at the transport methodology. In terms of concentrations, for the transport sector the spatial distribution is roughly the same although smaller concentration of $PM_{2.5}$ are simulated. For transport, the maximum value simulated for PM_{10} is 3.4 $\mu g.m^{-3}$ and for $PM_{2.5}$ is 0.6 $\mu g.m^{-3}$.

The final air quality results are then compared with the measuring data. Table 3-15 presents the comparison between the measurements and the simulated NO_2 concentrations (with the background concentrations and the adjustment factor) for the location of the monitoring stations, and a SA analysis of the contribution by sector for the corresponding cell.

Table 3-15: Comparison between the measurements and the simulated NO_2 concentrations (with the background concentrations and the adjustment factor) and contribution of each sector to the simulated values.

Station		**NO_2 concentrations**		**Contribution by sector for the corresponding cell (%)**		
Station	Station type	Measured	Simulated	Transport sector	Industrial sector	Commercial and Residential Sector
PT02004	Suburban Background	13.5	20.1	90.2	9.1	0.7
PT02017	Urban traffic	23.1	16.7	87.4	11.0	1.6
PT02018	Suburban Background	13.5	10.2	87.4	10.1	2.5

The final simulated concentrations present a good agreement with the measurements. For NO_2, the major contribution to the location of each monitoring station comes from the transport sector.

Table 3-16For the emission sectors considered, the emissions of particulate matter are assumed to be the same except for the transport sector, therefore, for industrial and commercial and residential sector the PM2.5 concentrations maps will be the same as PM10 concentration maps. For transport, the emission are different due to different PM10/PM2.5 contribution from exhaust and non-exhaust emissions, as explained before at the transport methodology. In terms of concentrations, for the transport sector the spatial distribution is roughly the same although smaller concentration of PM2.5 are simulated. For transport, the maximum value simulated for PM10 is 3.4 µg.m-3 and for PM2.5 is 0.6 µg.m-3.

The final air quality results are then compared with the measuring data. Table 3-15 presents the comparison between the measurements and the simulated NO2 concentrations (with the background concentrations and the adjustment factor) for the location of the monitoring stations, and a SA analysis of the contribution by sector for the corresponding cell.

Table 3-15 presents the comparison between the measurements and the simulated NO_2 concentrations (with the background concentrations and the adjustment factor) for the location of the monitoring stations, and a SA analysis of the contribution by sector for the corresponding cell.

Table 3-16: Comparison between the measurements and the simulated NO_2 concentrations (with the background concentrations and the adjustment factor) and contribution of each sector to the simulated values.

Station		**PM_{10} concentrations**		**Contribution by sector for the corresponding cell (%)**		
Station	Station type	Measured	Simulated	Transport sector	Industrial sector	Commercial and Residential Sector
PT02004	Suburban Background	25.5	12.8	32.9	42.0	25.1
PT02017	Urban traffic	23.6	12.6	26.6	44.1	29.2
PT02018	Suburban Background	26.7	12.1	18.4	42.9	38.7

For the locations of the monitoring stations the SA analysis indicate, for PM_{10} concentrations it indicates that the major contribution comes from the industrial sector. For $PM_{2.5}$, for the year of 2015, there was only available data from a suburban background monitoring station. For $PM_{2.5}$ the measured value is 14.7 and the simulated value is 10.2, for that point the industrial sector has the major contribution (50.2%).

3.5.4 Assessment of population exposure: baseline year

The population potentially exposed to harmful concentration levels portray the amount of people on each grid cell where simulated values are exceeding the EU/WHO guideline limits.

Figure 3-55 shows the population exposure to NO_2, PM_{10} and $PM_{2.5}$ baseline concentration values.

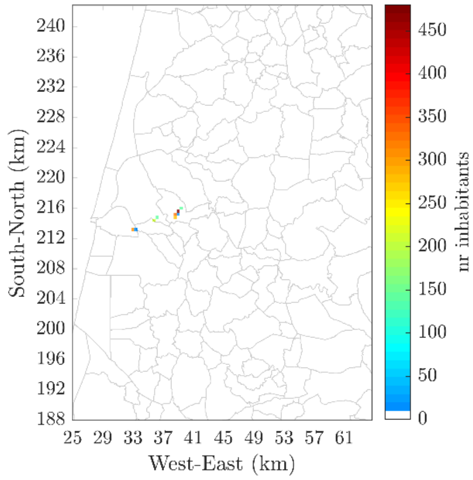
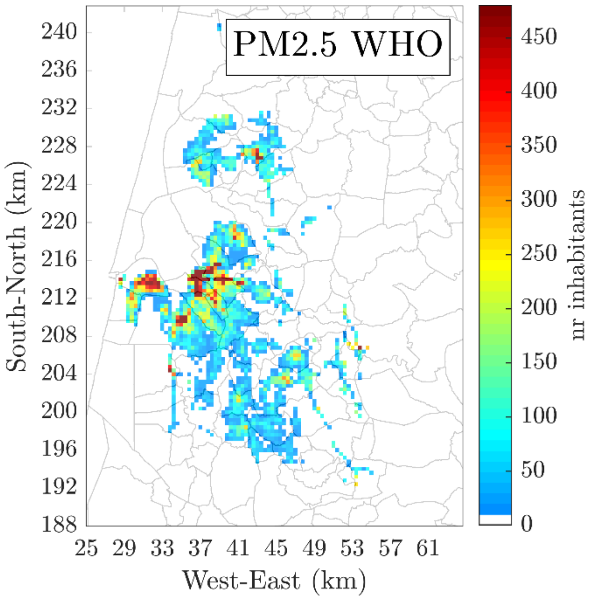
	EU annual limit value	WHO guideline value
NO_2 concentrations		
PM_{10} concentrations	There are no exceedances to the EU limits	There are no exceedances to the WHO Guidelines
$PM_{2.5}$ concentrations	There are no exceedances to the EU limits	

Figure 3-55: Population potentially exposed to values above the EU limits and WHO guideline values for NO_2, PM10 and PM2.5 baseline concentrations.

For NO_2 the limits established by the EU and the WHO are equivalent, being 40 µg.m^{-3} for the annual mean. In Aveiro, the NO_2 annual limits are exceeded in 15 cells corresponding to less than 1% (0.6%) total population within the entire Region potentially exposed to those concentrations.

As for particulate matter, the limits diverge between both standards, with WHO showing stricter limits. PM_{10} values under the EU annual mean limits are 40 µg.m^{-3} and under WHO guidelines are 20 µg.m^{-3}, for $PM_{2.5}$ the EU established for the annual mean limit value of 25 µg.m^{-3} and for the WHO limits it is established at 10 µg.m^{-3}. The results do not indicate any exceedances of PM10 concentrations, neither to the EU legal limit, nor to the WHO guidelines. For PM2.5 concentrations, the results also indicates that, while Aveiro Region complies with the legal limit values for PM2.5 concentrations, it does not comply with the guidelines of the World Health Organization, where 2614 cells are exceeding the value, which represents 49% of the population.

3.5.5 Assessment of air quality impacts at urban scale

BAU scenarios: NO_2 concentrations

The reductions of NO_x emissions in the BAU scenario will lead to reductions of the NO_2 concentrations. Figure 3-56 presents the NO_2 annual averaged concentrations considering the impacts of BAU scenario in 2025 and 2050. The maximum annual averaged NO_2 concentrations will be equal to 33.1 µg.m^{-3} in 2025 and to 9.8 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 42.6% and 90.2%, when compared to the baseline.

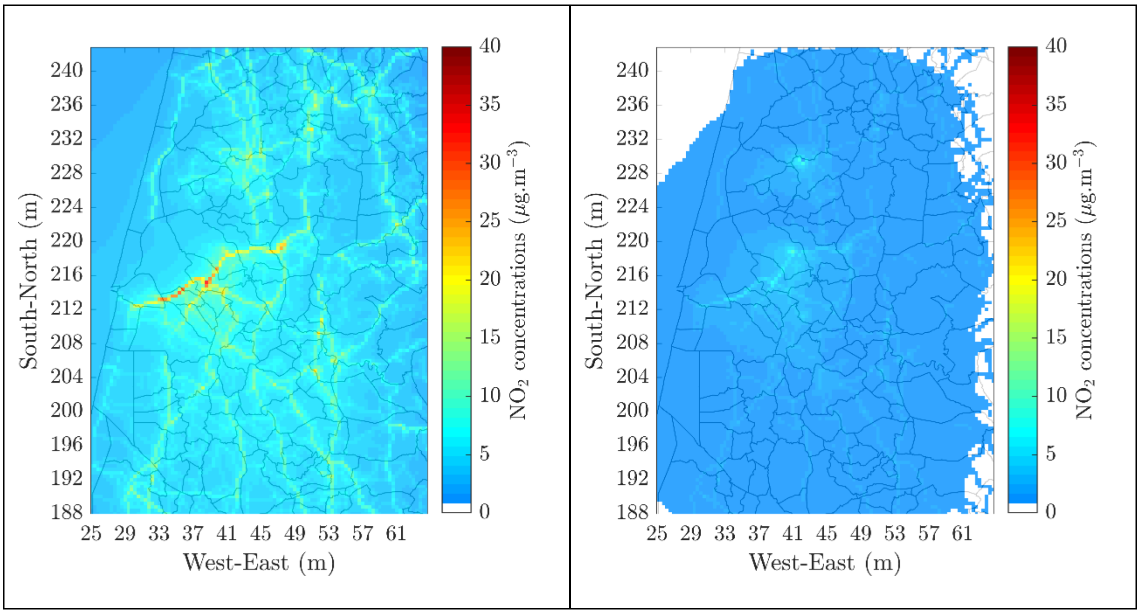


Figure 3-56: NO_2 annual average concentrations in the BAU scenario a) in 2025 and b) in 2050.

Figure 3-57 presents the differences of the NO_2 concentrations between the baseline year and the BAU scenarios in 2025 and 2050. These differences are absolute concentrations obtained from the relationship $NO_{2\ \text{baseline year}} - NO_{2\ \text{scenarios}}$ in µg.m^{-3}. The BAU scenario will lead to a maximum reduction of 24.6 µg.m^{-3} of the NO_2 concentrations in 2025, corresponding to a reduction of 42.6%, while the spatial average over the entire the domain will reduce 3.8 µg.m^{-3} of NO_2 concentrations, which corresponds to a reduction of 41.9%. In 2050 the BAU scenario will lead to a maximum reduction of the NO_2 concentrations of 51.0 µg.m^{-3} which corresponds to a reduction of 90.2%, while the average over the entire domain will reduce 7.8 µg.m^{-3} (85.2%).

