ClairCity: Citizen-led air pollution reduction in cities

Deliverable 5.7: City Impact Analysis Report - Ljubljana

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Document Details

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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 Ljubljana.

Contributions and Acknowledgements

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

Table of Content

In this document, we elaborate into the methodology and results of the modelling for the Ljubljana 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/d5-5a-assessment-of-impacts-ljubljana. 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 available for key roads only in Ljubljana. The Ljubljana transport model estimating transport volumes was unavailable to the ClairCity team. 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

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…

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 Ljubljana, traffic volume data was

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

available for most primary roads, sufficient for more extensive calibration compared to Sosnowiec.

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.

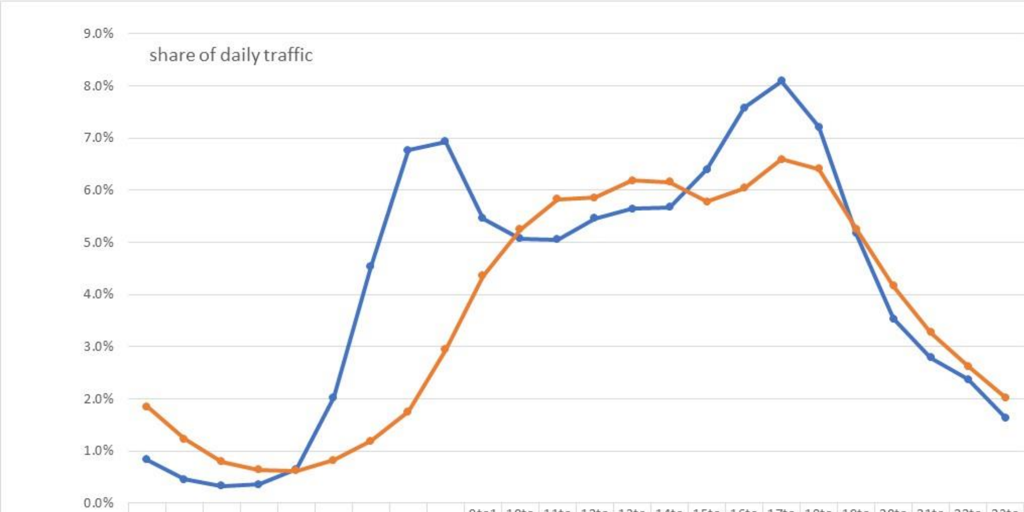
Post-processing

The initial demand generation and assignment need further refinement. This includes, for Ljubljana: **OD corrections and local road attractiveness**: For some of the origin or destinations in the network a straightforward correction can be applied to be in line with counting data. All the highest OSM class roads that cut the cordon around the case-study area are origins and destinations in the final trip matrix. This means that a single factor per origin row or destination column can be applied to match the total sum of a row / column with observed averages volumes per day. We added **Local count corrections** in a second step: An estimated selected link assignment is performed based on the shortest path trees emitted upstream and downstream of the observed road. These trees are combined with the observed splitting rate at diverge/merge points to adjust redistribution weights of the deviation with the counts.

This leads to the following estimated flows:

Figure 1-1: stimated transport flows in Ljubljana

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 have 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

We used the mode choice model built for Bristol as is for Ljubljana. We manually calibrated the mode choice model of Bristol to the observed (many cases estimated or modelled) modal split using the ASC values. Since the present time modal split in these cities is not too far from the one of Bristol, this is a reasonable approximation.

1.3 Air quality modelling

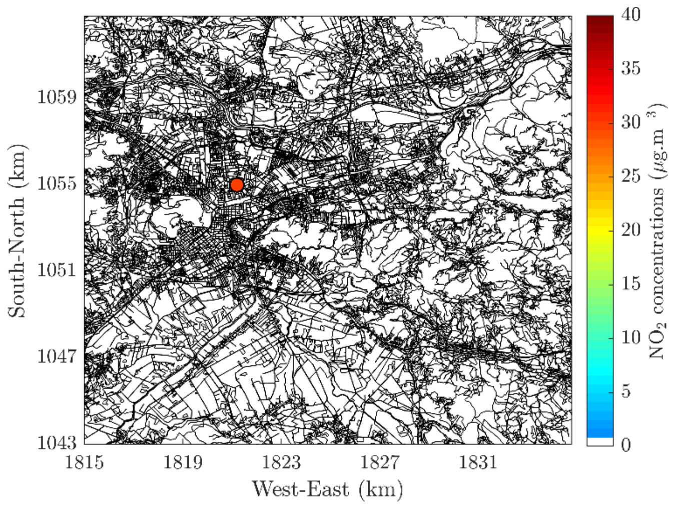
1.3.1 Background concentrations

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 0.38 µg.m^{-3}, for PM_{10} was 15.9 µg.m^{-3} and for $PM_{2.5}$ was 14.96 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 concentrations the modelling results could only be compared with 1 urban background monitoring station. For PM_{10} the results could be compared with 2 urban background stations and 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 $PM_{2.5}$.

NO_2 monitoring station	

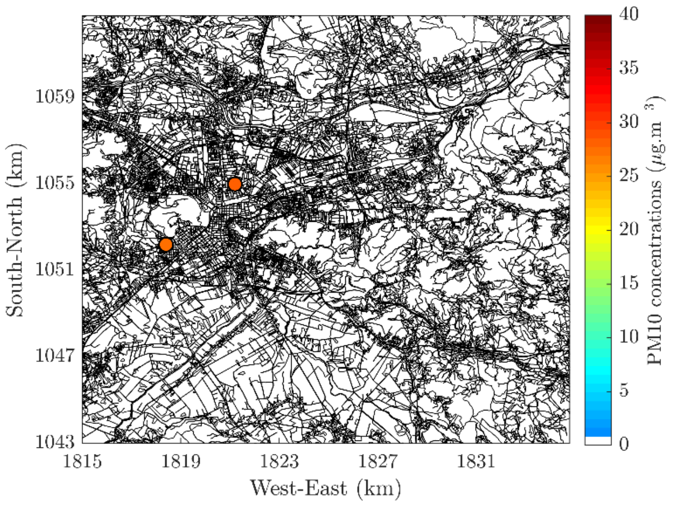
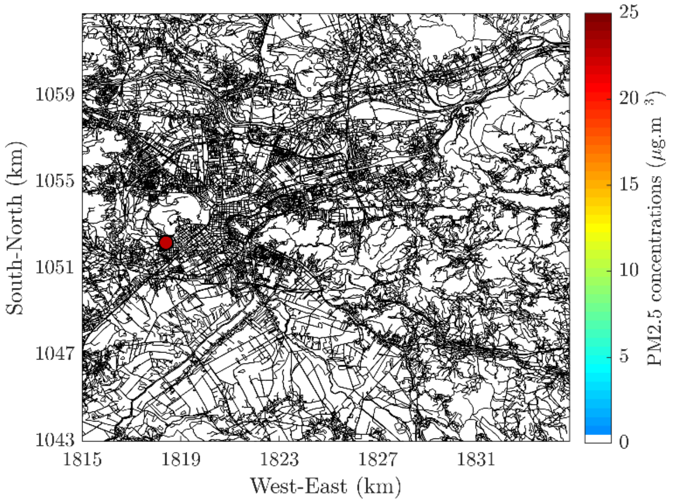
PM_{10} monitoring station	
$PM_{2.5}$ monitoring station	

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 1.61. For PM_{10} concentrations the resulting slope is equal to 0.65 and for $PM_{2.5}$ the slope is 0.43.

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

The SDW resulted in two proposed scenarios (a High and a Low version) which differ mainly in the ambition level and timeline in the selected policies. Afterwards a final scenario was developed from selected ingredients of these initial proposed scenarios. Each of these scenarios are explained sector-by-sector and scenario-by-scenario in the following subsections. 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 Ljubljana SDW and final scenario

Policy	Low Scenario	High Scenario	Final Scenario
Regional public passenger transport	Implementation of the Railhub solution by 2027	Implementation of the Railhub solution by 2027.	Implementation of the Railhub solution by 2027.
Change of parking norms	Parking norms (after OPN MOL) are reduced to 0.5 by 2020.	Parking norms (after OPN MOL) are reduced to 0.5 by 2020.	Parking norms (after OPN MOL) are reduced to 0.5 by 2020.
Cheaper public transport	Public transport is 50% cheaper for all.	Public transport is 50% cheaper for all.	Public transport is 50% cheaper for all.
Independence from the car	Incentives and subsidies for car-free neighbourhoods by 2017.	Incentives and subsidies for car-free neighbourhoods by 2017.	Incentives and subsidies for car-free neighbourhoods by 2017.
New areas for non-motorized traffic (pedestrian and bicycling areas)	Designing new areas with limited access for vehicles.	Designing new areas with limited access for vehicles.	Designing new areas with limited access for vehicles.
Higher frequency of buses and inclusion of train transport in city traffic	Increase of public transport for 10% until 2027.	Increase of public transport for 30% until 2027.	High Scenario.
New cycling routes and connections	New and modified cycling routes - 30% by 2021.	New and renovated cycling routes - 50% by 2021.	Low Scenario.

E-mobility	Electromobility is left to the market	Electromobility is left to the market.	Electromobility is left to the market.
Safe cycling and walking in the city	0 dead pedestrians and cyclists (target of 2027) within the ring road.	0 dead or heavily damaged pedestrians and cyclists until 2027 within the ring road.	0 dead or heavily damaged pedestrians and cyclists until 2027 within the ring road.
Green transport park for public transport LPP	Half of transport park fulfils standard EURO VI until 2025.	Half of transport park fulfils standard EURO VI until 2025.	Half of transport park fulfils standard EURO VI until 2025.

2.1 Transport

2.1.1 Baseline and BAU

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

- Walk 23%
- Bike 2%
- Car/van 60%
- Public transport 15%

(In comparison, in Bristol this was ~29%, ~2%, ~57%, ~11%)

To match the mode choice model of Bristol with these shares we derived the following changes in the ASC values:

ASC_1 = ASC_1-0.4
ASC_2 = ASC_2+0.1
ASC_4 = ASC_4+0.24
ASC_5 = ASC_5+0.3

The baseline passenger vehicle stock and its fleet evolution is according to our modified and updated MOVEET model. We adapt the input assumptions for the annual market share forecast from the ePURE report (Europe's Clean Mobility Outlook: Scenarios for the EU light-duty vehicle fleet, associated energy needs and emissions, 2020-2050) of Ricardo Energy & Environment (Ricardo 2018), namely the High xEV Scenario (see A5 in Ricardo 2018). We use this approach in each of the following regions too. The uptake of xEV (electric and hybrid) is different country by country (mostly for socio-economic, infrastructural, and policy reasons), and we model this by calibrating the general (global) xEV uptake curves to the actual observed registration numbers of xEV vehicles, resulting in a technology time shift parameter. For example in the BAU for Poland this technology time shift is 5 years, meaning that Poland is 5 years behind the general, average uptake curve. This parameter is important, because we can easily model different uptake scenarios by modifying this number on the model, advancing (or delaying) the uptake.

To scale the number of cars from Poland to the region in question we simply scaled the numbers according to the population of the region relative to the population of Poland (assuming that the car ownership rate in Poland and the region is the same).

2.1.2 Proposed SDW scenario's

For the Low scenarios we have modelled two versions, one with policies active on clean air days, and another one with policies active when air pollution levels are above a critical limit. These are referred to Low Clean and Low Polluted, respectively.

Encourage/incentivise electric vehicles and **Restrict (polluting) vehicles**: this policy guides us in making changes in the fleet evolution. In the Low Scenario people are aware that on days with bad air pollution they cannot drive their diesel cars anymore in the future, which will make them consider shifting towards new technologies earlier compared to the BAU. We model this by setting the technology shift parameter from 5 to -3 (basically accelerating the growth of xEV sale shares by 8 years). This results in the Low Clean Scenario. To calculate the Low Polluted scenario we simply assume that on polluted days (starting from 2030) diesel cars do not drive, so we a) turn off their emissions in the fleet model, and also b) note down the vehicle kilometre demand they would normally fulfil, and redistribute these kilometres over other modes in the mode choice calculation phase.

The High Scenario is very different, because while in the LOW Scenario people still keep their diesel cars (they simply do not use them on specific days), here we really scrap all diesel vehicles using the usual stepwise approach (similar to the Final Scenario of Bristol). The final ban is implemented by 2025 (with bans of Euro 3-4-5 by 2019-2021-2023). As people are also made aware in time that such a strict ban is coming, we accelerate the uptake of xEV technologies even more by using a technology shift parameter of -10 (which is admittedly very extreme, similar to the observed uptake rate of Norway). Leading up to the ban the sale shares of diesel cars are gradually cut back (according to the actual drop in diesel sales) to model that suddenly less diesels are going to be sold, while the sale shares of the remaining technologies are boosted to fill the formed gap[2]. This overall means that as diesel is getting phased out, less diesel cars are bought than in the model without scrappage, while the deficit is distributed over the other propulsion types.

During the calculation of the modal shifts in the Low Polluted scenario for 2035 and 2050 we made a small mistake which was only noticed during the calculation of the Final scenario. The final effect of this mistake was not too significant (it did not influence the definition of the Final scenario in any way), but to be fully transparent we still publish both the initial and the corrected result tables in the next sections. (The actual mistake we made during the calculation of the proposed scenarios was that while we redistributed the mentioned potential diesel kilometres, we forgot to remove them from the mileage of cars, therefore the resulting car mileage shares were higher than they should have been, and the mileage shares of the

[2] In Poland the passenger car market is dominated by used car sales (see **Error! Reference source not found.**), so "new" r egistrations have a wide age distribution. When growth rates are set to zero for years and vintages that are after the corresponding scrappage years then the sum of the remaining growth rates for diesel in a given year (that is after the scrappage) is not 1 anymore, but – in this specific example – between 0.63 to 0.29; we note these values down. To make sure that there is no unrealistic boost caused by this in sales for these younger still not-banned diesel vintages, the sale percentages of diesel are multiplied with these (smaller than one values), and the sale percentages of the other types are boosted slightly to have a total of 100% in sale shares. Finally the remaining growth rates of diesel (which summed up to between 0.63 and 0.29 until this step) are boosted to sum up to 1, which is required by how the growth rates are defined. A reminder: sale shares decide what percentage of cars are sold as diesel (and they sum up to 100% over the propulsion technologies for a given year), while growth rates decide the age distribution of these cars (and they always sum up to 1 for each propulsion type for any given each year).

other modes were consequently lower. The relative mileage changes that we used for scaling emission calculations were only affected for cars.) The Final scenario was calculated using the correct equations.

Make public transport free/cheaper: We model this by making public transport (including surface rail too as there are many tram lines in this region) free on polluted days in the Low Polluted Scenario, and always in the High Scenario.

- In model:
    - StageCost_4 = data['StageCost_4'] * 0
    - StageCost_5 = data['StageCost_5'] * 0

Raise public awareness of health/environmental impacts of air pollution and **Create/increase cycle lanes and infrastructure (storage, security)**: we model these together as their aimed goals are very similar and complement each other well. We modify the alternative specific constants to match the aimed modal splits for each Scenario. (Modifying ASC values is always a last resort, so if other policies are also active in a given reporting year, then we make the calculations first without modifying the ASCs, see what the outcome is, and then only if necessary do we modify the ASCs in the final step.)

In the Low Scenario we model a doubling in bike trips by 2025 (as a result of the infrastructure policy), then by 2035 we meet the goals outlined in the scenario overview table. For the latter we assume that the 10% drop in car shares shifts to slow modes and public transport in a 50-50 split.

- In Clean model 2025:
    - ASC_2 = ASC_2+0.8
- In Polluted model 2025:
    - ASC_2 = ASC_2+0.9 #Stronger change needed compared to Clean as free PT takes a bigger share (away from not only cars but potential cyclist)
- In Clean model 2035:
    - ASC_1 = ASC_1+0.2
    - ASC_2 = ASC_2+1
    - ASC_4 = ASC_4+0.70
    - ASC_5 = ASC_5+0.70
- In Polluted model 2035:
    - ASC_1 = ASC_1+0.1
    - ASC_2 = ASC_2+1
    - ASC_4 = ASC_4+0.2 #Weaker change needed compared to Clean since being free these PT modes already have a higher utility
    - ASC_5 = ASC_5+0.2

2.1.3 Final Scenario

The final scenario is simply a mix of already discussed modelling elements from the Low and High scenario according to the policy overview in Table 2-1, without any further changes.

Encourage/incentivise electric vehicles: the modelling of this is the same as the modelling of the Low Scenarios, except that in the Final Polluted Scenario the air-pollution-based diesel ban start already in 2025. (There is now scrappage like there was in the High Scenario.)

The rest of the policies were picked as a mix of the Low and High Scenarios, an as such were already discussed above.

We made some refinements to the modelling workflow for the calculation of this scenario, meaning:

As mentioned before, for the final scenario we also calibrated the mode choice model to the observed modal split using the ASC values. This resulted in a slightly modified mileage distribution for the modes, which serve as the baseline for our relative mileage change calculations for the reporting years. The calibrated ASC parameters were:

- Baseline:
  - ASC_1 = ASC_1-0.4
  - ASC_2 = ASC_2+0.1
  - ASC_4 = ASC_4+0.24
  - ASC_5 = ASC_5+0.3

For the modelling of the policy which had fixed modal shift goals for 2030 we already calculated results for 2025 too, assuming a linear change in the modal split from the 2015 observed to 2030. We model the redistribution of the 40% of car trips that go towards other modes as follows: 40% of cars go to slow and PT (30% to slow (20% bike, 10% walk), rest to PT (keeping the existing relative share of the two sub-modes). Past the 2030 horizon we keep the 2030 values constant. The final ASC values per scenario are:

- Clean 2025:
  - ASC_1 = ASC_1-0.4
  - ASC_2 = ASC_2+1.45
  - ASC_3 = ASC_3-0.8
  - ASC_4 = ASC_4+0.22
  - ASC_5 = ASC_5+0.18
- Clean 2035:
  - ASC_1 = ASC_1-0.05
  - ASC_2 = ASC_2+2
  - ASC_3 = ASC_3-0.9
  - ASC_4 = ASC_4+0.6
  - ASC_5 = ASC_5+0.7
- Polluted 2025:
  - ASC_1 = ASC_1-0.45
  - ASC_2 = ASC_2+1.45
  - ASC_3 = ASC_3-0.7
  - ASC_4 = ASC_4-0.2
  - ASC_5 = ASC_5-0.1
- Polluted 2035:
  - ASC_1 = ASC_1-0.275

- ASC_2 = ASC_2+1.9
- ASC_3 = ASC_3-0.95
- ASC_4 = ASC_4-0.05
- ASC_5 = ASC_5+0.1

On polluted days the diesel cars don't drive, but people still need to get around, so we assume they can all still get to their destinations using alternative modes, and redistribute their mileages such that we assume that 5-5% of the total immobilised diesel mileage goes to slow modes (they are limited since with bad air quality people will not really want to be outside), 5% goes to ride sharing (with someone that has a non-diesel car), and the rest is distributed equally over the public transport modes (42.5% – 42.5%). This redistribution exercise provides the final mileages for a given reporting year that can be compared to the baseline mileages to derive the scaling factor that is applied to the emission calculations coming from the fleet models.

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 Ljubljana.

The following tables document the methodology and data used for:

- Industrial sources (Table 2-2);
- Residential and commercial sources (Table 2-3);
- Wood statistics (Table 2-4);
- Naselje disaggregation variables (Table 2-5).