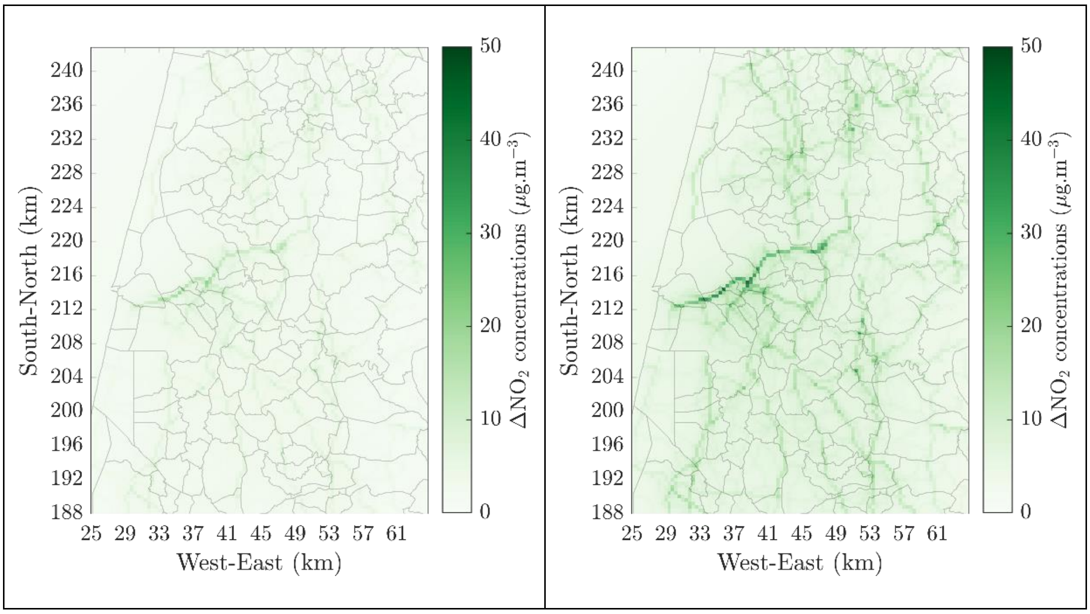


Figure 3-57: Differences of the NO_2 annual averaged concentrations in the BAU scenario a) in 2025 and b) in 2050.

Table 3-17 summarizes the overall impacts of BAU scenarios on air quality and population exposure. The population within the Aveiro Region potentially exposed to NO_2 concentrations will diminish from less than 1% in the baseline year to no inhabitants in risk of exposure with the implementation of the BAU scenario already in 2025. Therefore, the simulation results indicate full compliance with the EU annual limits everywhere in Aveiro Region with the BAU scenario already in 2025.

Table 3-17: Summary of results including the annual averages of NO_2 concentrations, together with the number of exceedances to the EU annual legal limit value (Exc.), as well as the number of exceedances to the EU annual legal limit value in grid cells with inhabitants allocated to (Exc. Inhabit.), the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit (Inhabit.), and the corresponding % of population (Pop.).

	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	2.6	57.7	9.2	15	11	1928	0.6%
BAU 2025	1.5	33.1	5.3	0	0	0	0%
BAU 2035	0.9	17.5	3.0	0	0	0	0%
BAU 2050	0.4	9.8	1.3	0	0	0	0%

BAU scenarios: PM_{10} concentrations

The slight reductions of PM emissions in the BAU scenario will also lead to reductions of the PM concentrations. Figure 3-58 presents the PM_{10} annual averaged concentrations considering the impacts of BAU scenario in 2025 and 2050. The maximum annual averaged PM_{10} concentrations will be equal to 16.6 µg.m^{-3} in 2025 and to 16.5 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 22.4% and 22.6%, when compared to the baseline.

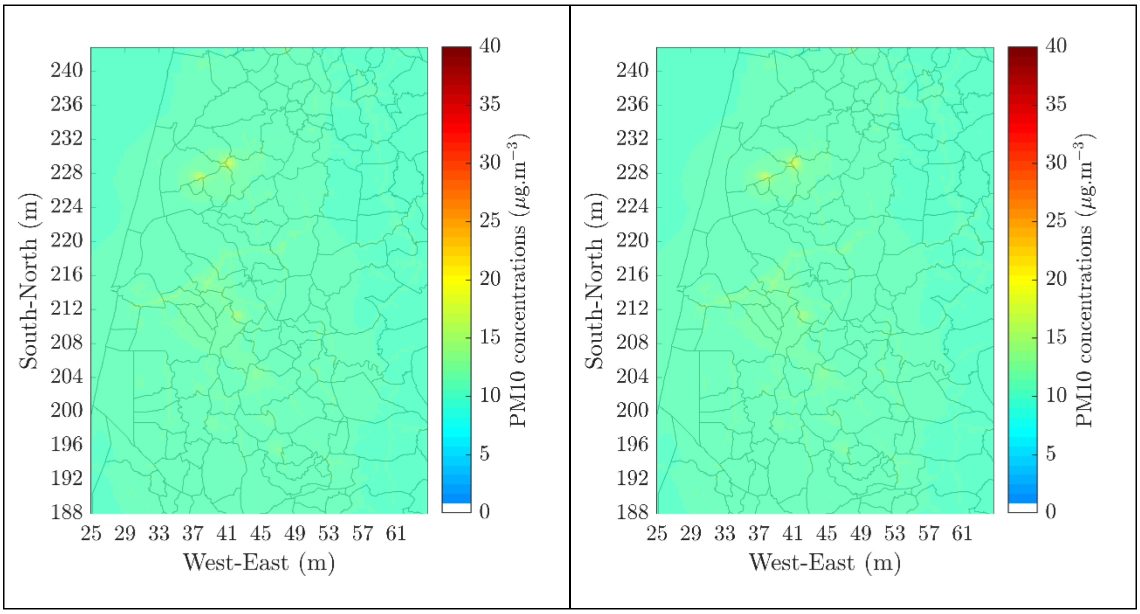


Figure 3-58: PM10 annual average concentrations in the BAU scenario a) in 2025 and b) in 2050.

Figure 3-59 presents the differences of the PM_{10} concentrations between the baseline year and the BAU scenarios in 2025 and 2050. The BAU scenario will lead to a maximum reduction of 3.5 µg.m^{-3} of the PM_{10} concentrations in 2025, corresponding to a reduction of 22.4%, while the spatial average over the entire the domain will reduce 0.6 µg.m^{-3} of PM_{10} concentrations, which corresponds to a reduction of 5.0%. The BAU scenario will lead to no further reductions in 2050, when compared to 2025.

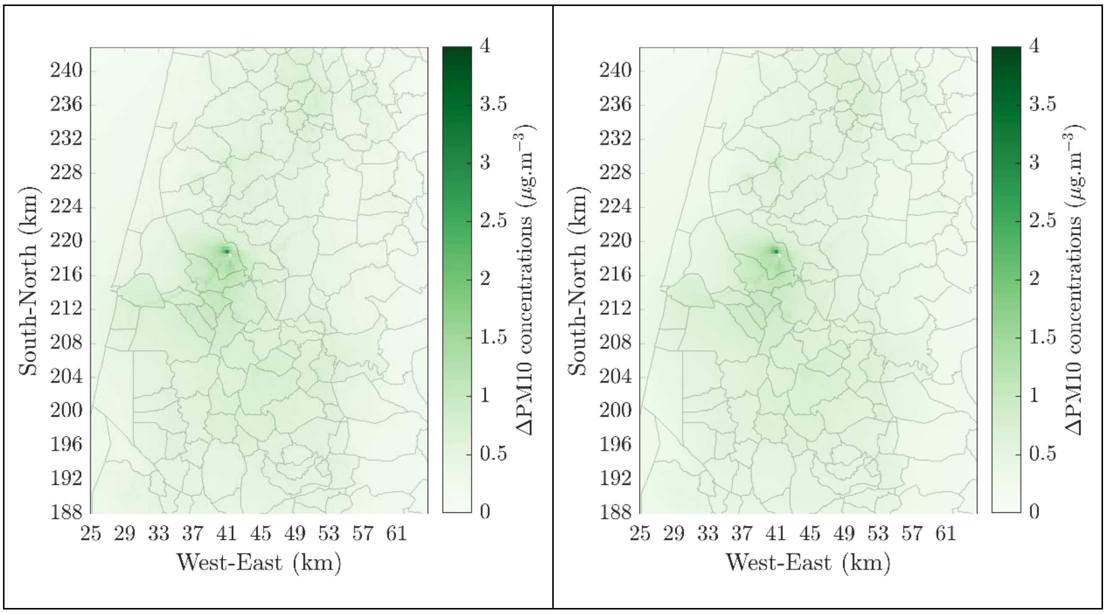


Figure 3-59: Differences of the PM10 annual averaged concentrations in the BAU scenario a) in 2025 and b) in 2050.

Table 3-18 summarizes the overall impacts of BAU scenarios on PM_{10} concentrations. The simulation results indicate no risk for the population within the Aveiro Region to be potentially exposed to PM_{10} concentrations above the EU legal limit value, as well as to the WHO guideline values already in 2015.

Table 3-18: Summary of the BAU impacts on the annual averages of PM_{10} concentrations.

	Min.	Max.	Aver.
2015	10.2	17.6	11.5
BAU 2025	10.1	16.6	10.9
BAU 2035	10.1	16.5	10.9
BAU 2050	10.1	16.5	10.9

BAU scenarios: $PM_{2.5}$ concentrations

Figure 3-60 shows the $PM_{2.5}$ annual averaged concentrations considering the impacts of BAU scenario in 2025 and 2050. The maximum annual averaged $PM_{2.5}$ concentrations will be equal to 11.8 µg.m^{-3} in 2025 and to 11.7 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 10.9% and 11.0%, when compared to the baseline.

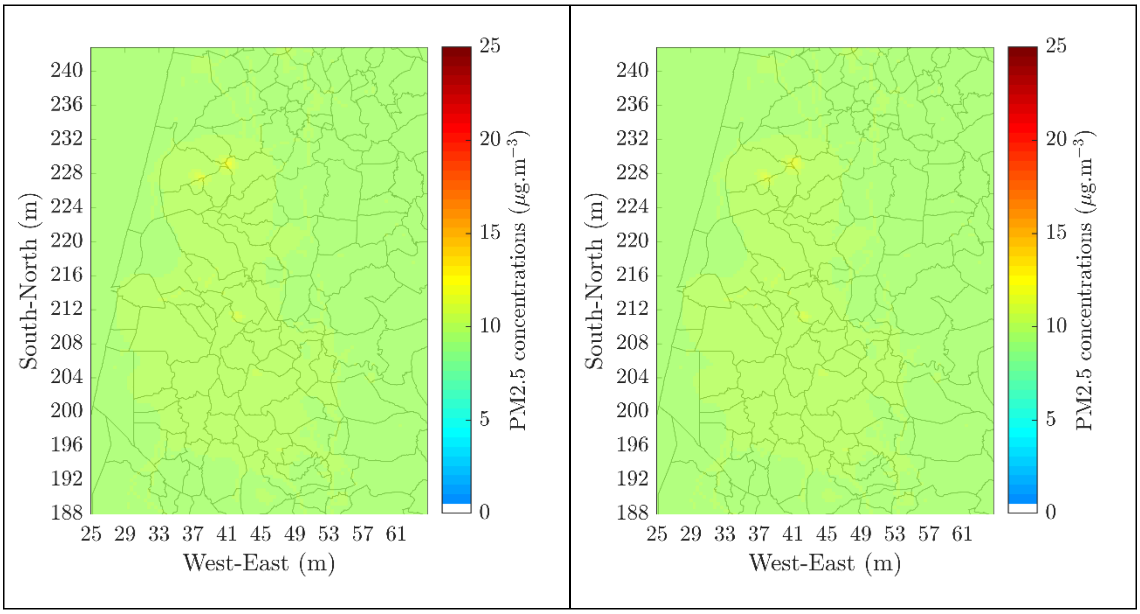


Figure 3-60: PM2.5 annual average concentrations in the BAU scenario a) in 2025 and b) in 2050.

Figure 3-61 presents the differences of the $PM_{2.5}$ concentrations between the baseline year and the BAU scenarios in 2025 and 2050. The BAU scenario will lead to a maximum reduction of 1.2 µg.m^{-3} of the $PM_{2.5}$ concentrations in 2025, corresponding to a reduction of 10.9%, while the spatial average over the entire the domain will reduce 0.2 µg.m^{-3} of $PM_{2.5}$ concentrations, which corresponds to a reduction of 1.9%. In 2050 the BAU scenario will lead to a maximum reduction of the $PM_{2.5}$ concentrations of 1.3 µg.m^{-3} which corresponds to a reduction of 11.0%, while the average over the entire domain will reduce 0.2 µg.m^{-3} (1.9%). The impacts of the BAU scenarios on the $PM_{2.5}$ concentrations over the Aveiro Region will be negligible.

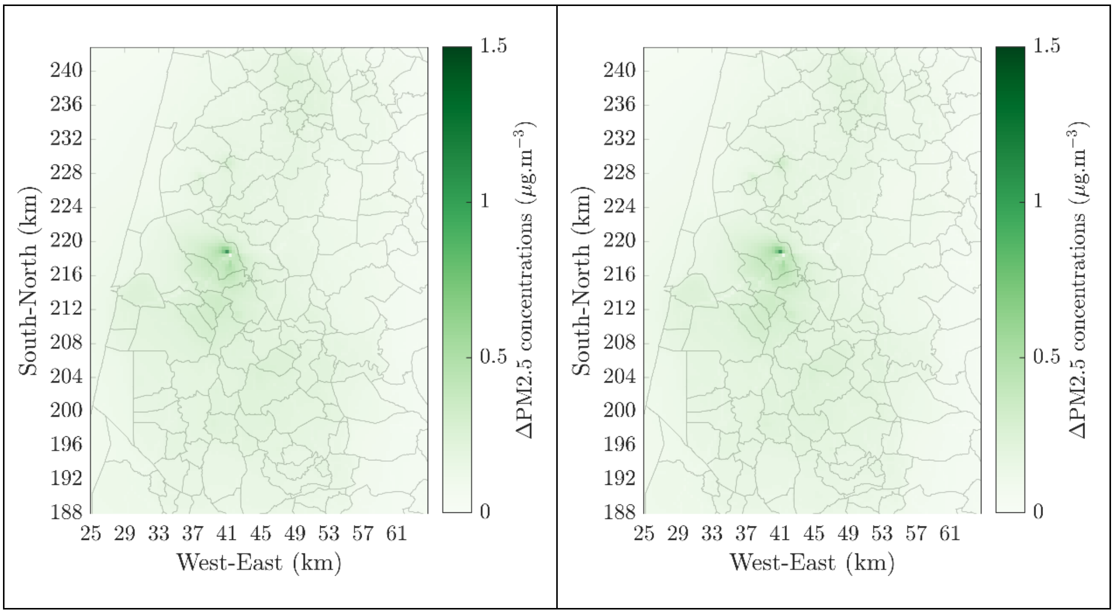


Figure 3-61: Differences of the PM2.5 annual averaged concentrations in the BAU scenario a) in 2025 and b) in 2050.

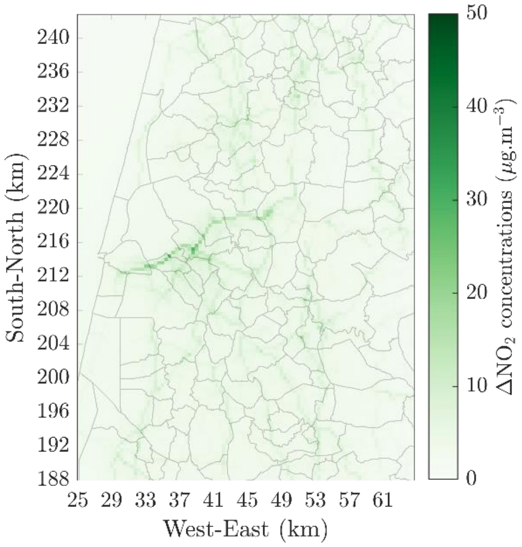
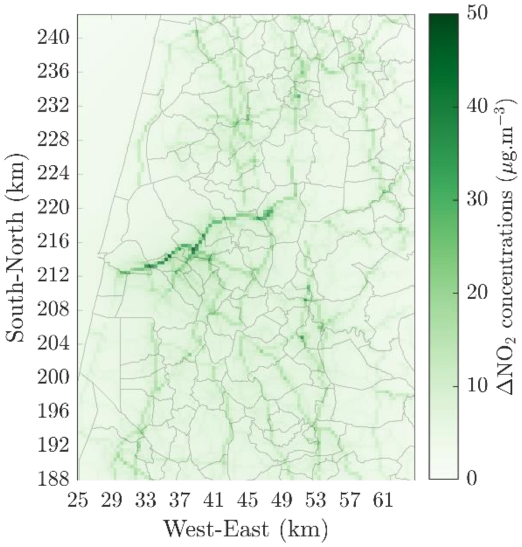
Table 3-19 summarizes the overall impacts of BAU scenarios on $PM_{2.5}$ concentrations and population exposure to those concentrations. The simulation results indicate full compliance with the EU annual limit value everywhere in the computational domain already in the baseline. However, the $PM_{2.5}$ concentrations are still above the WHO guideline values in 2050. The simulation results indicate no risk for the population within the Aveiro Region to be potentially exposed to $PM_{2.5}$ concentrations above the EU annual legal limit value, but, on contrary some inhabitants will be potential exposed to the stricter WHO guideline values even in 2050. Despite, the negligible impacts of the BAU scenarios on the $PM_{2.5}$ concentrations over the Aveiro Region, the results indicate relevant impacts in terms of population potentially exposed to WHO guideline values.

Table 3-19: Summary of results including the annual averages of $PM_{2.5}$ concentrations, together with the number of exceedances to the WHO guideline values (Exc.), as well as the number of exceedances to the WHO guideline values in grid cells with inhabitants allocated to (Exc. Inhabit.), the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit (Inhabit.), and the corresponding % of population (Pop.).

	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	9.4	12.1	9.8	2614	1997	170871	49.2%
BAU 2025	9.4	11.8	9.7	354	279	29831	8.6%
BAU 2035	9.4	11.7	9.7	319	250	26373	7.6%
BAU 2050	9.4	11.7	9.7	341	267	28566	8.2%

SDW scenarios: NO_2 concentrations

The two proposed scenarios from the SDW – low and high ambition scenarios – will impact the air quality over the Aveiro Region. Figure 3-62 shows the differences of the NO_2 annual concentrations with the implementation of the SDW scenarios compared to the baseline year. The maximum NO_2 concentrations will range from 24.2 µg.m^{-3} to 9.6 µg.m^{-3} between 2025 and 2050 with the implementation of the low ambition scenario, while with the implementation of the high ambition scenario the maximum NO_2 concentrations will range from 23.4 µg.m^{-3} to 8.3 µg.m^{-3}. Figure 3-62 also points out that the maximum reductions of the NO_2 concentrations are simulated over the main highways and national roads crossing the region, where we have simulated the main hot-spots in the emissions from the road transport sector, denoting a strong link between the reduction of NO_x emissions in the transport sector and the reductions of NO_2 concentrations achieved with the implementation of those scenarios. The low ambition scenario will led to an overall reduction of the NO_2 concentrations of 50.7% over the entire computational domain in 2025, and of 86.3% in 2050. While the high ambition scenario will lead to an averaged reduction over the entire area of the NO_2 concentrations of 52.3% in 2025, and of 88.1% in 2050.