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

Activity	Data availability	Source	Publication	Reference	Disaggregation variable
Industrial sector	Single facility	EIONET	Reporting Obligations Database (ROD), Deliveries for National Emission Ceiling Directive (NECD) - Large point source (LPS) emissions data by source category (GNFR) Slovenia NECD 2017 Report LPS emissions 2007 2015	http://cdr.eionet.europa.eu/si/eu/nec_revised/lps/envwox5ng	None (Point sources)
Industrial sector	Level 2 (Občine) only for Ljubljana	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Corine Land Cover for industrial plants and direct allocation for not point sources energy transformation plants

Table 2-3: Methodology and source of data for Ljubljana fuel consumptions evaluation - Residential and commercial sources.

Activity	Energy vector	Data availability	Source	Publication	Reference	Disaggregation variable
Residential sector	Natural Gas	Level 2 (Občine) only for Ljubljana	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Population
		Level 1 National for all other areas	Republika Slovenija, Ministrstvo za Infrastrukturo	Portal Energetike: Energetska Bilanca Republik Eslovenije - Zaleto 2015	http://www.energetika-portal.si/fileadmin/dokumenti/publikacije/energetska_bilanca/ebrs_2015.pdf	Population
	Wood	Level 2 (Občine) only for Ljubljana	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Population
		Level 1 National for all other areas	Republika Slovenija, Ministrstvo za Infrastrukturo	Portal Energetike: Energetska Bilanca Republik Eslovenije - Zaleto 2015	http://www.energetika-portal.si/fileadmin/dokumenti/publikacije/energetska_bilanca/ebrs_2015.pdf	Population
	LPG	Level 2 (Občine) only for Ljubljana	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Population
		Level 1 National for all other areas	Republika Slovenija, Ministrstvo za Infrastrukturo	Portal Energetike: Energetska Bilanca Republik Eslovenije - Zaleto 2015	http://www.energetika-portal.si/fileadmin/dokumenti/publikacije/energetska_bilanca/ebrs_2015.pdf	Population

Activity	Energy vector	Data availability	Source	Publication	Reference	Disaggregation variable
	Gasoil	Level 2 (Občine) only for Ljubljana	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Population
		Level 1 National for all other areas	Republika Slovenija, Ministrstvo za Infrastrukturo	Portal Energetike: Energetska Bilanca Republik Eslovenije - Zaleto 2015	http://www.energetika-portal.si/fileadmin/dokumenti/publikacije/energetska_bilanca/ebrs_2015.pdf	Population
	Coal	Level 2 (Občine) only for Ljubljana	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Population
		Level 1 National for all other areas	Republika Slovenija, Ministrstvo za Infrastrukturo	Portal Energetike: Energetska Bilanca Republik Eslovenije - Zaleto 2015	http://www.energetika-portal.si/fileadmin/dokumenti/publikacije/energetska_bilanca/ebrs_2015.pdf	Population
Service sector	Natural Gas	Level 2 (Občine)	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Population
		Level 1 National for all other areas	Republika Slovenija, Ministrstvo za Infrastrukturo	Portal Energetike: Energetska Bilanca Republik Eslovenije - Zaleto 2015	http://www.energetika-portal.si/fileadmin/dokumenti/publikacije/energetska_bilanca/ebrs_2015.pdf	Population

Activity	Energy vector	Data availability	Source	Publication	Reference	Disaggregation variable
	Wood	Level 2 (Občine)	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Population
		Level 1 National for all other areas	Republika Slovenija, Ministrstvo za Infrastrukturo	Portal Energetike: Energetska Bilanca Republik Eslovenije - Zaleto 2015	http://www.energetika-portal.si/fileadmin/dokumenti/publikacije/energetska_bilanca/ebrs_2015.pdf	Population
	LPG	Level 2 (Občine)	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Population
		Level 1 National for all other areas	Republika Slovenija, Ministrstvo za Infrastrukturo	Portal Energetike: Energetska Bilanca Republik Eslovenije - Zaleto 2015	http://www.energetika-portal.si/fileadmin/dokumenti/publikacije/energetska_bilanca/ebrs_2015.pdf	Population
	Gasoil	Level 2 (Občine)	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Population
		Level 1 National for all other areas	Republika Slovenija, Ministrstvo za Infrastrukturo	Portal Energetike: Energetska Bilanca Republik Eslovenije - Zaleto 2015	http://www.energetika-portal.si/fileadmin/dokumenti/publikacije/energetska_bilanca/ebrs_2015.pdf	Population

Table 2-4: Methodology and source of data for Ljubljana fuel consumptions evaluation – Wood statistics.

Variable	Data availability	Sources	Publication	Reference	Note
Technologies split	Level 1 (National)	Slovenian Environment Agency	Slovenia's Informative Inventory Report 2017. Submission under the UNECE Convention on Long-Range Transboundary Air Pollution and Directive (EU) 2016/2284 on the reduction of national emissions of certain atmospheric pollutants, Ljubljana, March 2017	http://cdr.eionet.europa.eu/si/un/clrtap/iir/envwmaww/Slovenia_IIR__2017.pdf	In the year 2015 there were 67 % conventional boilers burning wood and similar wood waste, 12 % advanced / ecolabelled stoves and boilers burning wood, 5 % pellet stoves and boilers burning wood pellets, 1 % open fireplaces burning wood, 15 % conventional stoves burning wood and similar wood waste

Table 2-5: Methodology and source of data for Ljubljana fuel consumptions evaluation – Naselje disaggregation variables.

Variable	Data availability	Sources	Publication	Reference	Note
Population	Level 3 (Naselje)	Statistical Office of the Republic of Slovenia	SI-Stat Database	https://pxweb.stat.si/pxweb/Dialog/varval.asp?ma=05C5004E&ti=&path=../Database/Demographics/05_population/10_Number_Population/25_05C50_Population_naselja/&lang=1	Population by large and 5-year age groups and sex, settlements, Slovenia, annually
Industrial areas coverage	Level 3 (Naselje)	Copernicus Land Monitoring Service	CORINE Land Cover	https://land.copernicus.eu/pan-european/corine-land-cover	A GIS query has been used to evaluated the coverage of industrial area on each Naselje and industrial emissions are allocated to the area based on dimension of area itself.

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 Slovenia 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[3] using scenario with additional measures (WAM)
- the national measures defined in the 'with measures' (adopted measures) projection in the frame of NECD[4] and in the Integrated National Energy and Climate Plan for Slovenia[5].

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.

On 29 October 2017, the Government adopted the Long-Term Strategy for Mobilizing Investments in the Energy Renovation of Buildings (DSEPS), determining the important objectives of reducing energy use in buildings. The vision, defined in DSEPS, is to achieve carbon-neutral energy use in buildings by 2050; Slovenia will achieve this by making considerable improvements in energy performance and by increasing the use of renewable energy sources in buildings. This will, in turn, significantly reduce emissions of other harmful substances into the atmosphere.

The **Ljubljana** BAU projections consider:

The Decree on the air quality plan in the area of the City of Ljubljana[6] in 2017 sets out key measures to tackle air pollution in Ljubljana. It aims at reducing the pollution of particulate matter to below limit values, to ensure compliance with the EU Ambient Air Quality Directive (2008/50/EC). It provides a detailed set of measures to reduce PM10 pollution and foresees a program to analyze the causes of pollution and analyze the effects of the implemented measures[7].

The following important actions are planned to promote efficient use of energy and renewable energy sources:

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[3] Republic of Slovenia, Ministry of the Environment and Spatial Planning 7th National Communication & 3rd Biennial Report from Slovenia under the United Nations Framework Convention on Climate Change, March 2018

[4] EEA Eionet, Reporting Obligations Database (ROD), Deliveries for National Emission Ceiling Directive (NECD) - Projected emissions by aggregated NFR sectors

[5] Integrated National Energy and Climate Plan for Slovenia, December 2018

[6] Odlok o načrtu za kakovost zraka na območju Mestne občine Ljubljana

[7] Odlok o načrtu za kakovost zraka na območju Mestne občine Ljubljana. Priloga 2: Podrobnejši program ukrepov na območju Mestne občine Ljubljana

- Increasing energy consumption, energy efficiency and utilization, and expanding district heating systems;
- Supply of district heating system from wood biomass;
- Increasing the consumption and utilization and expansion of natural gas networks by connecting the facilities to the gas network;
- Further promotion of the replacement of existing combustion plants with more appropriate combustion plants, more appropriate heating methods and other ways of heating with renewable energy sources and resources that ensure efficient use of energy;
- Advising the public on the proper use of small combustion plants and measuring the moisture content of wood biomass;
- Education and creation of a special website for the intelligent use of wood biomass as a fuel in small combustion plants;
- Conducting more rigorous monitoring of the burning of waste in small combustion plants;
- Ensuring the quality of wood fuels in small combustion plants via a common online platform;
- Establishment and operation of a mobile demonstration center for burning in small combustion plants
- Rehabilitation of Slovenian forests and the use of still useful biomass as solid fuel in boiler rooms in district heating;
- Management of sudden large surpluses of wood biomass after the impacts and outbreaks of forest diseases;
- Use of wood residues for heating in collective combustion plants;
- Local energy concept;
- Informing and encouraging the reduction of heat losses of buildings;
- Reservation of areas for low-energy construction of massive wooden buildings, heated with renewable energy sources, designed and built up considering the values and criteria in the city environment, identifiable identities - traditional architecture;
- Exact evidence of combustion plants;
- Energy recovery of municipal property.

Considering the importance of Ljubljana in the general context of Slovenia and by virtue of the observation that governance structure of air quality and carbon policies is centralized in Slovenia, we assume the goal of national planning in the residential and commercial sector also for the city.

These reductions have been added to national reductions discussed before.

Socio-economic drivers’ definition is reported in Table 2-6 while technologic drivers’ definition is reported in Table 2-7.

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.

Table 2-6: Ljubljana: Socio-economic drivers used to project emissions in industrial, residential and commercial sector.

Code	Name	Domain
LJU_B_R_L	Ljubljana BAU Residential - Liquid Fuels	all Naselje
LJU_B_R_G	Ljubljana BAU Residential - Natural gas	all Naselje
LJU_B_R_W	Ljubljana BAU Residential - Wood	all Naselje
LJU_B_C_L	Ljubljana BAU Commercial - Liquid Fuels	all Naselje
LJU_B_C_G	Ljubljana BAU Commercial - Natural gas	all Naselje
LJU_B_C_W	Ljubljana BAU Commercial - Wood	all Naselje

Table 2-7: Ljubljana: Technological drivers used to project emissions in industrial, residential and commercial sector.

Code	Name	Domain
LJU_NECI_NOx	Ljubljana NEC Industry NOx	all Naselje
LJU_NECI_PM	Ljubljana NEC Industry PM	all Naselje
LJU_NECB_NOx	Ljubljana NEC Building NOx	all Naselje
LJU_NECB_PM	Ljubljana NEC Building PM	all Naselje

2.2.3 SDW scenarios

Scenarios from the Stakeholder dialog workshop (SWD) includes no measures relating to the IRCI sector.

2.2.4 Unified Policy Scenario

Unified Policy Scenario includes no measures relating to the IRCI sector.

2.3 Carbon footprint

2.3.1 Baseline

The following tables document the methodology and data used for:

- Industrial sources (Table 2-8).
- Residential and commercial sources (Table 2-9).
- Naselje disaggregation variables (Table 2-10).

Table 2-8: Methodology and source of data for Ljubljana fuel consumptions evaluation - Industrial sources.

Activity	Energy vector	Data availability	Source	Publication	Reference	Disaggregation variable
Industrial sector	Gasoil	Level 2 (Občine)	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Corine Land Cover for industrial plants
	Gasoline	Level 2 (Občine)	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Corine Land Cover for industrial plants
	LPG	Level 2 (Občine)	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Corine Land Cover for industrial plants
	Electricity	Level 2 (Občine)	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Corine Land Cover for industrial plants

Table 2-9: Methodology and source of data for Ljubljana fuel consumptions evaluation - Residential and commercial sources.

Activity	Energy vector	Data availability	Source	Publication	Reference	Disaggregation variable
Residential sector	Natural Gas	Level 2 (Občine) only for Ljubljana	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Population
	Wood	Level 2 (Občine) only for Ljubljana	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Population
	LPG	Level 2 (Občine) only for Ljubljana	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Population
	Gasoil	Level 2 (Občine)	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Population
	Coal	Level 2 (Občine)	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Population

Activity	Energy vector	Data availability	Source	Publication	Reference	Disaggregation variable
	Electricity	Level 2 (Občine)	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Population
Service sector	Natural Gas	Level 2 (Občine)	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Population
	Wood	Level 2 (Občine)	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Population
	LPG	Level 2 (Občine)	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Population
	Gasoil	Level 2 (Občine)	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Population

Activity	Energy vector	Data availability	Source	Publication	Reference	Disaggregation variable
	Electricity	Level 2 (Občine)	EnerGisSolution	Energy Balance And Emission Estimation - City Of Ljubljana (MOL) (Project version: 2016.MOL.1996-2015) Table EB-A: Energy Balance	http://www.energis-solutions.com/en/EB-Ljubljana-MOL/energy-balance	Population

Table 2-10: Methodology and source of data for Ljubljana fuel consumptions evaluation – Naselje disaggregation variables.

Variable	Data availability	Sources	Publication	Reference	Note
Population	Level 3 (Naselje)	Statistical Office of the Republic of Slovenia	SI-Stat Database	https://pxweb.stat.si/pxweb/Dialog/varval.asp?ma=05C5004E&ti=&path=../Database/Demographics/05_population/10_Number_Population/25_05C50_Population_naselja/&lang=1	Population by large and 5-year age groups and sex, settlements, Slovenia, annually
Industrial areas coverage	Level 3 (Naselje)	Copernicus Land Monitoring Service	CORINE Land Cover	https://land.copernicus.eu/pan-european/corine-land-cover	A GIS query has been used to evaluated the coverage of industrial area on each Naselje and industrial emissions are allocated to the area based on dimension of area itself.

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 reported in the 7th national communication to UNFCCC[8] using scenario with additional measures (WAM). By 2050, despite the declaration of intent to move towards carbon neutrality, in the absence of precise data, the 2035 objective was kept constant. For industry in absence of energy consumptions projection subdivided by fuel the distribution between fuels has been kept constant.

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.

[8] Republic of Slovenia, Ministry of the Environment and Spatial Planning 7th National Communication & 3rd Biennial Report from Slovenia under the United Nations Framework Convention on Climate Change, March 2018

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 applicable[9]) for various reporting years in each scenario. For the Final scenario we also present the calibrated baseline.

[9] For scenarios where diesel mileages had to be redistributed we only made the calculations on the mileages and not on the modal split (for technical reasons).

Mode	Mileage change	Trip share (%)
1|Walk	0.972	28.3
2|Bicycle	2.088	3.8
3|Car/van	0.985	54.6
4|Bus/metro	0.965	8.6
5|Train/surface rail	0.990	2.2
6|Taxi	0.928	1.2
7|Other (incl. motorbike)	1.004	1.3

Figure 3-4: Scenario Low Clean (2025).

Mode	Mileage change	Trip share (%)
1|Walk	0.962	28.1
2|Bicycle	2.098	3.7
3|Car/van	0.914	48.9
4|Bus/metro	1.442	13.9
5|Train/surface rail	1.403	3.5
6|Taxi	0.805	1.0
7|Other (incl. motorbike)	0.768	1.1

Figure 3-5: Scenario Low Clean (2035-2050).

Mode	Mileage change	Trip share (%)
1|Walk	0.933	27.7
2|Bicycle	1.780	3.7
3|Car/van	0.749	50.9
4|Bus/metro	2.547	12.6
5|Train/surface rail	2.330	2.9
6|Taxi	0.754	1.1
7|Other (incl. motorbike)	0.391	1.1

Figure 3-6: Scenario Low Polluted (2025).

Mode	Mileage change
1|Walk	1.074
2|Bicycle	2.247
3|Car/van	0.545
4|Bus/metro	3.799
5|Train/surface rail	3.142
6|Taxi	0.716
7|Other (incl. motorbike)	0.364

Figure 3-7: Scenario Low Polluted (2035).

Mode	Mileage change
1|Walk	0.974
2|Bicycle	1.898
3|Car/van	0.682
4|Bus/metro	3.009
5|Train/surface rail	2.580
6|Taxi	0.716
7|Other (incl. motorbike)	0.364

Figure 3-8: Scenario Low Polluted (2050).

Mode	Mileage change	Trip share (%)
1|Walk	0.967	28.5
2|Bicycle	7.111	14.6
3|Car/van	0.542	35.2
4|Bus/metro	3.427	16.8
5|Train/surface rail	2.707	3.6
6|Taxi	0.440	0.6
7|Other (incl. motorbike)	0.223	0.6

Figure 3-9: Scenario High (2025-2035-2050).

Mode	Trip share (%)
1|Walk	22.94
2|Bicycle	2.10
3|Car/van	57.06
4|Bus/metro	12.14
5|Train/surface rail	3.07
6|Taxi	1.30
7|Other (incl. motorbike)	1.39

Figure 3-10: Trip shares in the calibrated mode choice model for the Baseline of the Final Scenario.

Mode	Mileage change	Trip share (%)
1|Walk	1.212	26.7
2|Bicycle	5.158	9.7
3|Car/van	0.832	42.0
4|Bus/metro	1.244	14.7
5|Train/surface rail	1.215	3.4
6|Taxi	1.302	1.6
7|Other (incl. motorbike)	1.386	1.8

Figure 3-11: Final Clean Scenario (2025).

Mode	Mileage change	Trip share (%)
1|Walk	▲ 1.327	28.6
2|Bicycle	▲ 7.324	13.3
3|Car/van	▼ 0.722	34.2
4|Bus/metro	▲ 1.439	16.5
5|Train/surface rail	▲ 1.601	4.6
6|Taxi	▲ 1.095	1.3
7|Other (incl. motorbike)	▲ 1.147	1.5

Figure 3-12: Final Clean Scenario (2035-2050).

Mode	Mileage change
1|Walk	▲ 1.411
2|Bicycle	▲ 4.727
3|Car/van	▼ 0.406
4|Bus/metro	▲ 3.545
5|Train/surface rail	▲ 2.995
6|Taxi	▲ 1.116
7|Other (incl. motorbike)	▼ 0.609

Figure 3-13: Final Polluted Scenario (2025).

Mode	Mileage change
1|Walk	▲ 1.417
2|Bicycle	▲ 6.520
3|Car/van	▼ 0.416
4|Bus/metro	▲ 3.300
5|Train/surface rail	▲ 2.812
6|Taxi	▲ 1.116
7|Other (incl. motorbike)	▼ 0.586

Figure 3-14: Final Polluted Scenario (2035).

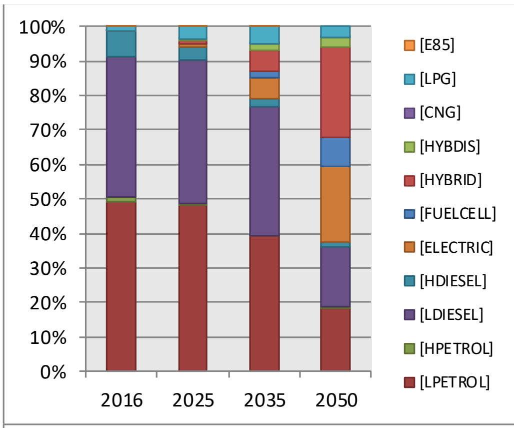
Mode	Mileage change
1|Walk	▲ 1.318
2|Bicycle	▲ 6.275
3|Car/van	▼ 0.514
4|Bus/metro	▲ 2.839
5|Train/surface rail	▲ 2.482
6|Taxi	▲ 1.116
7|Other (incl. motorbike)	▼ 0.586

Figure 3-15: Final Polluted Scenario (2050).