	2025	2050
Low ambition scenario		

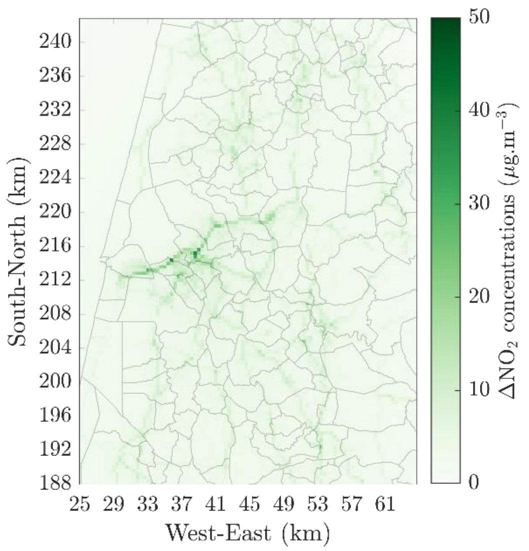
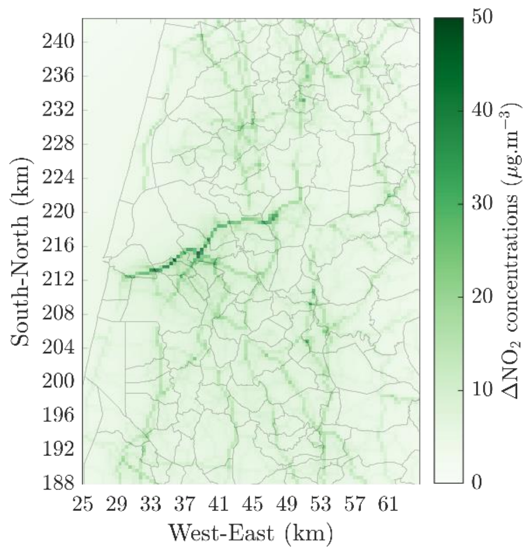
High ambition scenario		

Figure 3-62: Differences of the NO_2 annual averaged concentrations in the SDW scenarios a) in 2025 and b) in 2050.

Table 3-20 presents an overview of the overall impact of the SDW scenarios on the NO_2 concentrations, indicating that independently on the level of ambition of the scenarios all of them will lead to no risk of population exposure to those concentrations already in 2025.

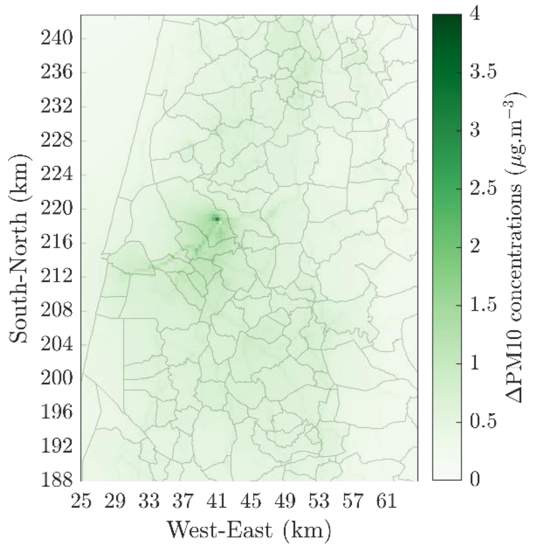
Table 3-20: Summary of the SDW impacts on the annual averages of NO_2 concentrations.

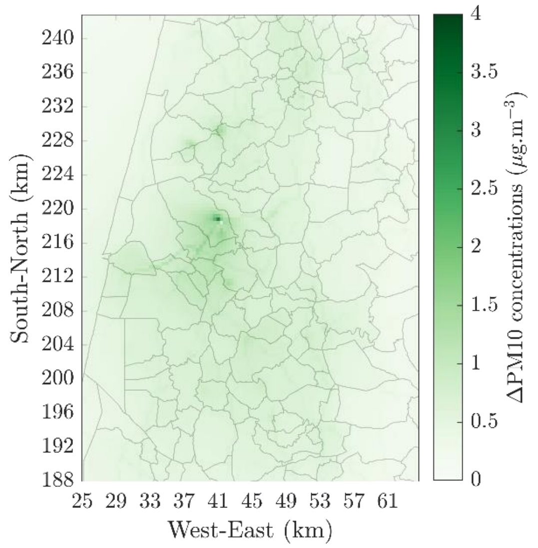
	Min.	Max.	Aver.
2015	2.6	57.7	9.2
Low 2025	1.3	24.2	4.5
Low 2035	0.8	12.8	2.6
Low 2050	0.4	9.6	1.2
High 2025	1.3	23.4	4.3
High 2035	0.7	11.5	2.3
High 2050	0.4	8.3	1.1

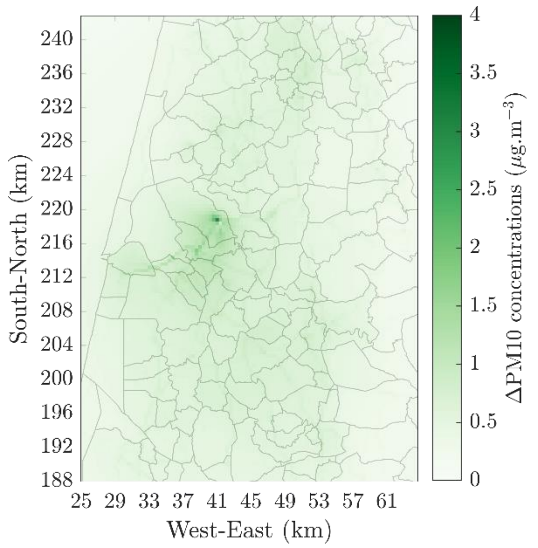
SDW scenarios: PM_{10} concentrations

The lack of measures in the SDW scenarios impacting the PM_{10} emissions will promote reduced reductions of PM_{10} concentrations, only in line with the measures projected in the BAU scenario, over the Aveiro Region as indicated in Figure 3-63. The differences contour maps of the annual PM_{10} concentrations point out a maximum concentration ranging from 16.6 µg.m^{-3} to 16.0 µg.m^{-3} between 2025 and 2050 with the implementation of the low ambition scenario, while the high ambition scenario will lead to a maximum concentration of PM_{10} concentrations from 14.7 µg.m^{-3} in 2050. The simulation results denote similar impacts of both scenarios, independently on the level of ambition.

	2025	2050
Low ambition scenario		
High ambition scenario		







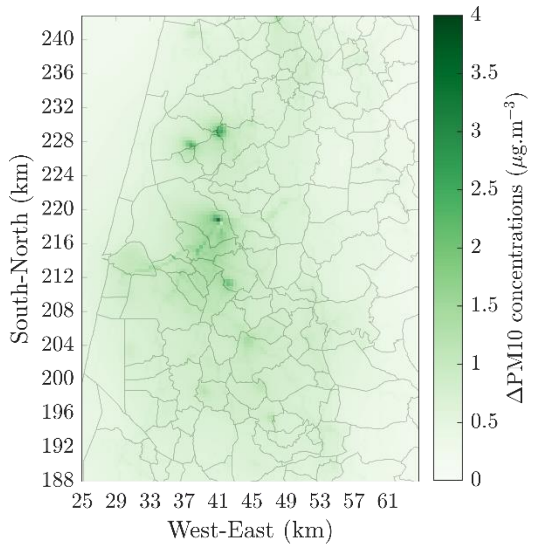


Figure 3-63: Differences of the PM10 annual averaged concentrations in the SDW scenario a) in 2025 and b) in 2050.

Table 3-21 presents an overview of the overall impact of the SDW scenarios on the PM_{10} concentrations. The low ambition scenario will lead to an overall reduction of 5.3% over the entire computational domain in 2025, and of 5.7% in 2050. While the high ambition scenario will lead to a reduction of 5.3% in 2025, and of 6.6% in 2050. The low and high ambition scenarios will lead to similar impacts on PM_{10} concentrations reductions.

Table 3-21: Summary of the SDW impacts on the annual averages of PM_{10} concentrations.

	Min.	Max.	Aver.
2015	10.2	17.6	11.5
Low 2025	10.1	16.6	10.9
Low 2035	10.1	15.9	10.8
Low 2050	10.1	16.0	10.8
High 2025	10.1	16.6	10.9
High 2035	10.0	14.7	10.7
High 2050	10.0	14.7	10.7

The simulation results indicate no risk for the population within the Aveiro Region to be potentially exposed to PM_{10} concentrations above the EU legal limit value, as well as to the WHO guideline values with the implementation of the low and high ambition scenarios.

SDW scenarios: $PM_{2.5}$ concentrations

Figure 3-64 shows the contour maps with the differences between the proposed scenarios and the baseline of the annual $PM_{2.5}$ concentrations. These contour maps point out a maximum concentration ranging from 11.8 $\mu g.m^{-3}$ to 11.5 $\mu g.m^{-3}$ between 2025 and 2050 with the implementation of the low ambition scenario, and ranging from 11.8 $\mu g.m^{-3}$ to 11.1 $\mu g.m^{-3}$ between 2025 and 2050 with the implementation of the high ambition scenario. The simulation results denote similar impacts of both scenarios, independently on the level of ambition.