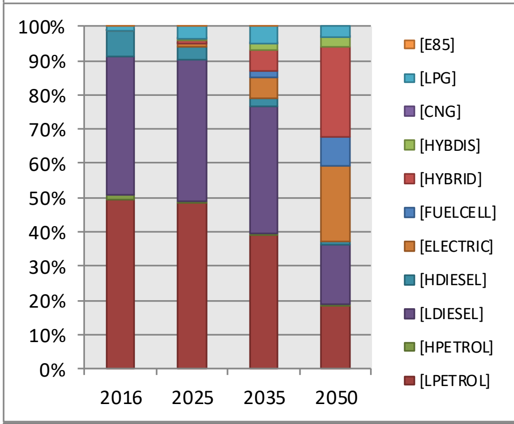
3.1.2 Fleet and Emissions

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

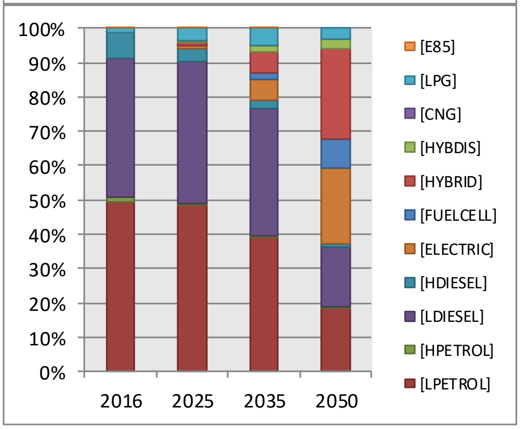
VENSIM model in percentage of total fleet per reporting year				
BAU	2016	2025	2035	2050
[LPETROL]	49.37%	48.30%	39.18%	18.43%
[HPETROL]	1.34%	0.53%	0.39%	0.19%
[LDIESEL]	40.62%	41.52%	37.09%	17.49%
[HDIESEL]	7.36%	3.86%	2.52%	1.18%
[ELECTRIC]	0.02%	0.74%	5.84%	22.06%
[FUELCELL]	0.00%	0.14%	1.94%	8.42%
[HYBRID]	0.01%	0.81%	6.07%	26.44%
[HYBDIS]	0.00%	0.47%	1.92%	2.72%
[CNG]	0.01%	0.02%	0.02%	0.01%
[LPG]	1.26%	3.61%	5.04%	3.06%
[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]	49.37%	48.30%	39.18%	18.43%
[HPETROL]	1.34%	0.53%	0.39%	0.19%
[LDIESEL]	40.62%	41.52%	37.09%	17.49%
[HDIESEL]	7.36%	3.86%	2.52%	1.18%
[ELECTRIC]	0.02%	0.74%	5.84%	22.06%
[FUELCELL]	0.00%	0.14%	1.94%	8.42%
[HYBRID]	0.01%	0.81%	6.07%	26.44%
[HYBDIS]	0.00%	0.47%	1.92%	2.72%
[CNG]	0.01%	0.02%	0.02%	0.01%
[LPG]	1.26%	3.61%	5.04%	3.06%
[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]	49.37%	48.30%	39.18%	18.43%
[HPETROL]	1.34%	0.53%	0.39%	0.19%
[LDIESEL]	40.62%	41.52%	37.09%	17.49%
[HDIESEL]	7.36%	3.86%	2.52%	1.18%
[ELECTRIC]	0.02%	0.74%	5.84%	22.06%
[FUELCELL]	0.00%	0.14%	1.94%	8.42%
[HYBRID]	0.01%	0.81%	6.07%	26.44%
[HYBDIS]	0.00%	0.47%	1.92%	2.72%
[CNG]	0.01%	0.02%	0.02%	0.01%
[LPG]	1.26%	3.61%	5.04%	3.06%
[E85]	0.00%	0.00%	0.00%	0.00%



VENSIM model in percentage of total fleet per reporting year				
FINAL	2016	2025	2035	2050
[LPETROL]	49.37%	48.30%	39.18%	18.43%
[HPETROL]	1.34%	0.53%	0.39%	0.19%
[LDIESEL]	40.62%	41.52%	37.09%	17.49%
[HDIESEL]	7.36%	3.86%	2.52%	1.18%
[ELECTRIC]	0.02%	0.74%	5.84%	22.06%
[FUELCELL]	0.00%	0.14%	1.94%	8.42%
[HYBRID]	0.01%	0.81%	6.07%	26.44%
[HYBDIS]	0.00%	0.47%	1.92%	2.72%
[CNG]	0.01%	0.02%	0.02%	0.01%
[LPG]	1.26%	3.61%	5.04%	3.06%
[E85]	0.00%	0.00%	0.00%	0.00%

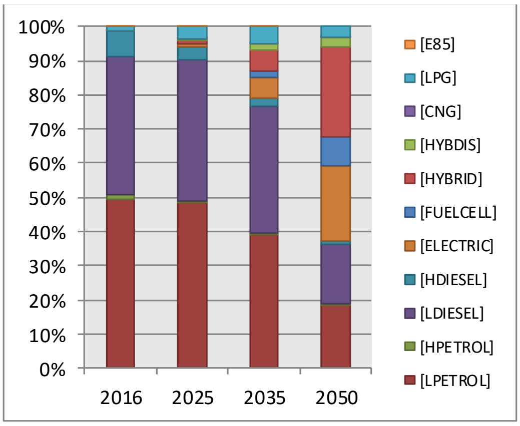


Figure 3-16: Passenger car fleet composition in the BAU and in SDW (Low vs. High) & final scenario.

Table 3-11: Relative emissions in the BAU and SDW scenario (top) and the final scenario (bottom).

MIDZWVR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	42.64%	23.74%	14.72%
LOW		42.64%	23.74%	14.72%
HIGH		42.64%	23.74%	14.72%

PM

Year	2015	2025	2035	2050
BAU	100.00%	43.01%	34.59%	32.00%
LOW		43.01%	34.59%	32.00%
HIGH		43.01%	34.59%	32.00%

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%	123.23%	144.14%

MOTO

Nox

Year	2015	2025	2035	2050
BAU	100.00%	86.17%	56.85%	35.00%
LOW		86.17%	56.85%	35.00%
HIGH		86.17%	56.85%	35.00%

PM

Year	2015	2025	2035	2050
BAU	100.00%	73.76%	70.99%	66.17%
LOW		73.76%	70.99%	66.17%
HIGH		73.76%	70.99%	66.17%

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%	38.55%	18.94%	11.57%
LOW		38.55%	18.94%	11.57%
HIGH		38.55%	18.94%	11.57%

PM

Year	2015	2025	2035	2050
BAU	100.00%	49.89%	40.79%	37.74%
LOW		49.89%	40.79%	37.74%
HIGH		49.89%	40.79%	37.74%

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%	54.68%	20.40%	7.00%
LOW		51.94%	18.59%	6.10%
HIGH		49.06%	16.71%	5.74%

PM

Year	2015	2025	2035	2050
BAU	100.00%	29.81%	14.38%	10.81%
LOW		28.32%	13.10%	9.41%
HIGH		26.75%	11.78%	8.86%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	111.34%	119.58%	131.61%
LOW		105.75%	108.94%	114.56%
HIGH		99.90%	97.96%	107.82%

BUS

Nox

Year	2015	2025	2035	2050
BAU	100.00%	105.77%	72.91%	44.89%
LOW		132.69%	118.94%	79.70%
HIGH		115.58%	139.91%	86.13%

PM

Year	2015	2025	2035	2050
BAU	100.00%	42.34%	34.00%	31.69%
LOW		53.12%	55.45%	56.26%
HIGH		46.27%	65.23%	60.80%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	110.46%	122.02%	141.66%
LOW		138.58%	199.04%	251.51%
HIGH		120.71%	234.13%	271.82%

VAN

Nox

Year	2015	2025	2035	2050
BAU	100.00%	48.66%	22.07%	10.86%
LOW		47.29%	21.16%	10.41%
HIGH		45.85%	20.23%	10.23%

PM

Year	2015	2025	2035	2050
BAU	100.00%	36.41%	24.49%	21.41%
LOW		35.67%	23.85%	20.71%
HIGH		34.88%	23.19%	20.43%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	111.17%	121.40%	137.87%
LOW		108.38%	116.09%	129.35%
HIGH		105.46%	110.60%	125.98%

MIDZWVR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	42.64%	23.74%	14.72%
UPS		42.64%	23.74%	14.72%

PM

Year	2015	2025	2035	2050
BAU	100.00%	43.01%	34.59%	32.00%
UPS		43.01%	34.59%	32.00%

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%	86.17%	56.85%	35.00%
UPS		86.17%	56.85%	35.00%

PM

Year	2015	2025	2035	2050
BAU	100.00%	73.76%	70.99%	66.17%
UPS		73.76%	70.99%	66.17%

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%	38.55%	18.94%	11.57%
UPS		38.55%	18.94%	11.57%

PM

Year	2015	2025	2035	2050
BAU	100.00%	49.89%	40.79%	37.74%
UPS		49.89%	40.79%	37.74%

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%	54.68%	20.40%	7.00%
UPS		52.39%	17.88%	5.96%

PM

Year	2015	2025	2035	2050
BAU	100.00%	29.81%	14.38%	10.81%
UPS		28.56%	12.60%	9.21%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	111.34%	119.58%	131.61%
UPS		106.67%	104.78%	112.08%

BUS

Nox

Year	2015	2025	2035	2050
BAU	100.00%	105.77%	72.91%	44.89%
UPS		135.69%	120.82%	78.42%

PM

Year	2015	2025	2035	2050
BAU	100.00%	42.34%	34.00%	31.69%
UPS		54.32%	56.33%	55.36%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	110.46%	122.02%	141.66%
UPS		141.71%	202.19%	247.49%

VAN

Nox

Year	2015	2025	2035	2050
BAU	100.00%	48.66%	22.07%	10.86%
UPS		47.51%	20.81%	10.34%

PM

Year	2015	2025	2035	2050
BAU	100.00%	36.41%	24.49%	21.41%
UPS		35.79%	23.60%	20.61%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	111.17%	121.40%	137.87%
UPS		108.84%	114.01%	128.11%

3.2 Spatial-temporal

- Data pre-processing

As in the case of Sosnowiec, Poland, we obtained the temperature dataset from the same commercial weather service company, this time from station Ljubljana/Bezigrad Slovenia, with coordinates 46.07N, 14.52E, 299m. Thus, the nature of the dataset is exactly the same as in the Sosnowiec case. Consequently, it also has the same pre-processing techniques and similar procedures as applied in the Sosnowiec case.

Table 3-12: Resulting intra-day profiles.

Typical days (TD)	Pattern (%)		
	Commercial	Residential	
	NOX and PM10	NOX	PM10
11-02-2015	0,360444509	0,361109137	0,366153499
15-02-2015	0,362594755	0,363263348	0,368337802
12-08-2015	0,162255713	0,161912768	0,159309898
16-08-2015	0,166863384	0,1665107	0,163833915

3.3 IRCI

3.3.1 Baseline

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

- Ljubljana Naselje Residential, Commercial & Institutional NO_x emissions (Figure 3-17),
- Ljubljana Naselje Residential, Commercial & Institutional PM_{10} emissions (Figure 3-18),
- Ljubljana Naselje Residential, Commercial & Institutional PM_{10} emissions from biomass use (Figure 3-19),
- Ljubljana Industry NO_x area emissions (Figure 3-20),
- Ljubljana Industry PM_{10} area emissions (Figure 3-21),
- Ljubljana Industry NO_x point emissions (Figure 3-22),
- Ljubljana Industry PM_{10} point emissions (Figure 3-23).

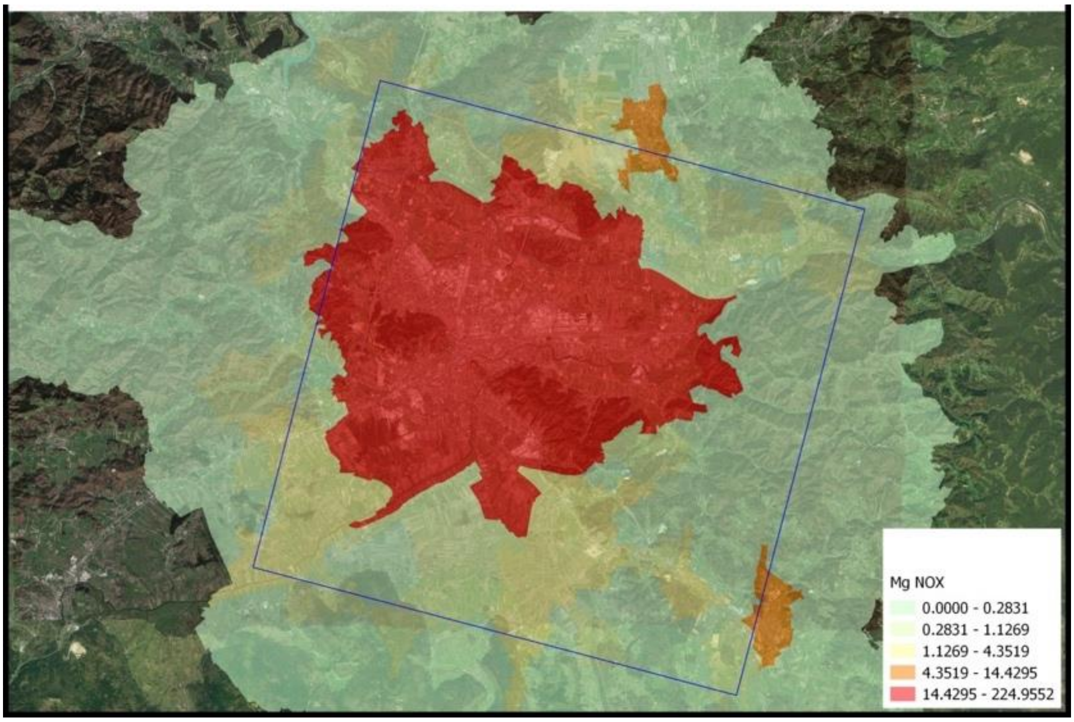


Figure 3-17: Ljubljana Naselje Residential, Commercial & Institutional NOx emissions – all sectors and fuels.

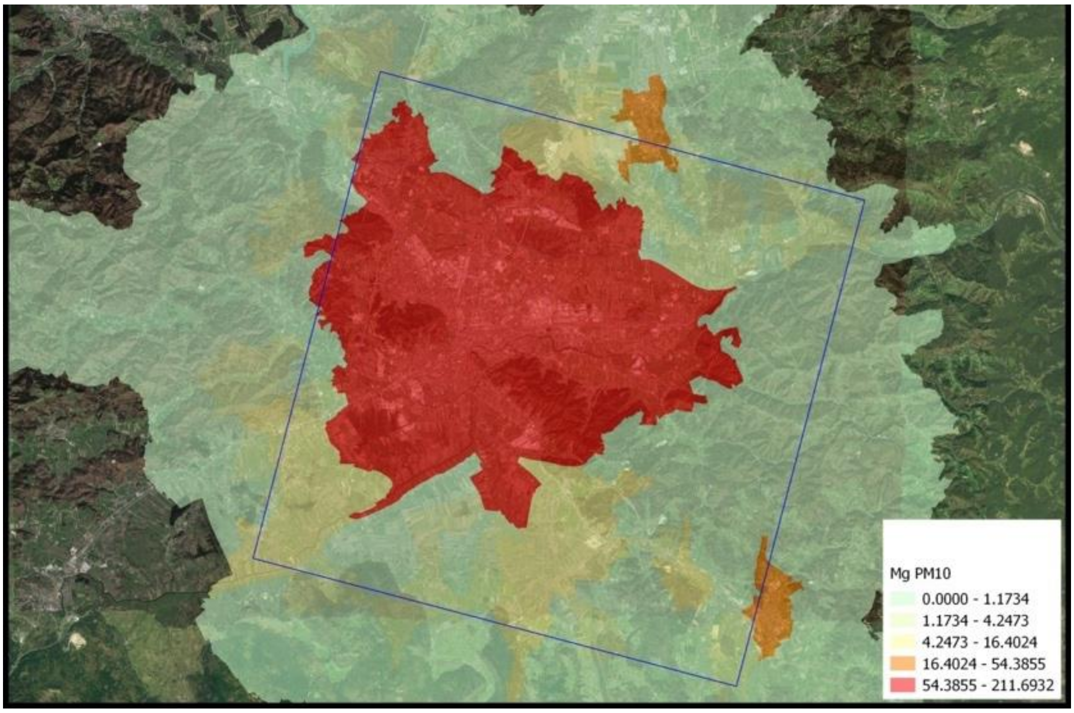


Figure 3-18: Ljubljana Naselje Residential, Commercial & Institutional PM10 emissions – all sectors and fuels.

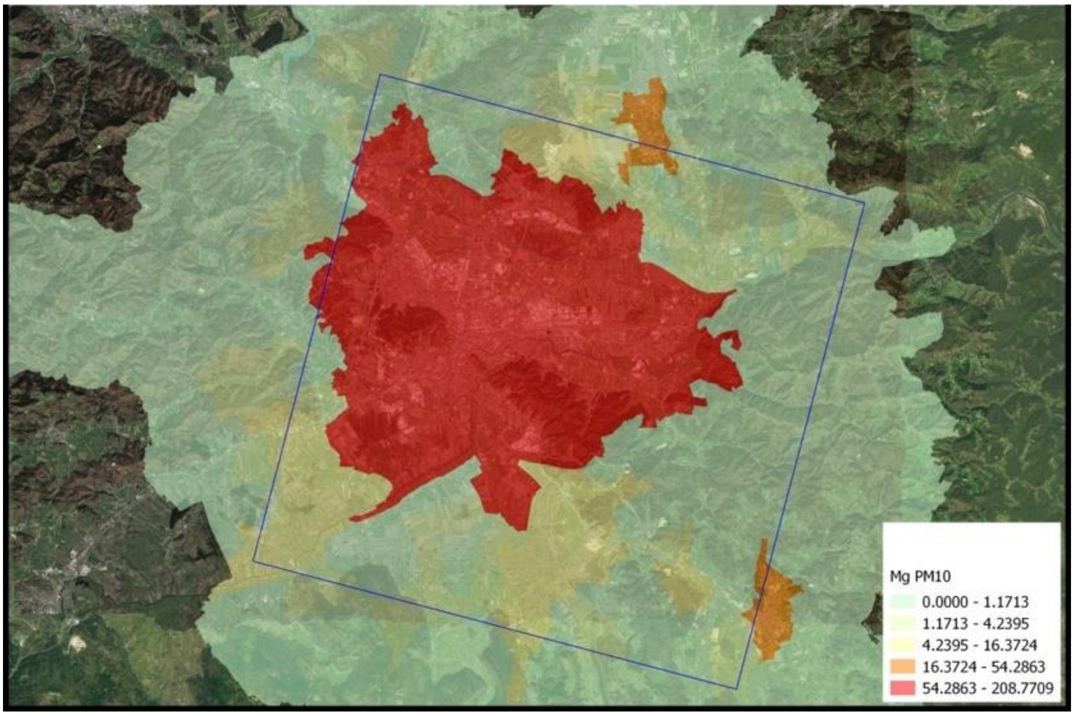


Figure 3-19: Ljubljana Naselje Residential, Commercial & Institutional PM10 emissions – biomass.