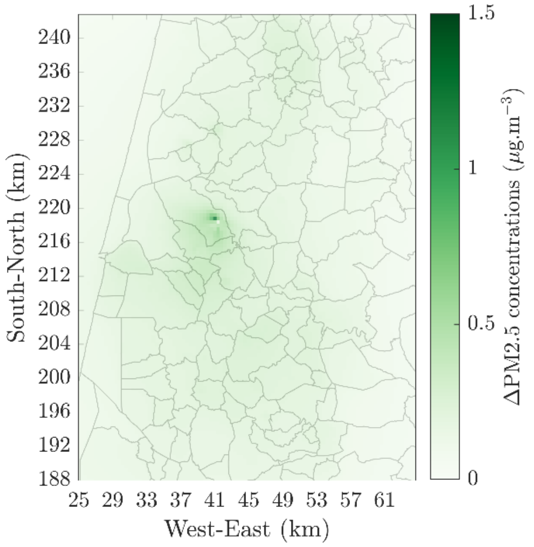
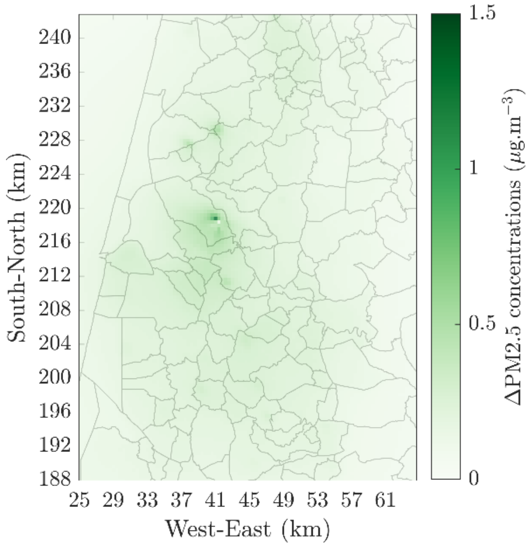
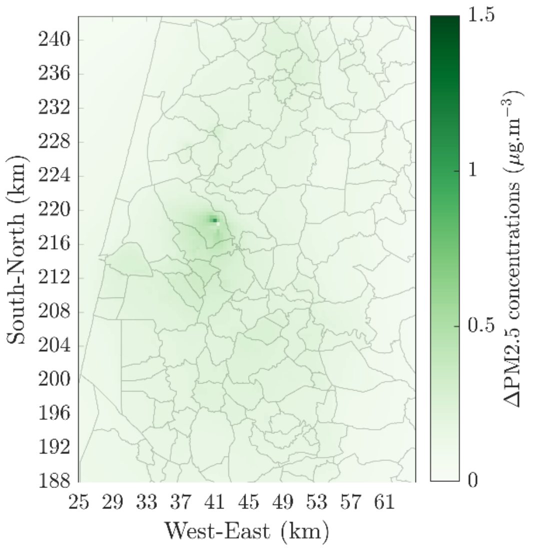
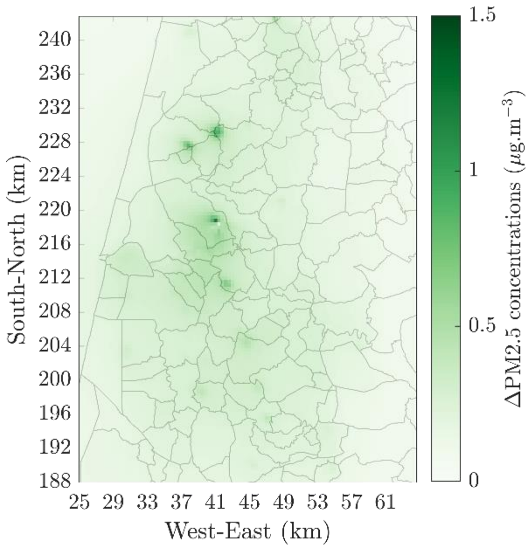
	2025	2050
Low ambition scenario		
High ambition scenario		

Figure 3-64: Differences of the PM2.5 annual averaged concentrations in the FUPS scenario a) in 2025 and b) in 2050.

Table 3-22 presents an overview of the overall impact of the SDW scenarios on the $PM_{2.5}$ concentrations. The low ambition scenario will lead to an overall reduction of 2.0% of the $PM_{2.5}$ concentrations over the entire computational domain in 2025, and of 2.1% in 2050. While the high ambition scenario will lead to a reduction of 2.0% of the $PM_{2.5}$ concentrations in 2025, and of 2.5% in 2050. The low and high ambition scenarios will lead to similar impacts on PM_{10} concentrations reductions. The simulation results indicate full compliance with the EU annual limit value everywhere in the computational domain already in the baseline. However, the $PM_{2.5}$ concentrations are still above the WHO guideline values within some grid cells of the domain in 2050, independently on the level of ambition of the scenarios. The simulation results indicate no risk for the population within the Aveiro Region to be potentially exposed to $PM_{2.5}$ concentrations above the EU annual legal limit value, but, on contrary some inhabitants will be potential exposed to the stricter WHO guideline values even in 2050, independently of the level ambition.

Table 3-22: Summary of results including the annual averages of PM2.5 concentrations, together with the number of exceedances to the WHO guideline values (Exc.), as well as the number of exceedances to the WHO guideline values in grid cells with inhabitants allocated to (Exc. Inhabit.), the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit (Inhabit.), and the corresponding % of population (Pop.).

	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	9.4	12.1	9.8	2614	1997	170871	49.2%
Low 2025	9.4	11.8	9.7	300	234	22566	6.5%
Low 2035	9.4	11.5	9.6	204	161	13409	3.9%
Low 2050	9.4	11.5	9.6	224	178	16358	4.7%
High 2025	9.4	11.8	9.7	308	239	22349	6.4%
High 2035	9.4	11.1	9.6	88	62	3554	1.0%
High 2050	9.4	11.1	9.6	100	73	5159	1.5%

FUPS scenarios: NO_2 concentrations

The reductions of NO_x emissions in the FUPS scenario will lead to reductions of the NO_2 concentrations. Figure 3-56 presents the NO_2 annual averaged concentrations considering the impacts of FUPS scenario in 2025 and 2050. The maximum annual averaged NO_2 concentrations will be equal to 24.2 µg.m^{-3} in 2025 and to 9.0 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 58.6% and 91.4%, when compared to the baseline.

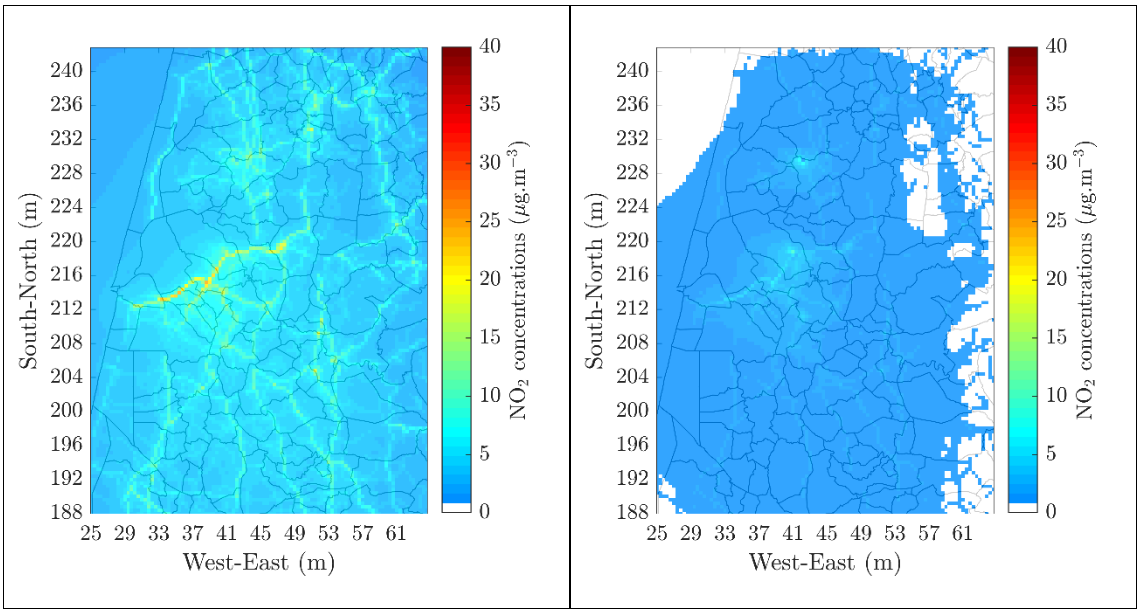


Figure 3-65: NO_2 annual average concentrations in the FUPS scenario a) in 2025 and b) in 2050.

Figure 3-66 shows the differences of the NO_2 annual concentrations with the implementation of the FUPS scenarios compared to the baseline year. Figure 3-62 shows also the link between the reduction of NO_x emissions in the transport sector and the reductions of NO_2 concentrations achieved with the implementation of the FUPS scenario. The FUPS scenario will led to an overall reduction of the NO_2 concentrations of 50.7% over the entire computational domain in 2025, and of 86.6% in 2050.

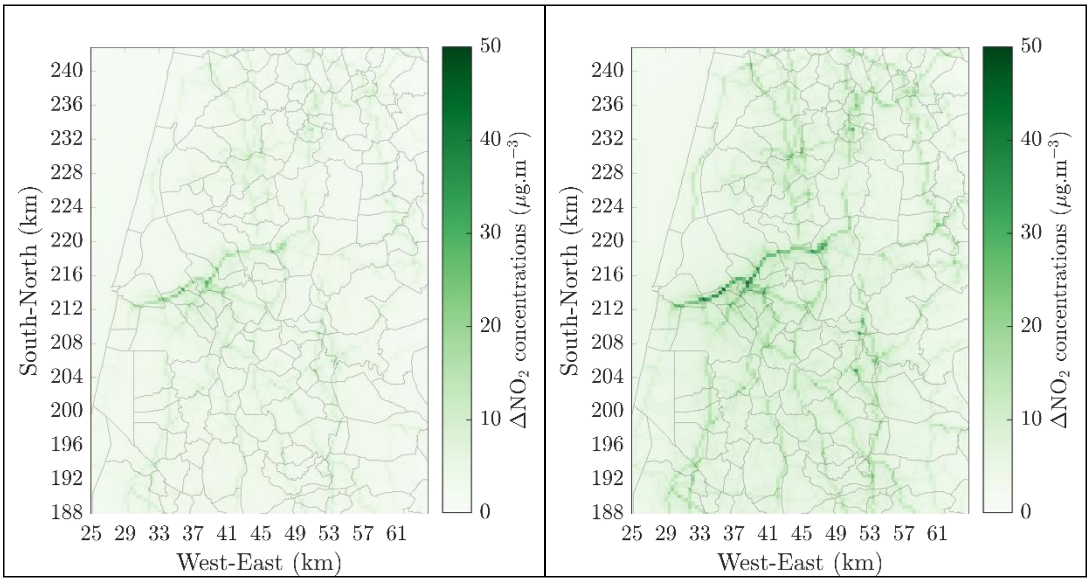


Figure 3-66: Differences of the NO_2 annual averaged concentrations in the FUPS scenario a) in 2025 and b) in 2050.

Table 3-23 shows the summary of the overall impact of the FUPS scenario on the NO_2 concentrations, indicating no risk of population exposure to those concentrations above the EU annual legal limit value already in 2025.