Figure 3-20: Ljubljana Industry Sector NOx area emissions.

Figure 3-21: Ljubljana Industry Sector PM10 area emissions.

Figure 3-22: Ljubljana IRC Industry NOx point emissions.

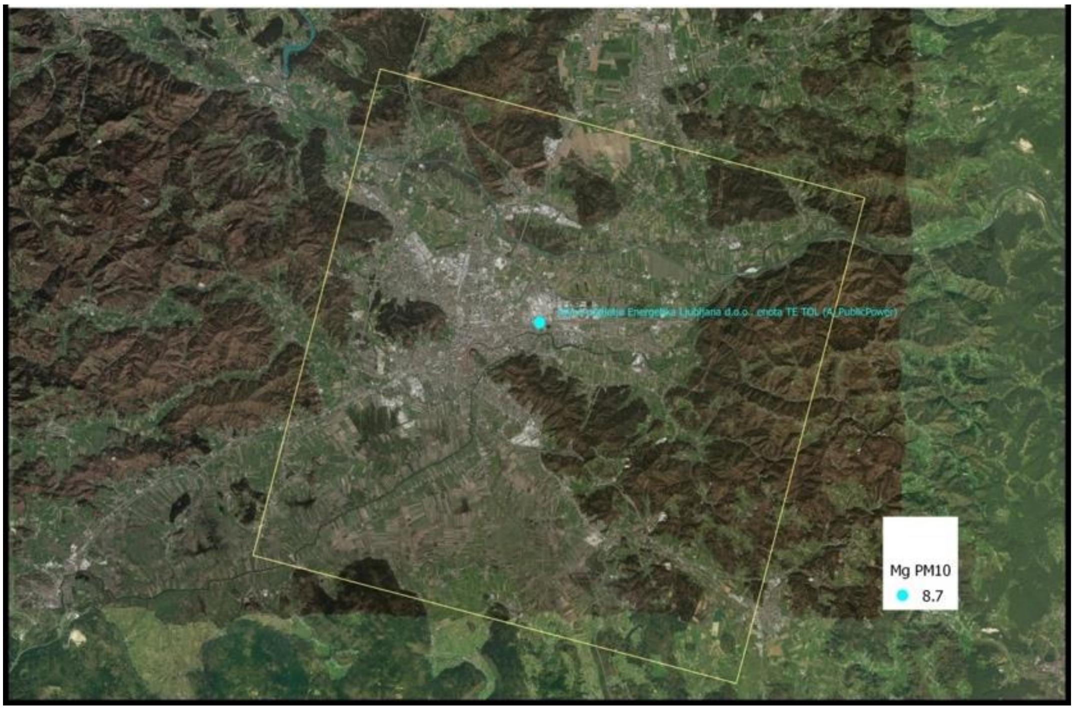


Figure 3-23: Ljubljana IRC Industry PM10 point emissions.

Finally, in the following Figure 3-24 and Figure 3-25 the emissions for the different activities & fuels in the only *Ljubljana Občine* are reported.

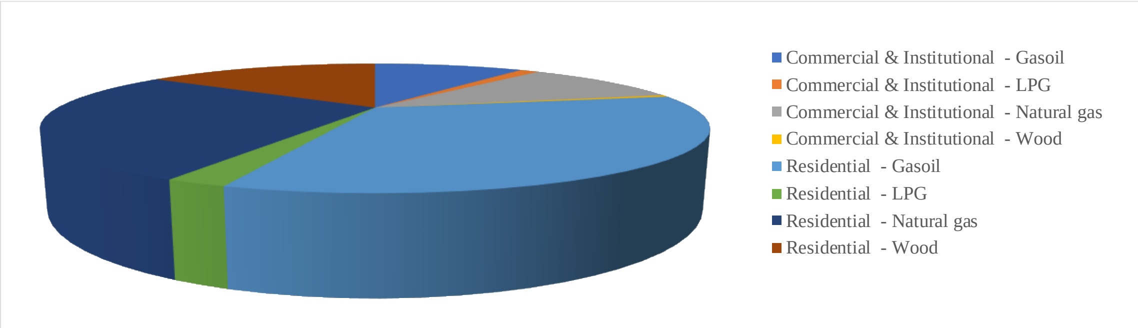


Figure 3-24: Ljubljana Občine Residential, Commercial & Institutional NOx emissions.

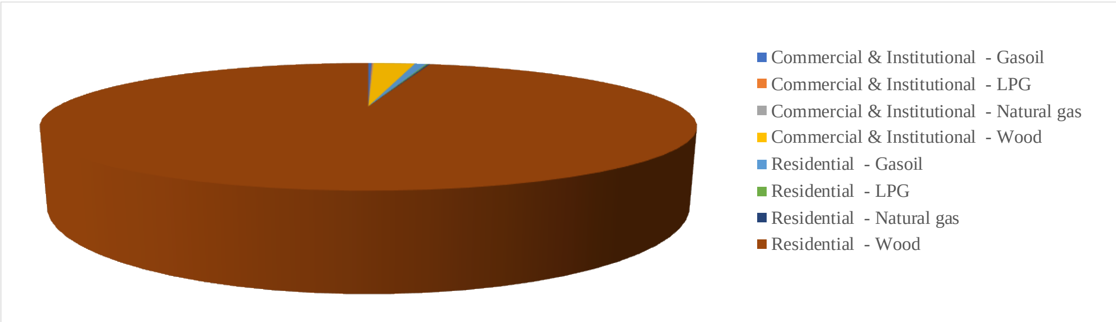


Figure 3-25: Ljubljana Občine Residential, Commercial & Institutional PM10 emissions.

3.3.2 BAU

The evolutions of industrial area emissions are reported in Figure 3-26 for nitrogen oxides (NO_x) and for suspended particles with diameter less than 10µ (PM_{10}). The variation is evaluated as the average variation of industrial emissions in NEC national projection.

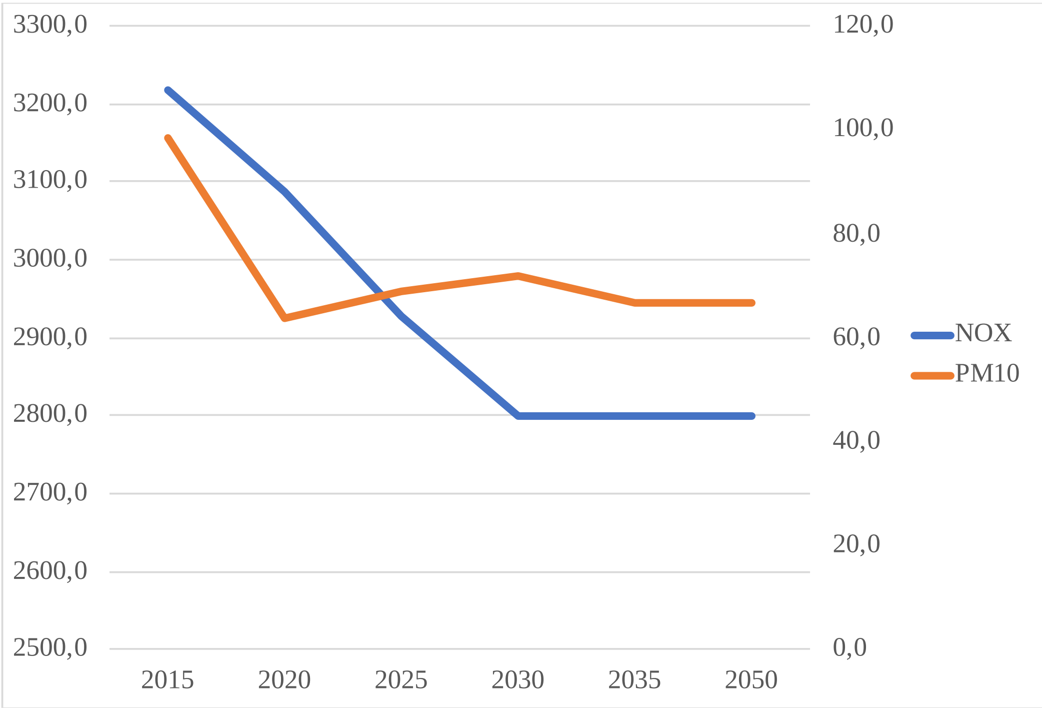


Figure 3-26: Ljubljana BAU Industrial sources NOx and PM10 emissions (Mg).

In Figure 3-27 for nitrogen oxides (NO_x) and in Figure 3-28 for suspended particles with diameter less than 10µ (PM_{10}) the evolutions of the residential, commercial & institutional emissions in Ljubljana are reported.

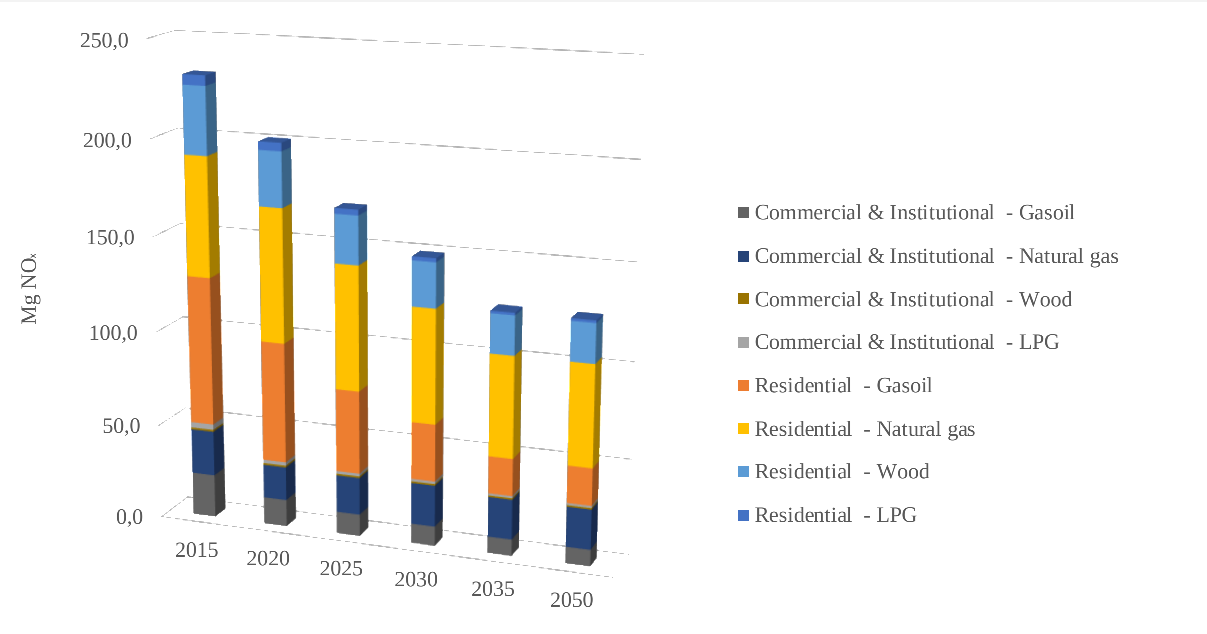


Figure 3-27:Ljubljana BAU total Residential, Commercial & Institutional NOx emissions.

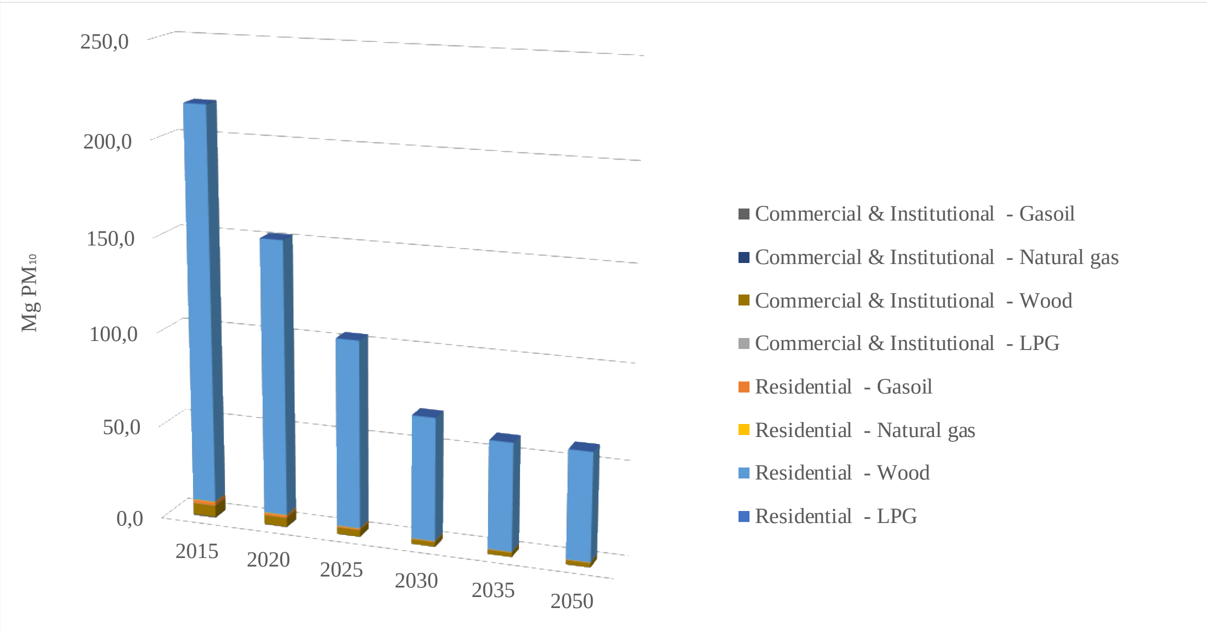


Figure 3-28: Ljubljana BAU Residential, Commercial & Institutional PM10 emissions.

3.3.3 Stakeholder dialog workshop Scenarios

Scenarios from the Stakeholder dialog workshop (SWD) includes no measures relating to the IRCI sector.

3.3.4 Unified Policy Scenario

Unified Policy Scenario includes no measures relating to the IRCI sector.

3.4 Carbon footprint

3.4.1 Baseline

In Table 3-13, the Carbon Footprint by fuel is reported for Ljubljana expressed as CO_2, CO_2 equivalent and CO_2 equivalent on Life Cycle.

Table 3-13: Ljubljana Carbon Footprint by Fuel (Mg).

Energy Vector	CO_2	CO_{2eq}	$CO_{2eq,LCA}$
Biomass	-	863	2.134
Gasoil/diesel	260.000	260.701	297.844
Gasoline	124.496	124.855	156.879
LPG	15.643	15.643	19.362
Natural gas	217.185	217.185	258.221
Industrial wastes	1.260	1.277	1.277
Electricity	672.443	676.084	714.926
Total	**1.291.026**	**1.296.608**	**1.450.643**

In figure below, the Carbon Footprint expressed as CO_2 equivalent on Life Cycle is reported by fuel and sector.

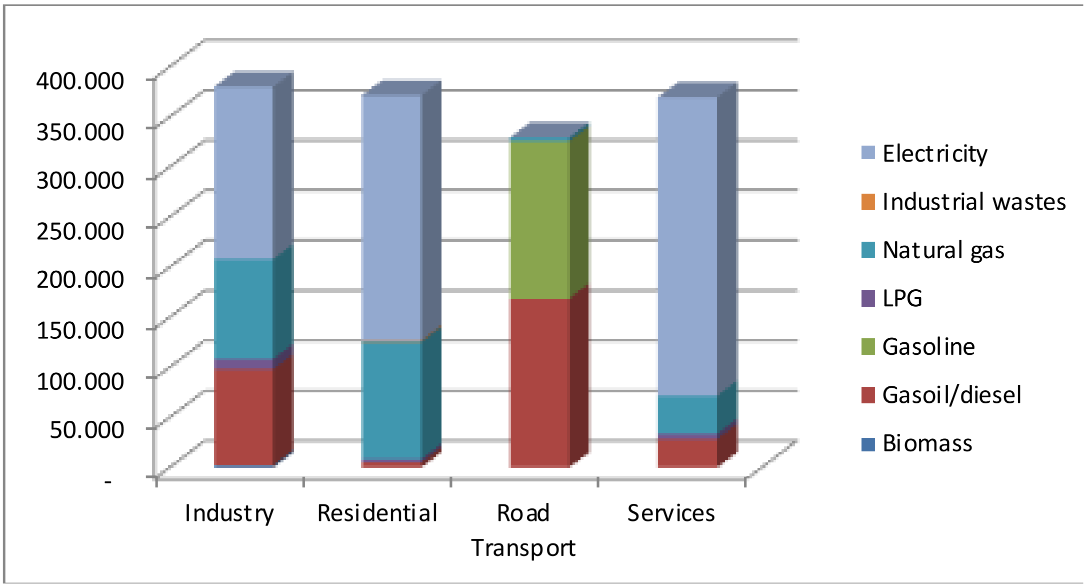


Figure 3-29: Ljubljana Carbon Footprint (Mg CO2 equivalent on Life Cycle).

In the following maps the results for sectors Carbon footprint are finally reported (industry and transport Carbon footprint are allocated only to Ljubljana Občine: In detail are reported:

- Ljubljana Naselje Carbon Footprint for all sectors and fuel (Figure 3-30),
- Ljubljana Naselje Carbon Footprint for Residential sector (Figure 3-31);
- Ljubljana Naselje Carbon Footprint for Services sector (Figure 3-32).

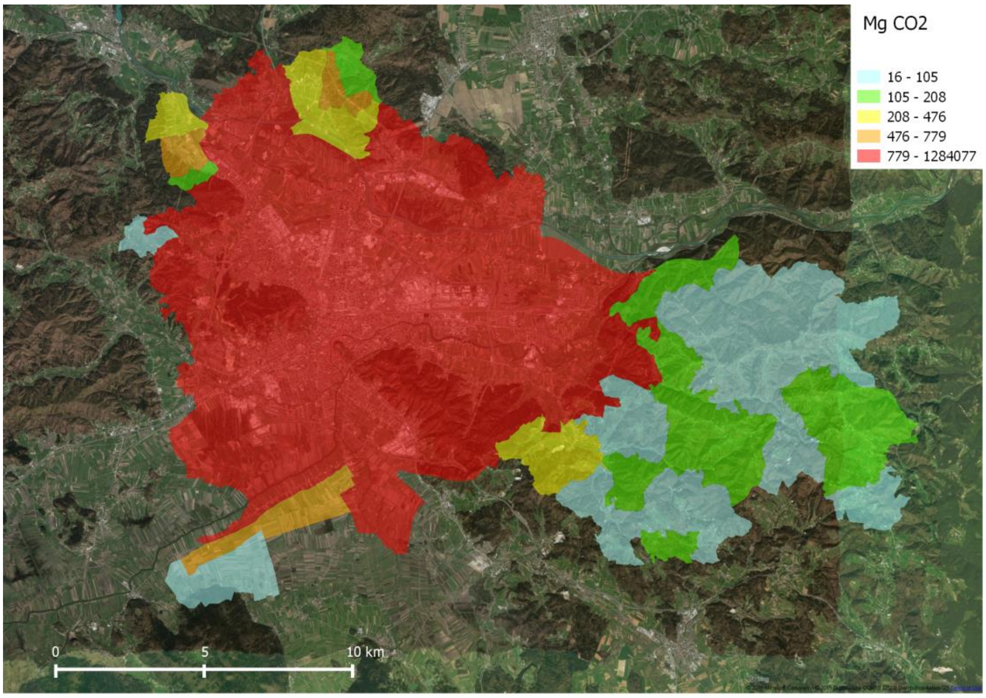


Figure 3-30: Ljubljana Naselje Carbon Footprint – all sectors.

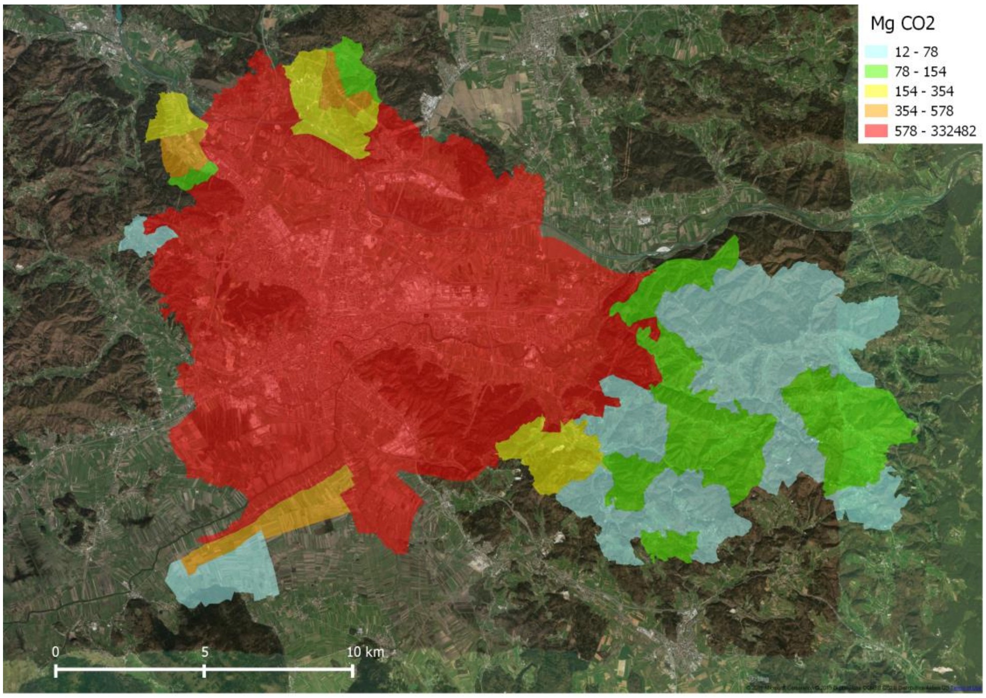


Figure 3-31: Ljubljana Naselje Carbon Footprint – residential sector.

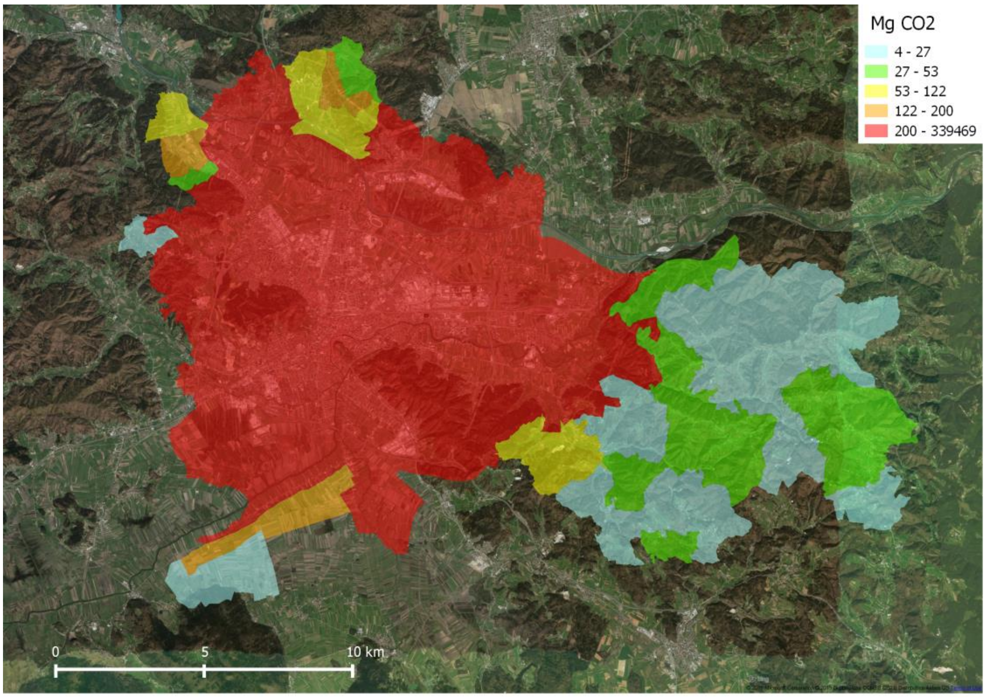


Figure 3-32: Ljubljana Naselje Carbon Footprint – services sector.

3.4.2 BAU

In Table 3-14 Carbon Footprint by sector is reported for Ljubljana BAU expressed as CO_2, CO_2 equivalent and CO_2 equivalent on Life Cycle. In Table 3-15 CO_2 equivalent on Life Cycle reductions on 2015 are reported.

Table 3-14: Ljubljana BAU Carbon Footprint by Sector (Gg).

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide (CO_2)						
Residential	337,6	341,0	295,2	245,9	214,8	214,8
Services	341,3	325,9	291,0	258,8	234,0	234,0
Transport	275,1	280,8	280,3	268,0	255,6	211,8
Industry	337,1	367,4	368,6	363,3	362,3	362,3
Total	***1.291,0***	***1.315,1***	***1.235,0***	***1.136,0***	***1.066,6***	***1.022,8***
Carbon dioxide equivalent (CO_{2eq})						
Industry	339,6	342,8	296,8	247,3	216,0	216,0

Services	342,8	327,5	292,3	259,9	235,0	235,0
Transport	275,8	281,6	281,0	268,7	256,2	212,4
Residential	338,3	368,8	369,9	364,6	363,5	363,5
Total	***1.296,6***	***1.320,6***	***1.240,1***	***1.140,5***	***1.070,7***	***1.026,8***
Carbon dioxide equivalent on life cycle (CO_{2eq})						
Residential	380,0	384,5	333,5	278,2	243,5	243,5
Services	369,6	351,6	314,8	280,8	254,5	254,5
Transport	329,5	336,4	335,7	320,1	304,4	249,9
Industry	371,5	405,0	407,6	403,4	403,6	403,6
Total	***1.450,6***	***1.477,5***	***1.391,6***	***1.282,5***	***1.206,0***	***1.151,5***

Table 3-15: Ljubljana 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	101	88	73	64	64
Services	100	95	85	76	69	69
Transport	100	102	102	97	92	76
Industry	100	109	110	109	109	109
Total	***100***	***102***	***96***	***88***	***83***	***79***

Carbon Footprint, expressed as CO_2 equivalent on Life Cycle, is reported in Figure 3-33 by sector and in Figure 3-34 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.

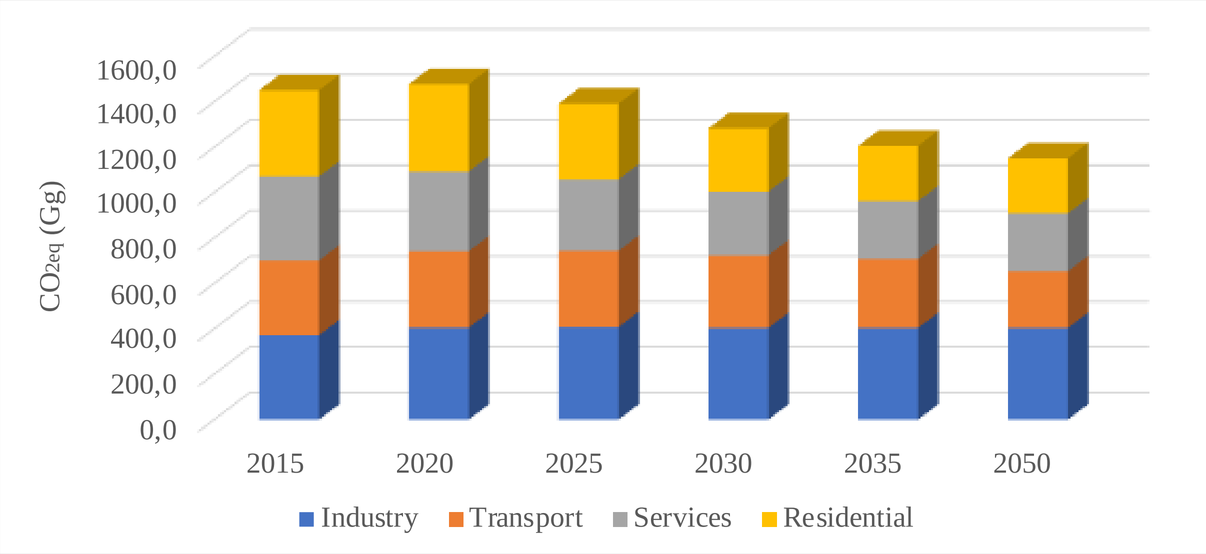


Figure 3-33: Ljubljana BAU Carbon Footprint by sector (Gg CO2 equivalent on Life Cycle).

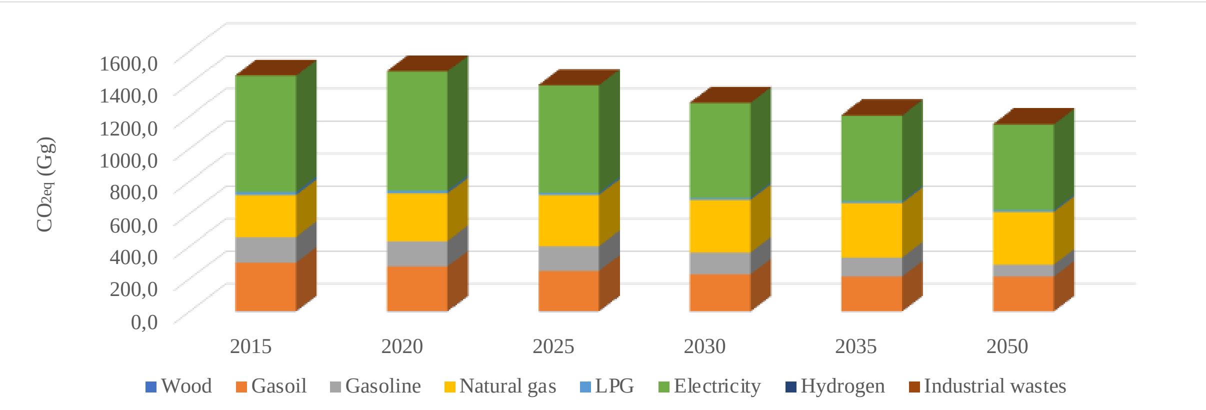


Figure 3-34: Ljubljana BAU Carbon Footprint by fuel (Gg CO2 equivalent on Life Cycle).

3.4.3 Stakeholder dialog workshop Scenarios

In Table 3-16 Carbon Footprint by sector is reported for Ljubljana Scenario *low* expressed as CO_2, CO_2 equivalent and CO_2 equivalent on Life Cycle. In Table 3-17 CO_2 equivalent on Life Cycle reductions on 2015 are reported.

Table 3-16: Ljubljana Scenario low Carbon Footprint by Sector (Gg).

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide (CO_2)						

Residential	337,6	341,0	295,2	245,9	214,8	214,8
Services	341,3	320,3	286,1	252,5	228,4	228,4
Transport	275,1	270,7	261,3	237,5	211,2	118,3
Industry	337,1	367,4	368,6	363,3	362,3	362,3
Total	***1.291,0***	***1.299,4***	***1.211,2***	***1.099,2***	***1.016,6***	***923,7***
Carbon dioxide equivalent (CO_{2eq})						
Residential	339,6	342,8	296,8	247,3	216,0	216,0
Services	342,8	321,8	287,4	253,6	229,4	229,4
Transport	275,8	271,5	262,0	238,1	211,7	118,6
Industry	338,3	368,8	369,9	364,6	363,5	363,5
Total	***1.296,6***	***1.304,9***	***1.216,1***	***1.103,6***	***1.020,6***	***927,4***
Carbon dioxide equivalent on life cycle (CO_{2eq})						
Residential	380,0	384,5	333,5	278,2	243,5	243,5
Services	369,6	345,7	309,6	274,1	248,6	248,6
Transport	329,5	324,4	313,2	284,4	252,6	141,8
Industry	371,5	405,0	407,6	403,4	403,6	403,6
Total	***1.450,6***	***1.459,5***	***1.363,9***	***1.240,1***	***1.148,3***	***1.037,5***

Table 3-17: Ljubljana 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	101	88	73	64	64
Services	100	94	84	74	67	67
Transport	100	98	95	86	77	43
Industry	100	109	110	109	109	109
Total	***100***	***101***	***94***	***85***	***79***	***72***

For the Scenario *low*, Carbon Footprint, expressed as CO_2 equivalent on Life Cycle, is reported in Figure 3-35 by sector and in Figure 3-36 by fuel.

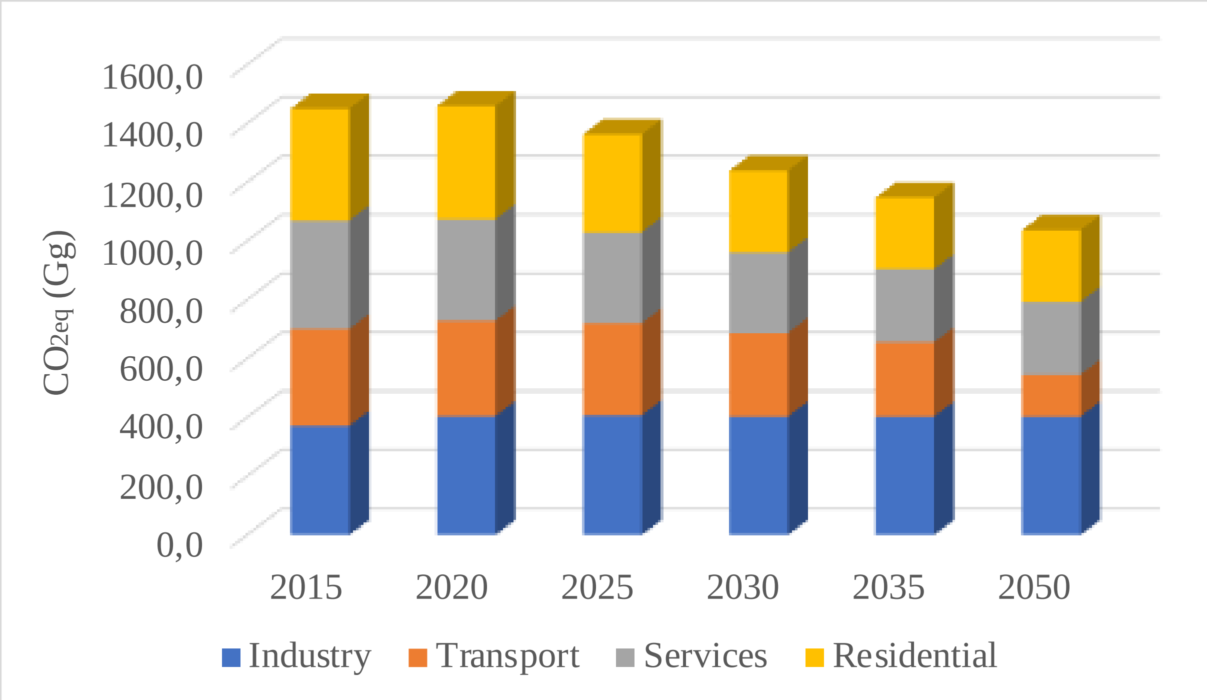


Figure 3-35: Ljubljana Scenario low Carbon Footprint by sector (Gg CO2 equivalent on Life Cycle).

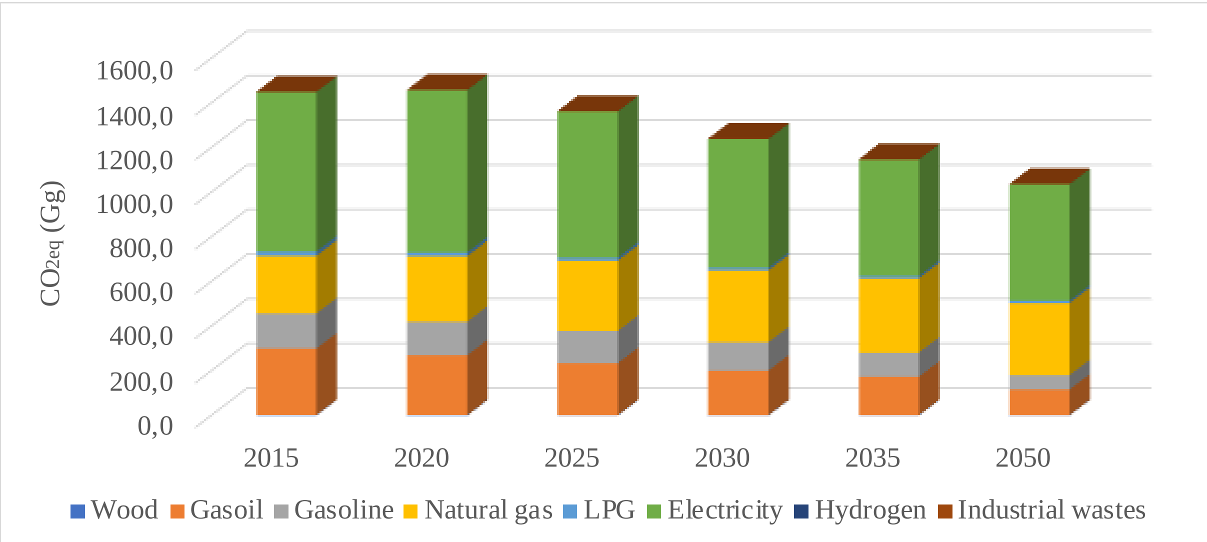


Figure 3-36: Ljubljana Scenario low Carbon Footprint by fuel (Gg CO2 equivalent on Life Cycle).

In Table 3-18 Carbon Footprint by sector is reported for Ljubljana Scenario *high* expressed as CO_2, CO_2 equivalent and CO_2 equivalent on Life Cycle. In Table 3-19 CO_2 equivalent on Life Cycle reductions on 2015 are reported.

Table 3-18: Ljubljana Scenario high Carbon Footprint by Sector (Gg).