Table 3-23: Summary of the FUPS impacts on the annual averages of NO_2 concentrations.

	Min.	Max.	Aver.
2015	2.6	57.7	9.2
FUPS 2025	1.3	24.2	4.5
FUPS 2035	0.8	12.7	2.5
FUPS 2050	0.4	9.0	1.2

FUPS scenarios: PM_{10} concentrations

Figure 3-67 and Figure 3-68 present the impact of the FUPS scenario on PM_{10} concentrations. The contour maps with the differences of the annual PM_{10} concentrations point out a maximum concentration ranging from 16.6 µg.m^{-3} to 14.7 µg.m^{-3} between 2025 and 2050 with the implementation of the FUPS scenario.

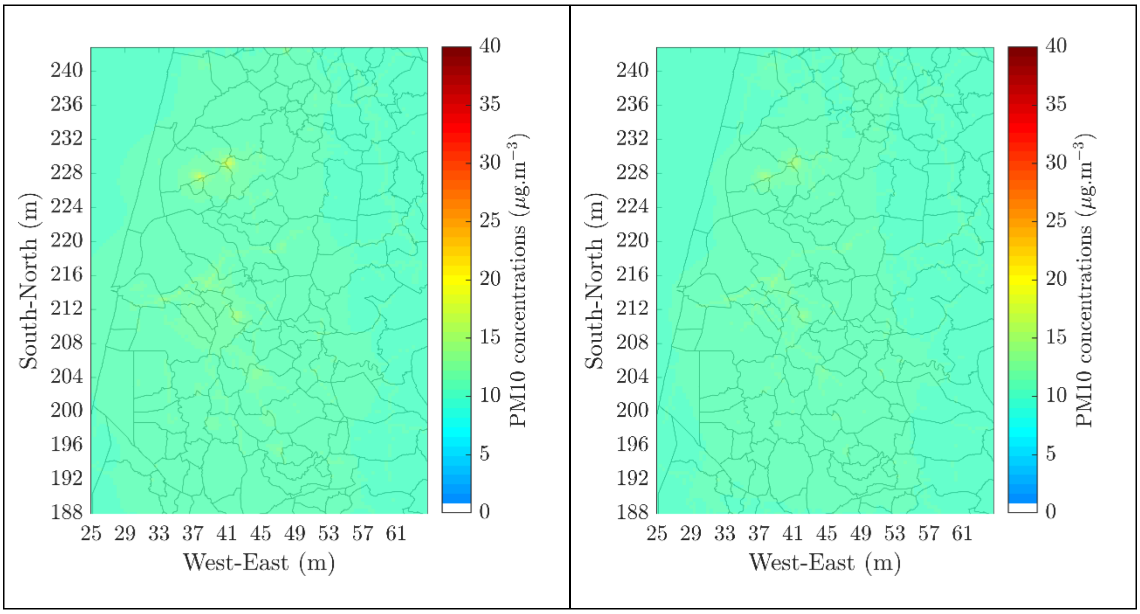


Figure 3-67: PM_{10} annual average concentrations in the FUPS scenario a) in 2025 and b) in 2050.

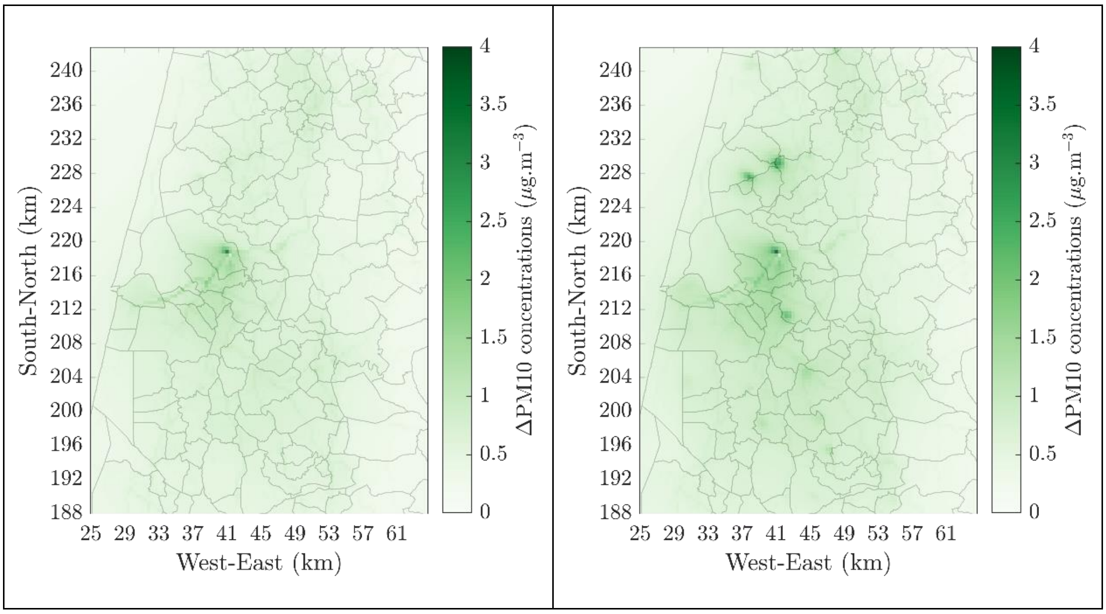


Figure 3-68: Differences of the PM_{10} annual averaged concentrations in the FUPS scenario a) in 2025 and b) in 2050.

Table 3-24 presents an overview of the overall impact of the FUPS scenario on the PM_{10} concentrations. This scenario will lead to an overall reduction of 5.3% over the entire computational domain in 2025, and of 6.6% in 2050.

Table 3-24: Summary of results including the annual averages of PM_{10} concentrations.

	Min.	Max.	Aver.
2015	16.4	22.9	17.5
FUPS 2025	16.1	19.3	16.7
FUPS 2035	16.1	18.7	16.5
FUPS 2050	16.1	18.9	16.6

The simulation results indicate no risk for the population within the Aveiro Region to be potentially exposed to PM_{10} concentrations above the EU legal limit value, as well as to the WHO guideline values with the implementation of the FUPS scenario.

FUPS scenarios: $PM_{2.5}$ concentrations

Figure 3-69 shows the $PM_{2.5}$ annual averaged concentrations considering the impacts of FUPS scenario in 2025 and 2050. The maximum annual averaged $PM_{2.5}$ concentrations will be equal to 11.8 µg.m^{-3} in 2025 and to 11.1 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 11.2% and 12.5%, when compared to the baseline.

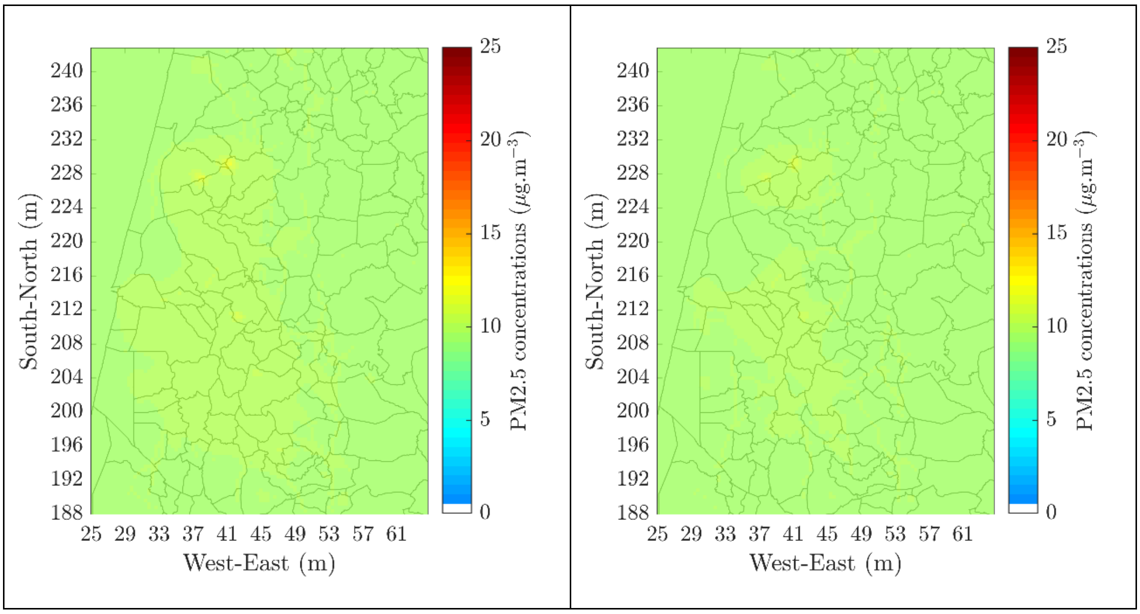


Figure 3-69: PM2.5 annual average concentrations in the FUPS scenario a) in 2025 and b) in 2050.

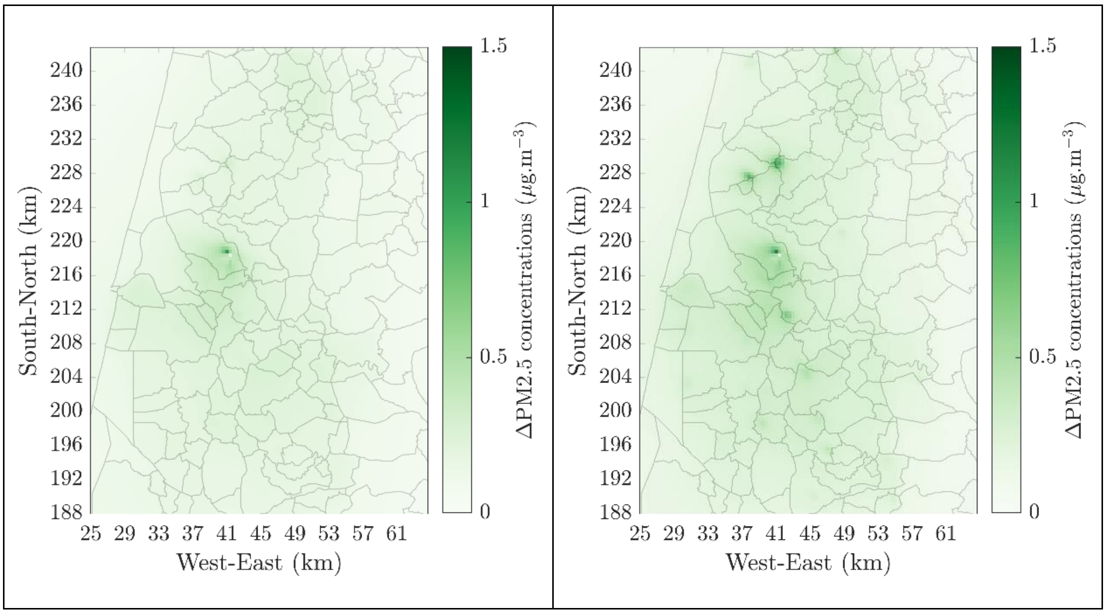


Figure 3-70: Differences of the PM2.5 annual averaged concentrations in the FUPS scenario a) in 2025 and b) in 2050.