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide (CO_2)						
Residential	337,6	341,0	295,2	245,9	214,8	214,8
Services	341,3	320,3	286,1	252,5	228,4	228,4
Transport	275,1	265,1	247,5	220,8	193,9	114,8
Industry	337,1	367,4	368,6	363,3	362,3	362,3
Total	***1.291,0***	***1.293,7***	***1.197,4***	***1.082,5***	***999,4***	***920,2***
Carbon dioxide equivalent (CO_{2eq})						
Residential	339,6	342,8	296,8	247,3	216,0	216,0
Services	342,8	321,8	287,4	253,6	229,4	229,4
Transport	275,8	265,8	248,2	221,4	194,4	115,1
Industry	338,3	368,8	369,9	364,6	363,5	363,5
Total	***1.296,6***	***1.299,2***	***1.202,3***	***1.086,8***	***1.003,3***	***924,0***
Carbon dioxide equivalent on life cycle (CO_{2eq})						
Residential	380,0	384,5	333,5	278,2	243,5	243,5
Services	369,6	345,7	309,6	274,1	248,6	248,6
Transport	329,5	317,6	296,7	264,2	231,8	137,5
Industry	371,5	405,0	407,6	403,4	403,6	403,6
Total	***1.450,6***	***1.452,7***	***1.347,3***	***1.219,9***	***1.127,4***	***1.033,2***

Table 3-19: Ljubljana 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	101	88	73	64	64
Services	100	94	84	74	67	67

Transport	100	96	90	80	70	42
Industry	100	109	110	109	109	109
Total	***100***	***100***	***93***	***84***	***78***	***71***

For the Scenario *high*, Carbon Footprint, expressed as CO_2 equivalent on Life Cycle, is reported in Figure 3-37 by sector and in Figure 3-38 by fuel.

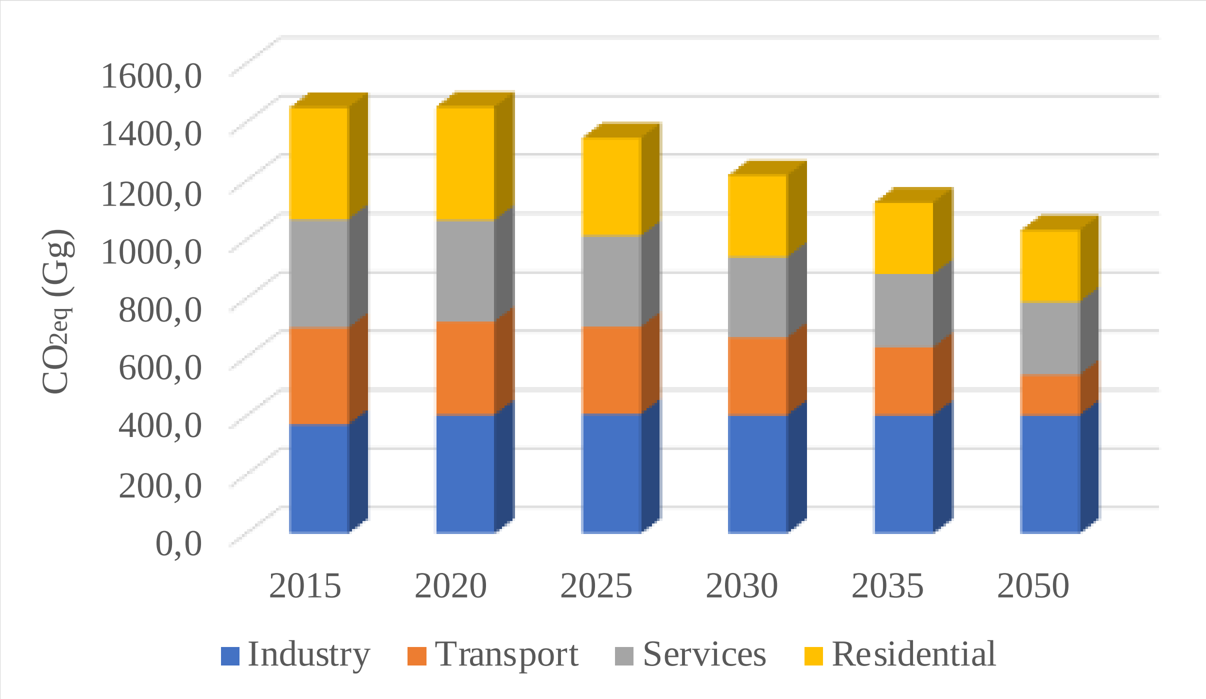


Figure 3-37: Ljubljana Scenario high Carbon Footprint by sector (Gg CO2 equivalent on Life Cycle).

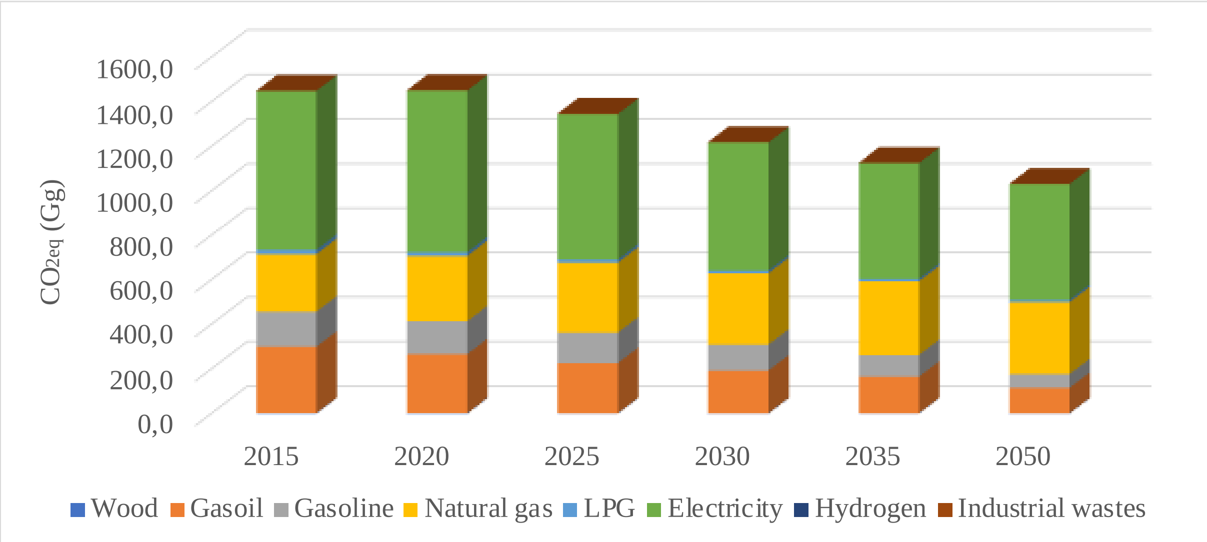


Figure 3-38: Ljubljana Scenario high Carbon Footprint by fuel (Gg CO2 equivalent on Life Cycle).

Total Carbon Footprint in the different scenarios is compared in Figure 3-39 expressed as CO_2 equivalent on Life Cycle.

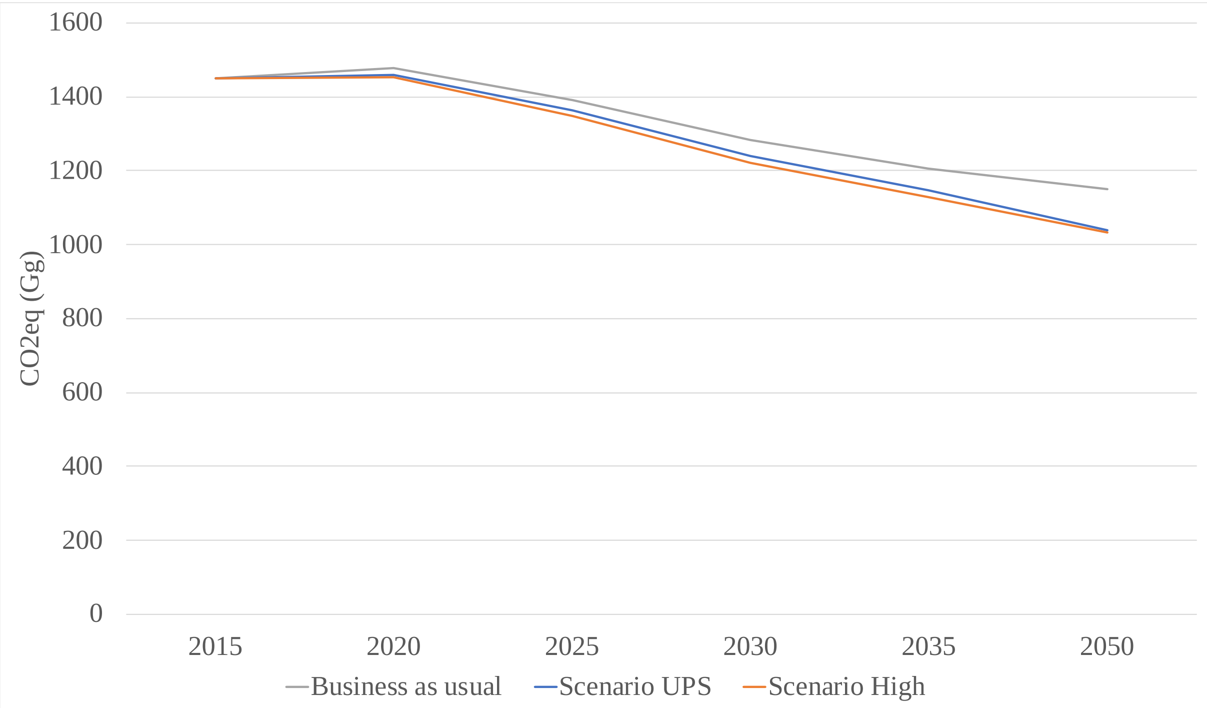


Figure 3-39: Ljubljana Carbon Footprint (Mg CO2 equivalent on Life cycle) by scenario.

3.4.4 Unified Policy Scenario

In Table 3-20 Carbon Footprint by sector is reported for Ljubljana Unified Policy Scenario expressed as CO_2, CO_2 equivalent and CO_2 equivalent on Life Cycle. In Table 3-21 CO_2 equivalent on Life Cycle reductions on 2015 are reported.

Table 3-20: Ljubljana Unified Policy Scenario Carbon Footprint by Sector (Gg).

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide (CO_2)						
Residential	337,6	341,0	295,2	245,9	214,8	214,8
Services	341,3	325,9	291,0	258,8	234,0	234,0
Transport	275,1	273,3	264,0	235,0	204,6	115,3
Industry	337,1	367,4	368,6	363,3	362,3	362,3
Total	***1.291,0***	***1.307,6***	***1.218,8***	***1.103,0***	***1.015,6***	***926,3***
Carbon dioxide equivalent (CO_{2eq})						
Residential	339,6	342,8	296,8	247,3	216,0	216,0
Services	342,8	327,5	292,3	259,9	235,0	235,0
Transport	275,8	274,1	264,7	235,6	205,1	115,6
Industry	338,3	368,8	369,9	364,6	363,5	363,5
Total	***1.296,6***	***1.313,1***	***1.223,7***	***1.107,4***	***1.019,6***	***930,1***
Carbon dioxide equivalent on life cycle (CO_{2eq})						
Residential	380,0	384,5	333,5	278,2	243,5	243,5
Services	369,6	351,6	314,8	280,8	254,5	254,5
Transport	329,5	327,5	316,5	281,4	244,6	138,3
Industry	371,5	405,0	407,6	403,4	403,6	403,6
Total	***1.450,6***	***1.468,6***	***1.372,4***	***1.243,8***	***1.146,2***	***1.039,9***

Table 3-21: Ljubljana 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	101	88	73	64	64
Services	100	95	85	76	69	69
Transport	100	99	96	85	74	42
Industry	100	109	110	109	109	109
Total	***100***	***101***	***95***	***86***	***79***	***72***

Unified Policy Scenario, 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.

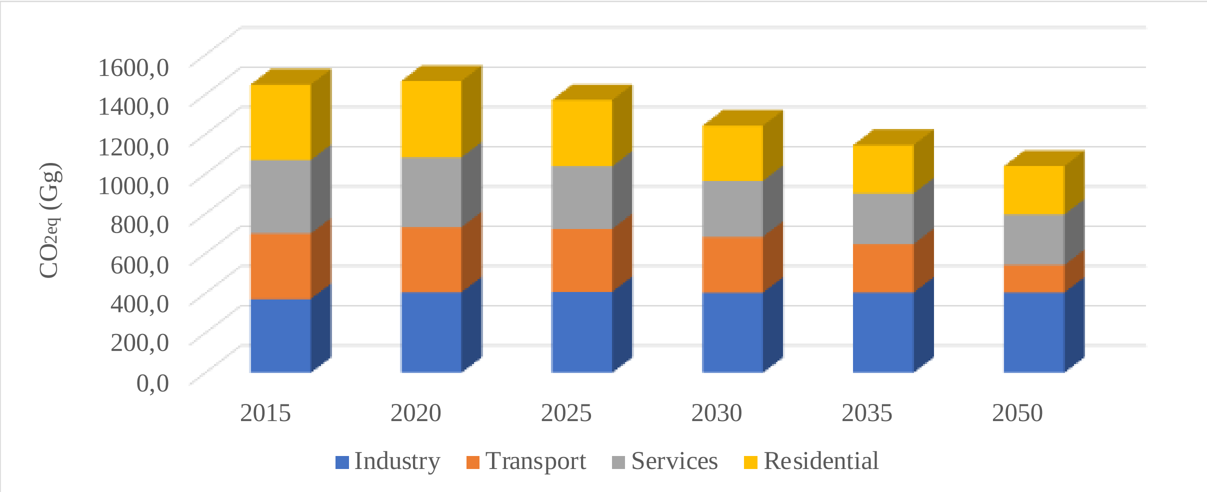


Figure 3-40: Ljubljana Unified Policy Scenario Carbon Footprint by sector (Gg CO2 equivalent on Life Cycle).

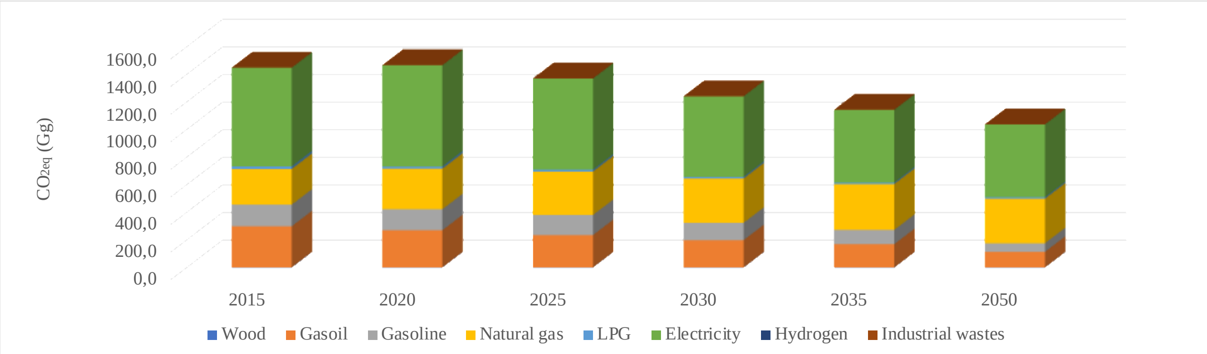


Figure 3-41: Ljubljana Unified Policy Scenario Carbon Footprint by fuel (Gg CO2 equivalent on Life Cycle).

Total Carbon Footprint in the business as usual (BAU) and unified policy scenario (UPS) is compared in Figure 3-42 expressed as CO_2 equivalent on Life Cycle.

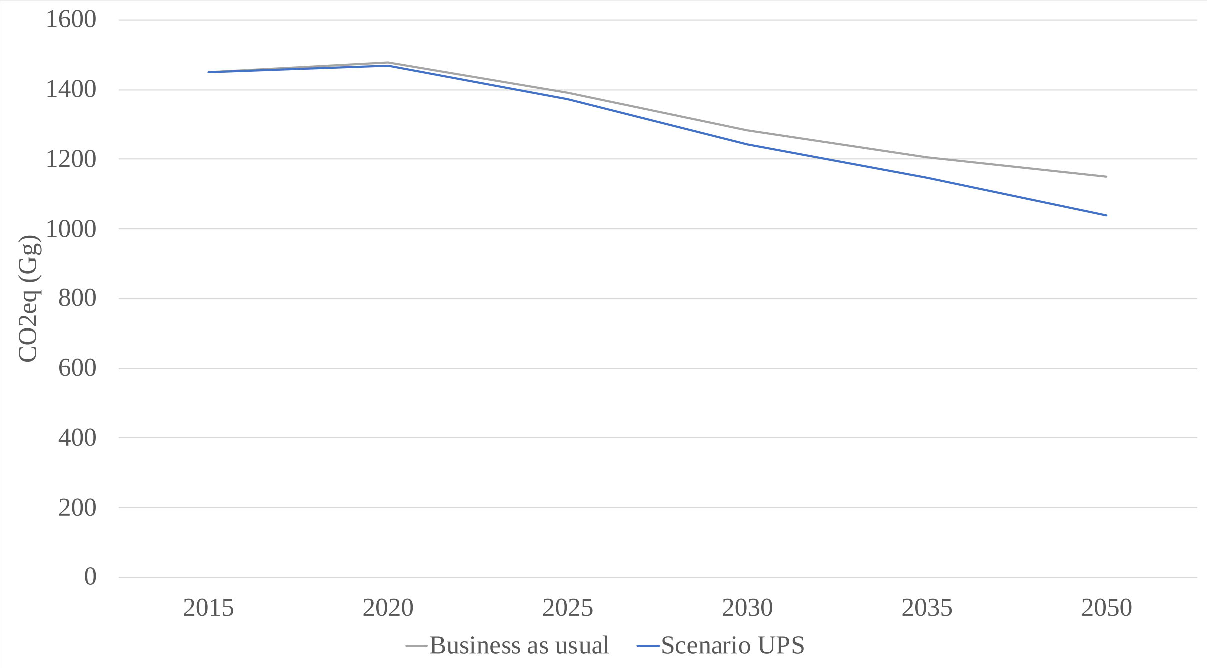


Figure 3-42: Ljubljana Carbon Footprint (Mg CO2 equivalent on Life cycle) by scenario.

In Figure 3-43 results are reported by sector and in Figure 3-44 by sector and fuel. Finally, in Figure 3-45 Carbon Footprint on life cycle generated by citizens' activities is reported in BAU and UPS scenario.

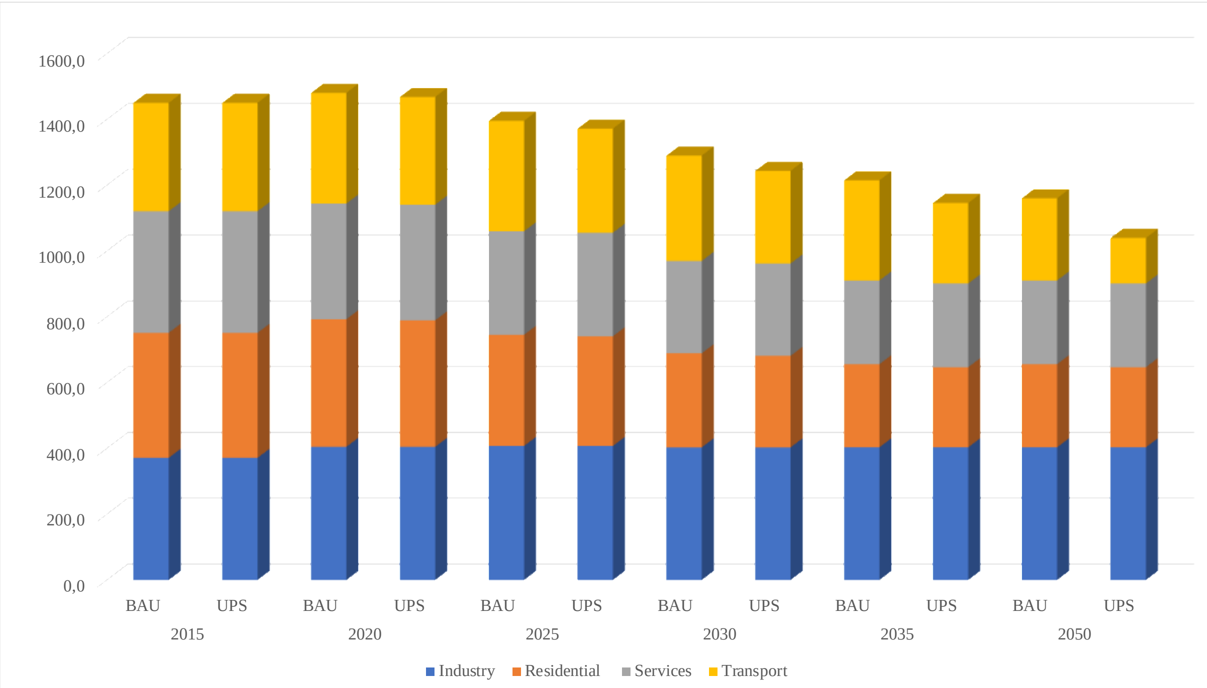


Figure 3-43: Ljubljana Carbon Footprint on life cycle BAU and UPS comparison by sector (Mg CO2 equivalent).