Table 3-25 presents an overview of the overall impact of the FUPS scenarios on the $PM_{2.5}$ concentrations. This scenario will lead to an overall reduction of 2.0% of the $PM_{2.5}$

concentrations over the entire computational domain in 2025, and of 2.5% in 2050. It is of notice that since the FUPS scenario does not include any related measure with the residential sector, neither to the industrial sector beyond the BAU targets, the two main contributor sectors to PM emissions, this Unified Scenario will lead to similar impacts on $PM_{2.5}$ concentrations reductions, when compared to the BAU scenario.

The simulation results indicate full compliance with the EU annual limit value everywhere in the computational domain already in the baseline. However, the $PM_{2.5}$ concentrations are still above the WHO guideline values within some grid cells of the domain in 2050. The simulation results indicate no risk for the population within the Aveiro Region to be potentially exposed to $PM_{2.5}$ concentrations above the EU annual legal limit value, but, on contrary some inhabitants will be potential exposed to the stricter WHO guideline values even in 2050.

Table 3-25: Summary of results including the annual averages of $PM_{2.5}$ concentrations, together with the number of exceedances to the WHO guideline values (Exc.), as well as the number of exceedances to the WHO guideline values in grid cells with inhabitants allocated to (Exc. Inhabit.), the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit (Inhabit.), and the corresponding % of population (Pop.).

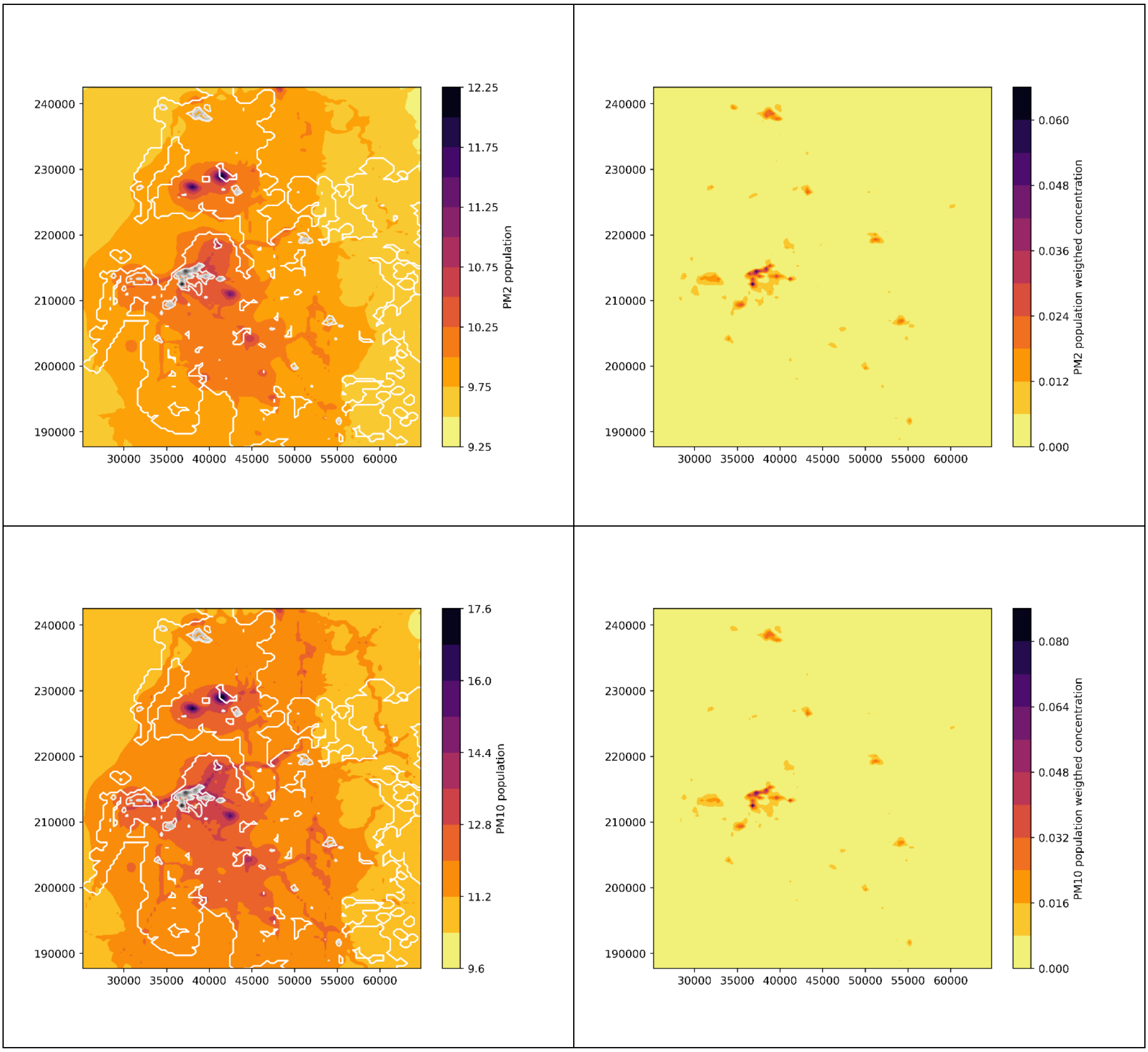
	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	9.4	12.1	9.8	2614	1997	170871	49.2%
FUPS 2025	9.4	11.8	9.7	300	234	22566	6.5%
FUPS 2035	9.4	11.1	9.6	87	61	4520	1.3%
FUPS 2050	9.4	11.1	9.6	98	71	5333	1.5%

3.6 Health impacts

3.6.1 Baseline

The health impacts related to exposure to NO_2, PM10, and PM2.5 were calculated based on the baseline emissions scenario. The figures below show maps to illustrate the areas of highest concern regarding human exposure to the individual pollutants. The left panels show the concentration maps overlaid with the population density distribution within the study area. The concentration levels are shown in a colour scale from yellow to dark purple (the same concentrations as presented in section 3.3.6) and population density with contours from light to dark grey (no colour bar), the darker the grey, the denser the population is. On the right panels, the concentration weighted population maps indicating where the population is mostly affected by the air concentration levels in Aveiro Region, for individual pollutants. The population weighted concentration maps indicate that exposure is the highest at the cities of Aveiro and Estarreja and other smaller villages across the area.

The assessment includes the estimation of premature deaths and year potentially lost due to air pollution exposure. The results for the baseline scenario indicate there has been 194, 154, and 63 premature deaths, and 1657, 1988, and 714 years of life potentially lost attributed to $PM_{2.5}$, PM_{10}, and NO_2 pollution levels in Aveiro Region in 2015, respectively.



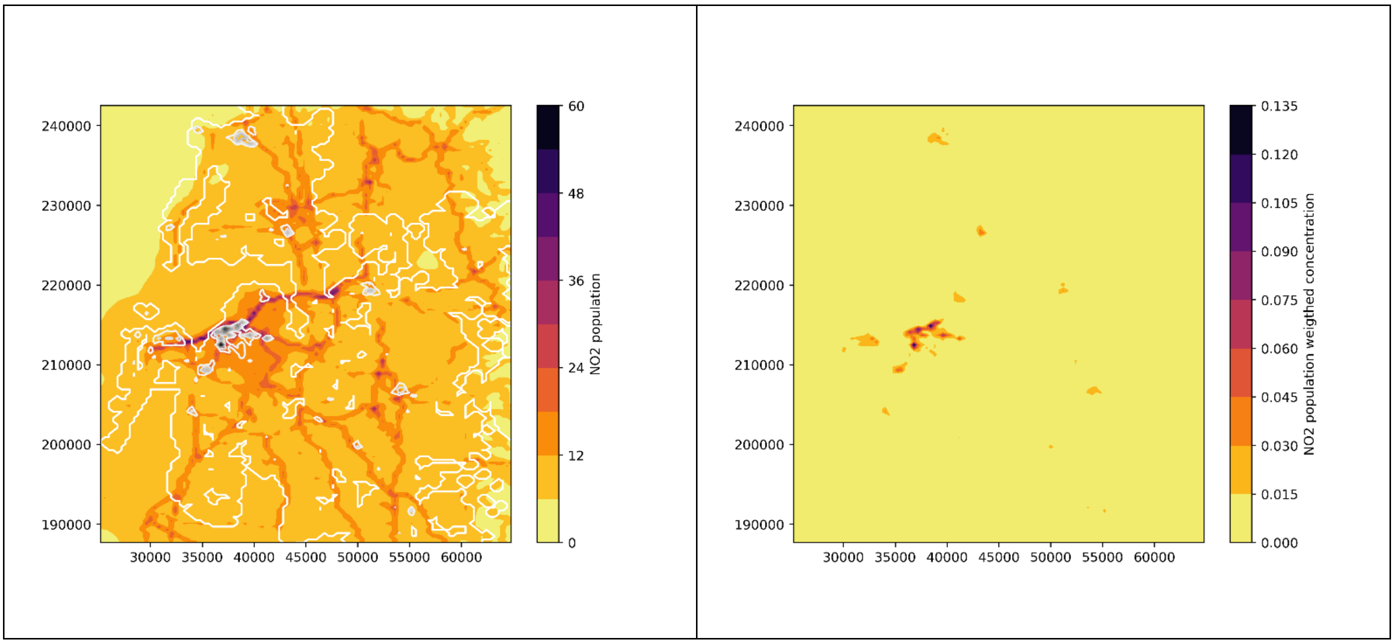


Figure 3-71: Concentration maps overlaid with population density contours (left), population weighted concentration maps (right) for PM2.5 (top), PM10 (centre), and NO_2 (bottom) based on the baseline emission scenario (2015), for Aveiro Region.