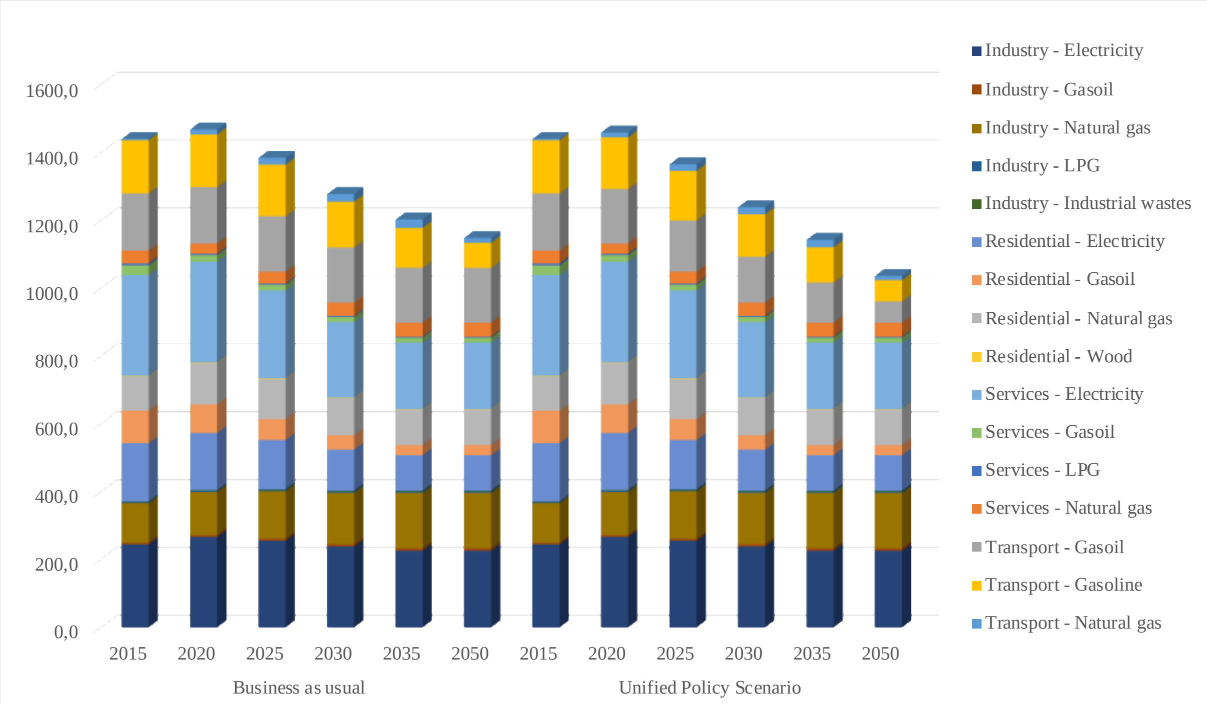


Figure 3-44: Ljubljana Carbon Footprint on life cycle BAU and UPS comparison by sector and fuel (Mg CO2 equivalent).

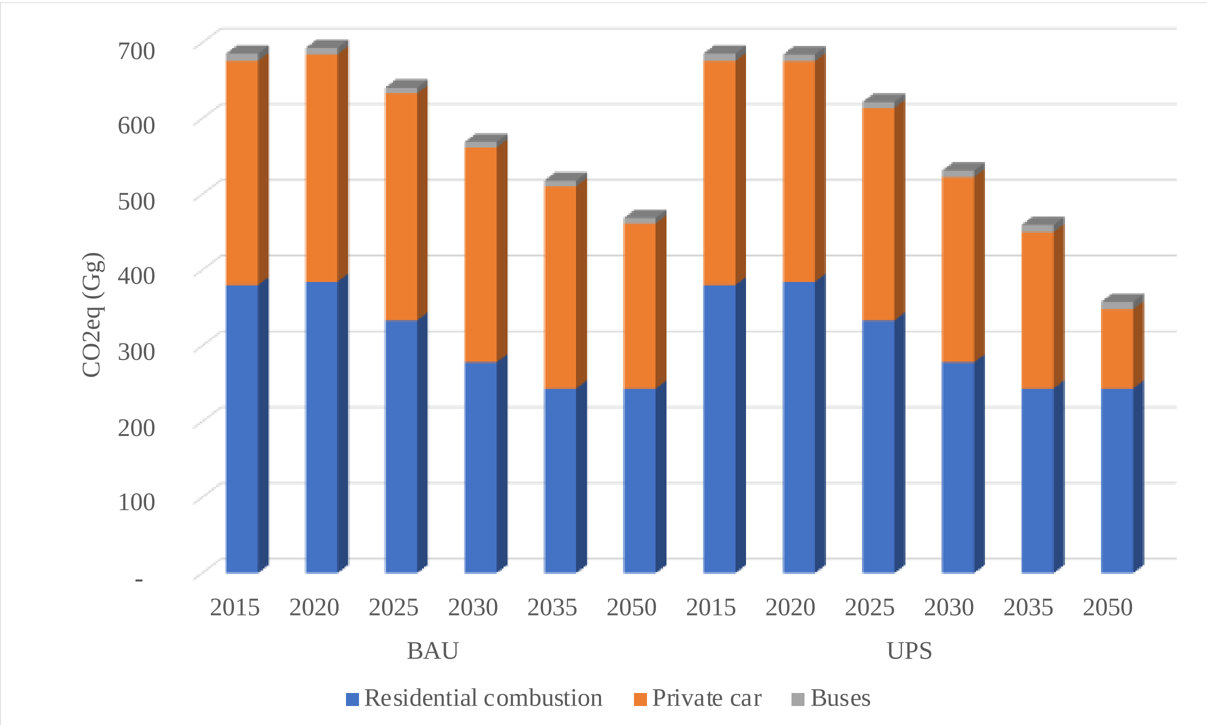
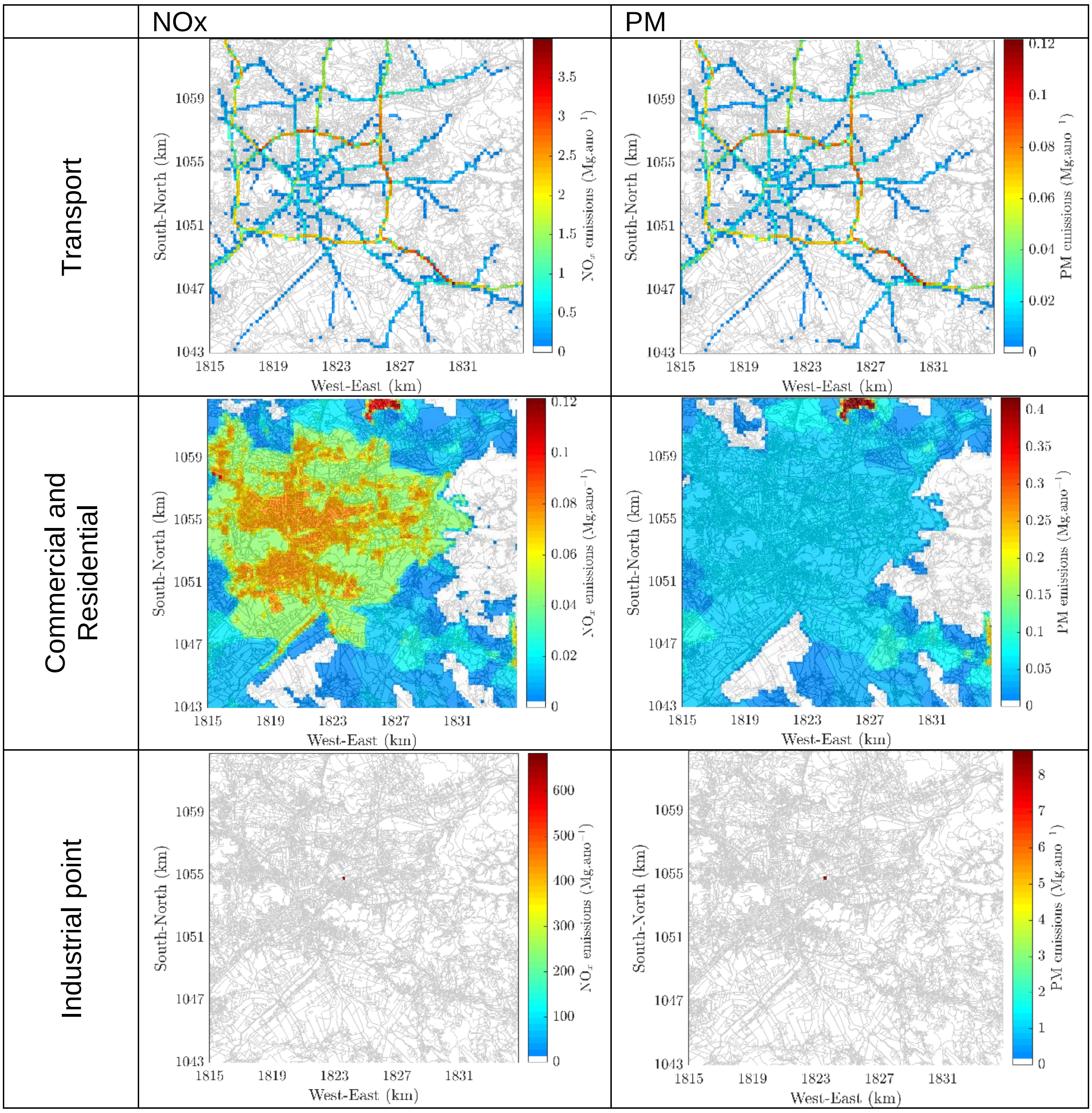


Figure 3-45: Ljubljana Carbon Footprint on life cycle generated by citizens' activities in BAU and UPS scenario (Mg CO2 equivalent).

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 3-46 shows the emission values for NO_x and PM in $Mg.year^{-1}$ for each sector.



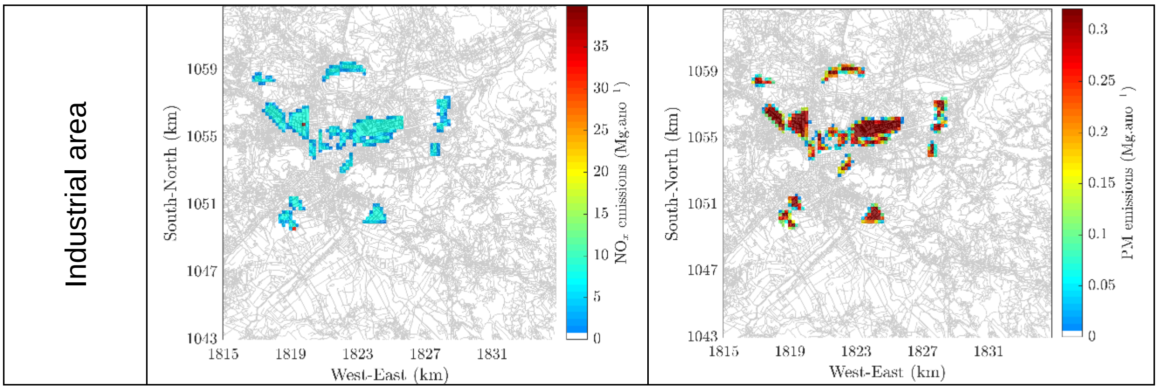


Figure 3-46: Emission values for NOx and PM by sector, in Mg.year^{-1}.

3.5.2 Assessment of air quality at mesoscale: baseline year

The meteorological characterization in Ljubljana, at 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 3-47.

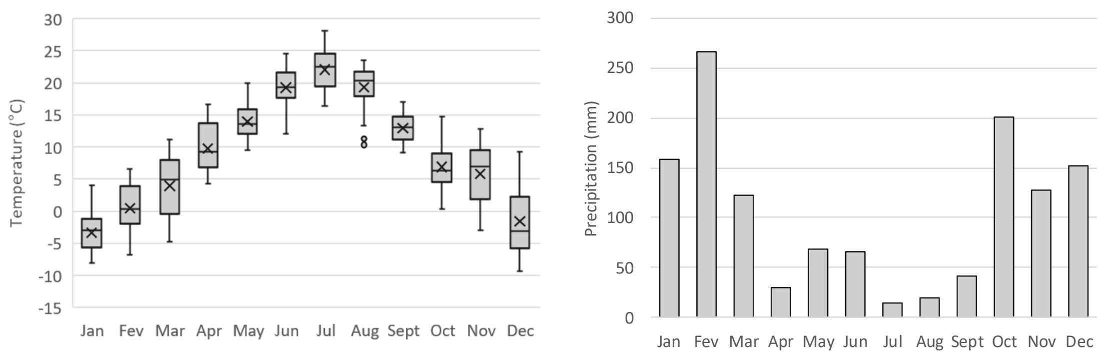


Figure 3-47: (Left) Box and whisker plot of temperature by month; boxes indicate the lower and upper quartile; horizontal line in each box represents the median temperature; the mean temperature for each month is indicated by a x; vertical lines extending from each

According to Figure 3-47**Error! Reference source not found.**, in Ljubljana, the minimum mean temperatures are obtained in January, December and February, with -3.4°C, -1.6°C and 0.5°C, respectively. The month where the highest mean temperature is recorded is July, with 22.1°C, followed by June and August, with 19.3°C. Regarding precipitation, the months with the highest accumulated precipitation go from October to March (with values from 120 to 260 mm), while the driest month is July with 16 mm. During almost the whole year, the prevailing wind blows from the 1st (NE) and 3rd (SW) quadrants, with a wind speed up to 8 m.s^{-1}.

The air quality characterization in Ljubljana, 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 3-48).

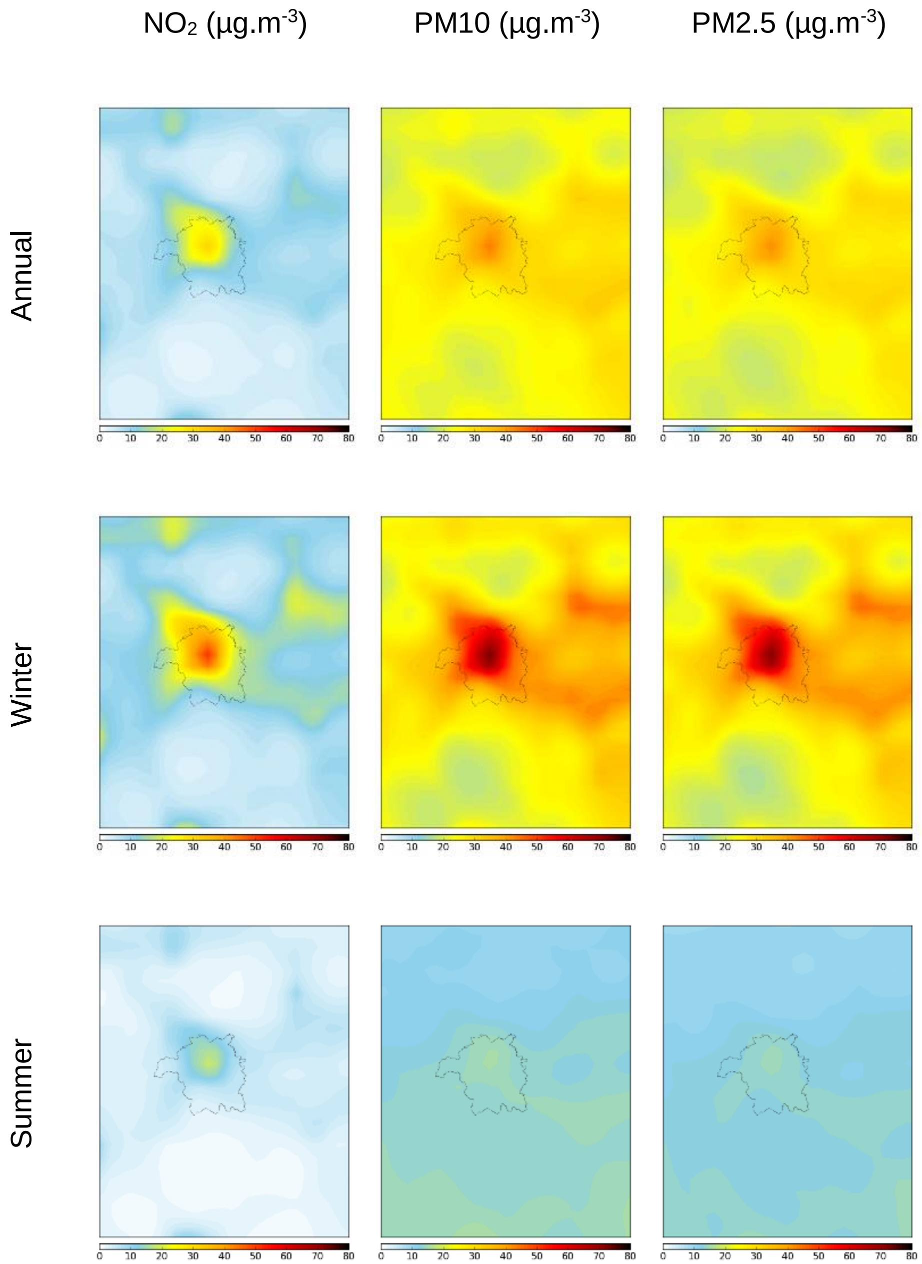


Figure 3-48: Spatial distribution of NO_2, PM10 and PM2.5 concentrations, for the different periods analysed (annual, winter and summer) in Ljubljana.

For each pollutant, NO_2, PM10 and PM2.5, results presented in Figure 3-48 show similar spatial patterns for the different periods and pollutants analysed. For all pollutants, the highest concentration values are found in Ljubljana municipality area.

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 35 µg.m^{-3}, 57 µg.m^{-3} and 21 µg.m^{-3}, respectively. For PM10, the maximum concentration values are close to 44 µg.m^{-3}, for the annual average, 73 µg.m^{-3} in winter and 21 µg.m^{-3} in summer. For PM2.5, the highest concentration values are 42 µg.m^{-3}, 72 µg.m^{-3} and 15 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 Ljubljana, 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 Ljubljana for the three periods previously defined, are analysed in Figure 3-49.