3.6.1.1 BAU and UPS

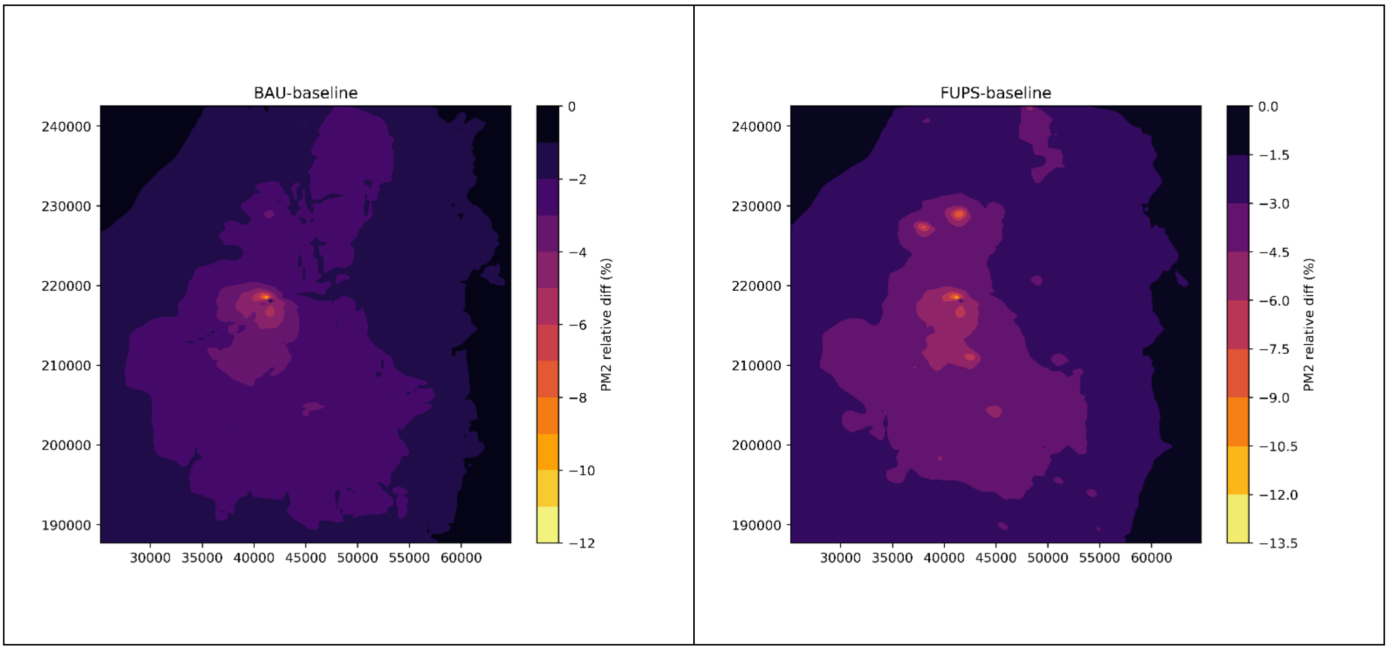
The analysis of the health impact benefits of implementing emission control measures can be quantified by benchmarking the health indicators estimated based on the BAU and UPS emission scenarios. The results in relative terms (%) are described in the table below. Note that independently of the indicators, the impact is the same since the indicators are related (see Equation [2.7.6]).

Table 3-26: Health impact benefits of implementing emission control measures in Aveiro Region (%).

	PM2.5			PM10			NO2		
	2025	2035	2050	2025	2035	2050	2025	2035	2050
BAU	-2	-2	-2	-5	-5	-5	-85	-99	-100
UPS	-2	-3	-3	-5	-7	-7	-95	-100	-100

The results show that both future emission scenarios will contribute to the improvement on human health, reducing the health impact indicators for all air pollutants. The reduction for particulate matter will be very low, for both future emission scenarios BAU scenario seems to be the most efficient on reducing the numbers on premature deaths and years of life lost for NO_2. However, for particulate matter, there is no difference between the scenarios. According to these results, both future scenarios will have a large impact in 2050, with showing a high rate of reduction already in 2015. There no change for particulate matter, independently of the future emission scenario considered.

The mapping of the air quality impact benefits of implementing emission control measures is a good proxy to support the analysis on the impact of the emission scenario. The maps for the year 2050 are shown in Figure 3-72 shows the comparison between future and current emission scenario. Note that the maps have different scales and they show the reduction, thus the higher the negative values, the larger the reduction is. For particulate matter, the figures show a similar pattern and magnitude for concentration levels. This small difference explains the similar results for both future emission scenarios. NO_2 concentration levels have a larger reduction across the area, reducing the impact of NO_2 on human health of the people living in Aveiro Region. Thus, NO_2 reduction scenarios seem to be more successful to target areas where people live than the scenarios for particulate matter. Again, for NO_2, a slight increase on the health impact benefit across the years is expected due to the implementation of the emissions control measures for both emissions scenarios, reaching the 100% reduction for both future scenarios. For particulate matter there is little or no change across the years.



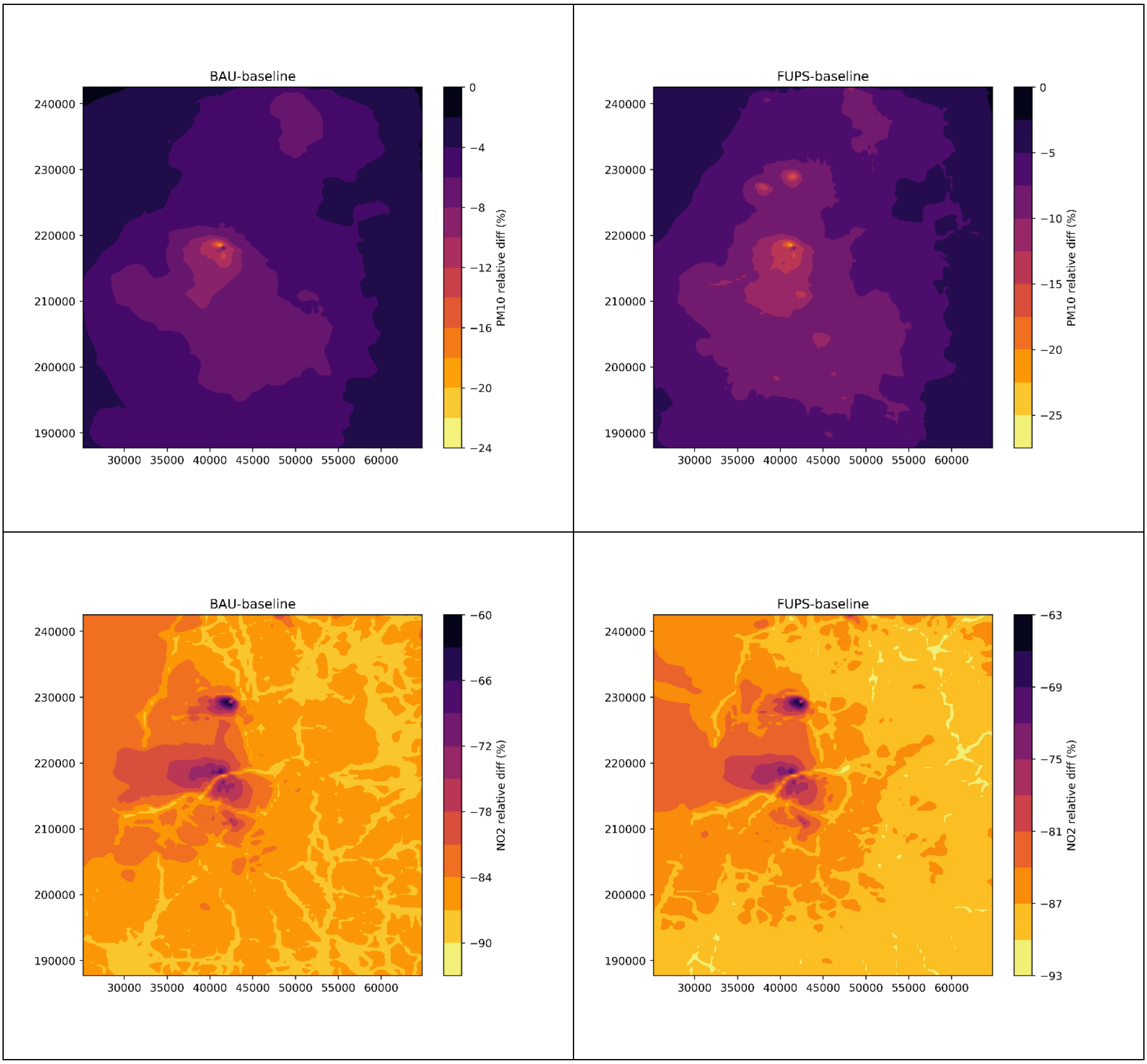


Figure 3-72: Air quality impact benefits of implementing emission control measures in 2050 for Aveiro Region, BAU vs baseline on the left and UPS vs baseline on the right for PM2.5 (top), PM10 (centre), and NO_2 (bottom).

4 Conclusions

This report presents the overall results on the impact assessment approach to consider the impacts on emissions (air pollution and carbon), air quality concentrations, exposure and health of the ClairCity baseline and future scenarios for Aveiro Region. The baseline and all the scenarios are quantified as input to the ClairCity Policy Report to be delivered at the end of the process. The ClairCity framework contributes to assess air pollution through the source apportionment of air pollutant emissions and concentrations, as well as, carbon emissions, not only by technology, but by citizens' behaviour.

The impact assessment data illustrating the work undertaken can be found on the ClairCity Data Portal, as follow: https://claircitydata.cbs.nl/dataset/d5-5d-assessment-of-impacts-cira. Access can be arranged upon request. Furthermore, it was created a ClairCity community on Zenodo.org, where the full dataset was uploaded from the ClairCity Data Portal to Zenodo. The comunity is available on the link: https://zenodo.org/communities/claircity.