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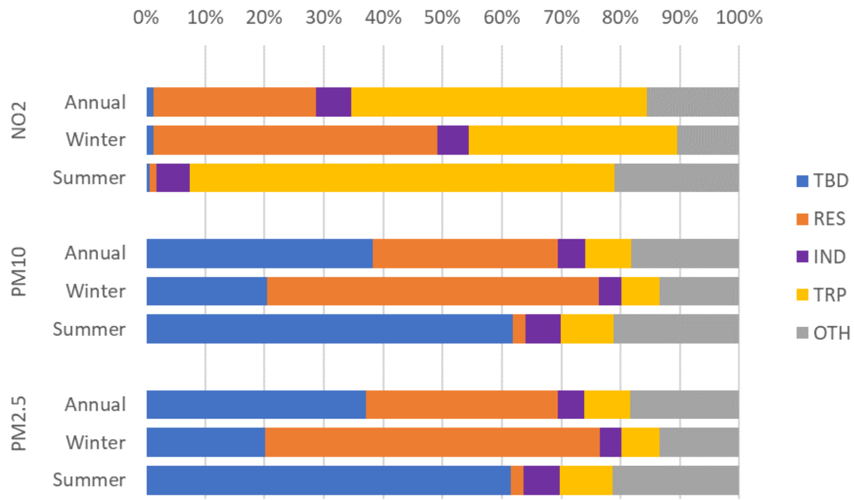


Figure 3-49: Annual, winter and summer averages contribution for each source group for NO_2, PM10 and PM2.5 concentrations, for Ljubljana urban area; (TBD- transboundary transport, RES - residential and commercial combustion, IND - industrial combustion and processes.

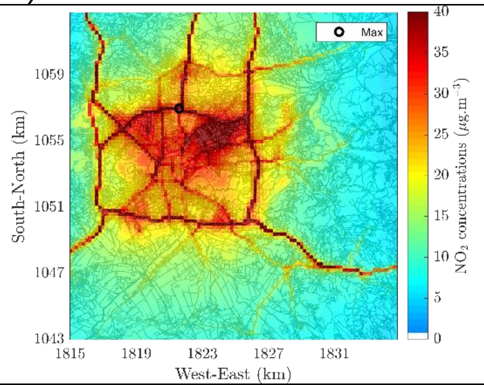
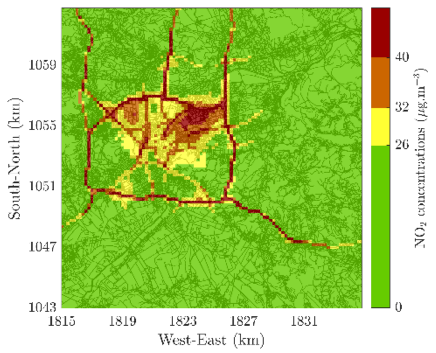
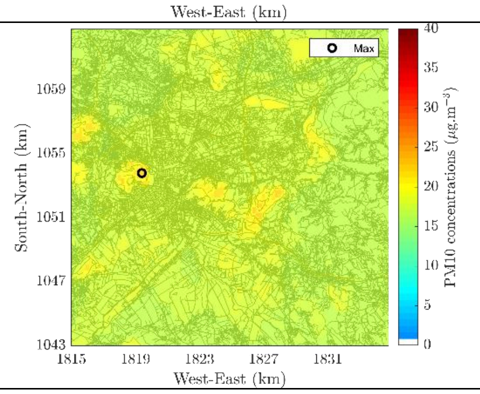
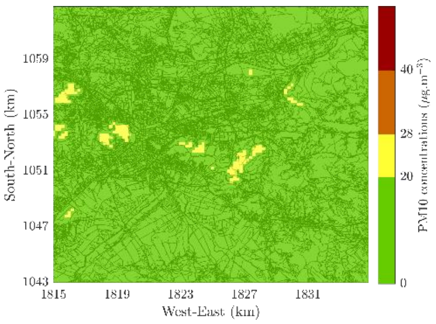
The average annual contributions of each source group reveal that, for NO_2, the largest contribution is from TRP, followed by RES. RES presents higher values in the winter (about 50%), while TRP show maximum contribution during summer (about 70%).

For PM10, the annual average contributions of each source group reveal that one of the major contributions is from TBD (38%), 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 62%. Source contribution results also point to a great influence of the contribution of different human activities, such as residential and commercial combustion and road transport, to the PM10 levels, with the residential commercial combustion being higher in the winter period and the road transport in the summer period. For PM2.5, the analysis is similar to 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 3-50 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		
PM_{10} concentrations		

PM2.5 concentrations

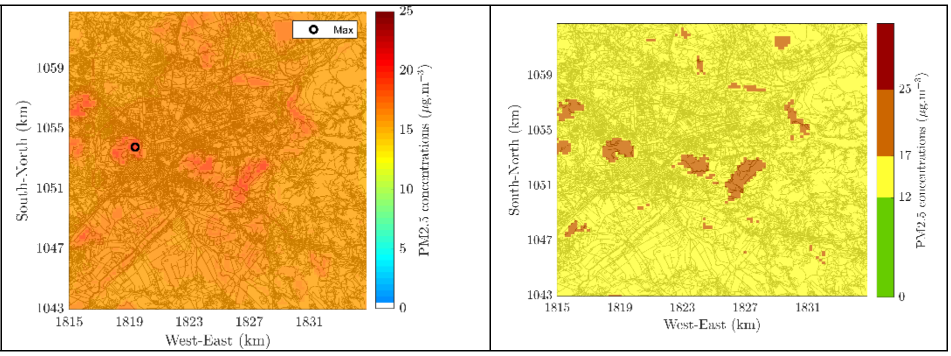


Figure 3-50: Annual average of the NO2, PM10 and PM2.5 concentrations, including the background concentrations and the adjustment factor. a) using a standard color scheme, and b) using a customized color scheme based on the EC assessment thresholds.

The maximum value of the annual NO_2 concentrations in 2015 is equal to 76.8 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 80.7, followed by the industrial sector with a contribution of 17.0%, and the sector the residential and commercial with a contribution of 2.3 %. These contributions are obtained from the source apportionment analysis. The average value of the NO_2 concentrations over the entire domain is equal to 15.9 and the source apportionment analysis indicates that transport is contributing with 43.5%, industrial sector with 46.6% and the residential and commercial sector with 9.9% to the simulated concentrations.

The maximum value of the annual PM_{10} concentrations in 2015 is equal to 22.7 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 1.2% from transport sector, 2.3% from the industrial and 96.5% from the residential and commercial sector. The average value over the entire domain is equal to 17.4 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 6.0%, industrial sector with 5.7% and the residential and commercial sector with 88.3%.

The maximum value of the annual $PM_{2.5}$ concentrations in 2015 is equal to 19.5 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 0.6% from transport sector, 2.3% from the industrial and 97.1% from the residential and commercial sector. The average value over the entire domain is equal to 15.9 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 3.1%, industrial sector with 5.9% and the residential and commercial sector with 91.0%.

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 3-51 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.

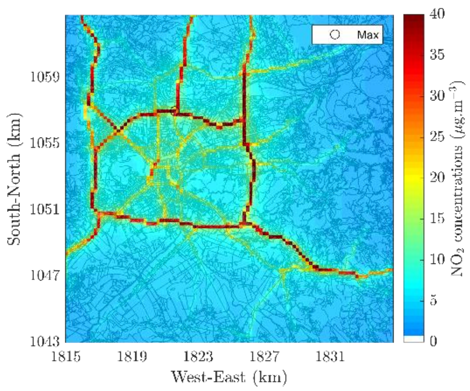
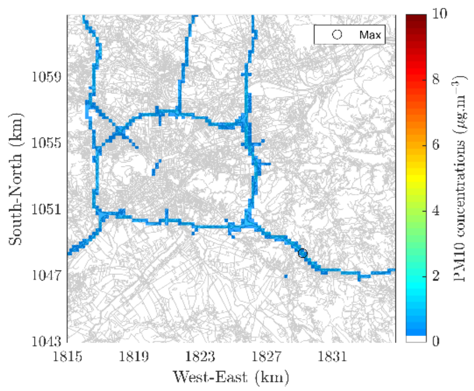
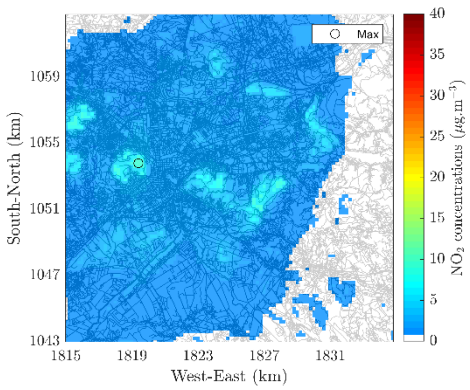
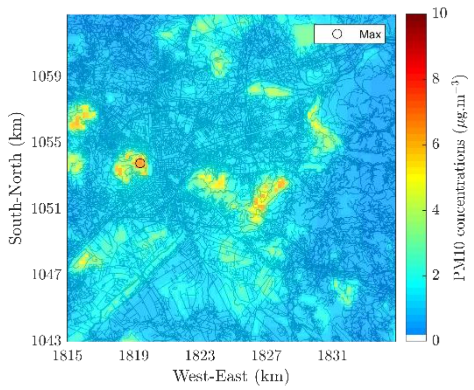
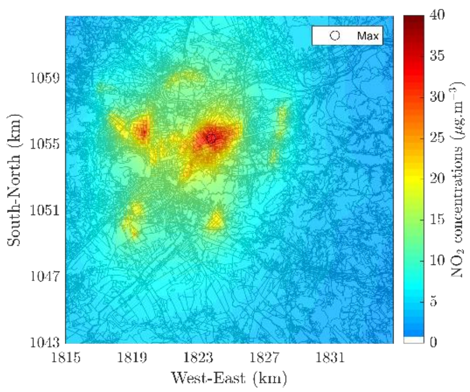
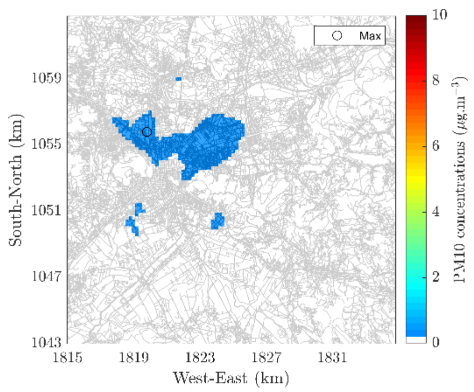
	NO$_2$ concentrations	PM$_{10}$ concentrations
Transport sector		
Commercial and Residential sector		
Industrial sector		

Figure 3-51: 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 0.99 µg.m^{-3} and for $PM_{2.5}$ is 0.33 µg.m^{-3}.

The final air quality results are then compared with the measuring data. As previously explained, the adjustment factor is calculated by a linear regression between the measurements and the simulation concentrations. Since for NO_2, for the year of 2015, only measured data from an urban background monitoring station was available, the measured and simulated value is the same. For NO_2 the measured/simulated value for that point is 29.7. The SA analysis indicates a major contribution from the industrial sector (60.7%), followed by transport sector with 31.7% and commercial and residential sector with a contribution of 7.6%.

Table 3-22 presents the comparison between the measurements and the simulated concentrations (with the background concentrations and the adjustment factor) for all the monitoring sites and the sector contribution for each location.

Table 3-22: Comparison between the measurements and the simulated NO2 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 (%)**		
ID	Station type	Measurement	Simulated	Transport sector	Industrial sector	Com. and Res. Sector
SI0003A	Urban background	27.9	17.3	5.9	15.1	79.0
SI0058A	Urban background	27.4	17.6	4.5	6.7	88.9

For $PM_{2.5}$, for the year of 2015, there was only one monitoring station. For PM_{10} and $PM_{2.5}$, based on the SA analysis, the major contribution comes from the commercial and residential sector.

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 3-52 shows the population exposure to NO_2, PM_{10} and $PM_{2.5}$ baseline concentration values.

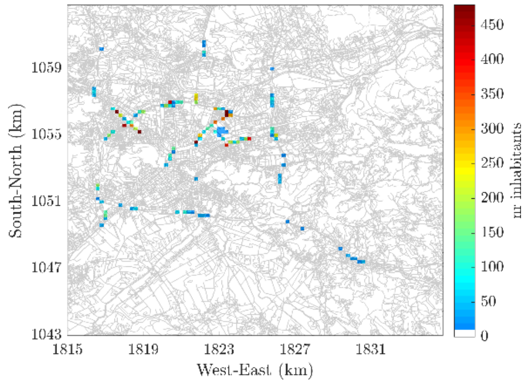
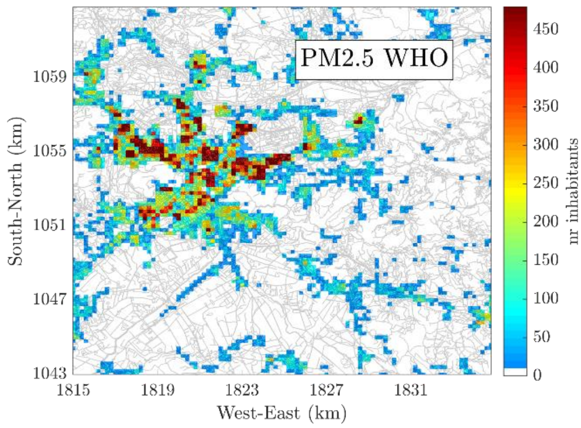
<table>
<tr><th></th><th>EU annual limit value</th><th>WHO guideline value</th></tr>
<tr><td>NO₂ concentrations</td><td colspan="2"></td></tr>
<tr><td>PM₁₀ concentrations</td><td>There are no exceedances to the EU limits</td><td></td></tr>
<tr><td>PM₂.₅ concentrations</td><td>There are no exceedances to the EU limits</td><td></td></tr>
</table>

Figure 3-52: 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 Ljubljana, the NO_2 annual limits are exceeded in 304 cells corresponding to 5% of the total population within the urban area 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}. For PM_{10} and $PM_{2.5}$ concentration maps for the baseline point out no exceedances to the EU legal limit values, although for the WHO guidelines the annual concentrations indicate exceedances to the limit values. For PM_{10}, 147 cells are exceeding the guideline value but only 2 cells have inhabitants allocated to those cells, which represents 0.04% of the population within the simulation area potentially affected. For $PM_{2.5}$, 100% of the population within the simulation area are potentially exposed to those concentrations.

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 3-53 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 53.8 µg.m^{-3} in 2025 and to 32.9 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 35.0% and 80.8%, when compared to the baseline.

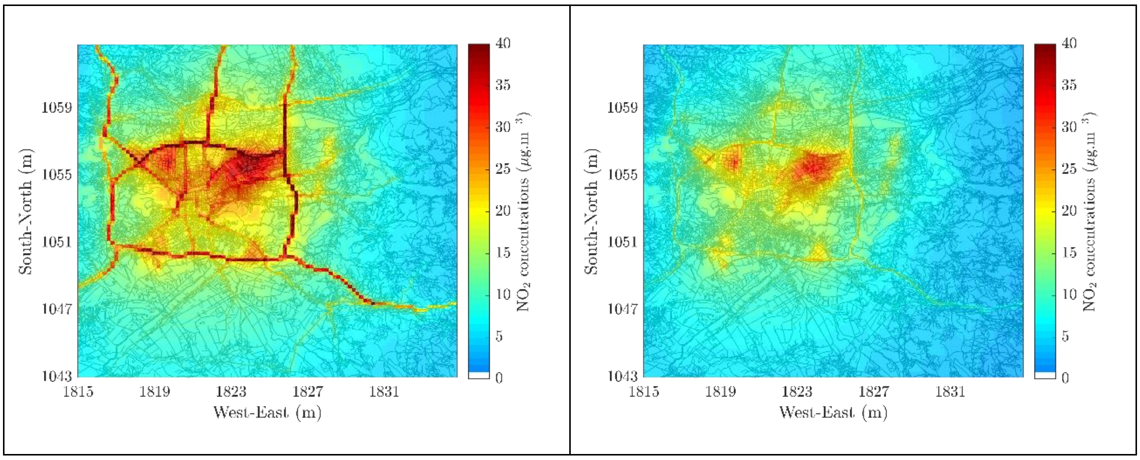


Figure 3-53: NO_2 annual average concentrations in the BAU scenario a) in 2025 and b) in 2050.

Figure 3-54 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 24.4 µg.m^{-3} of the NO_2 concentrations in 2025, corresponding to a reduction of 35.0%, while the spatial average over the entire the domain will reduce 3.6 µg.m^{-3} of NO_2 concentrations, which corresponds to a reduction of 22.3%. In 2050 the BAU scenario will lead to a maximum reduction of the NO_2 concentrations of 55.4 µg.m^{-3} which corresponds to a reduction of 80.8%, while the average over the entire domain will reduce 7.4 µg.m^{-3} (45.3%).

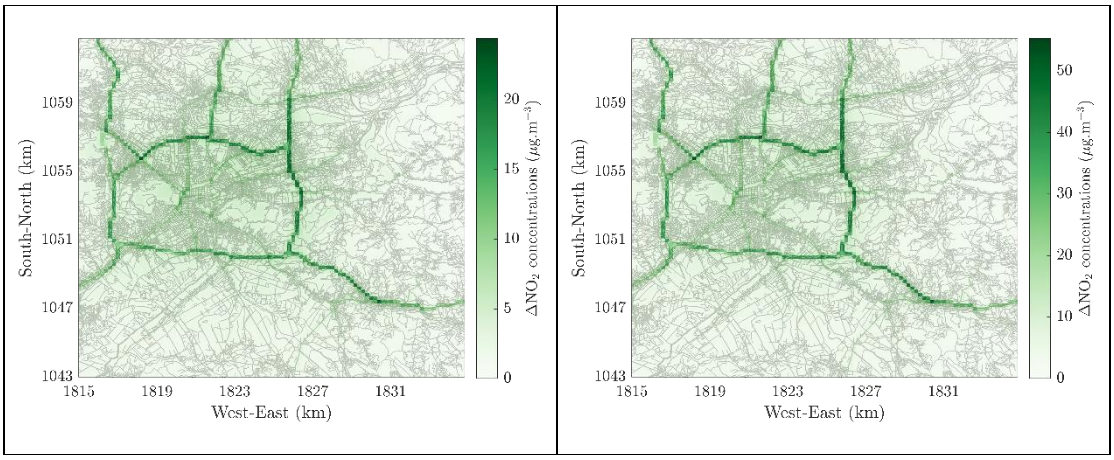


Figure 3-54: Differences of the NO_2 annual averaged concentrations in the BAU scenario a) in 2025 and b) in 2050.

Table 3-23 summarizes the overall impacts of BAU scenarios on air quality and population exposure. The population within the urban area of Ljubljana potentially exposed to NO_2 concentrations will diminish from 4.5% in the baseline year to no inhabitants in risk of exposure with the implementation of the BAU scenario in 2035. Therefore, the simulation results indicate full compliance with the EU annual limits everywhere in Ljubljana with the BAU scenario already in 2035.

Table 3-23: Summary of results including the annual averages of NO2 concentrations, together with the number of exceedances to the EU annual legal limit value (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	5.1	76.8	15.9	304	170	14141	4.5%
BAU 2025	4.0	53.8	12.3	51	34	2533	0.8%
BAU 2035	3.2	37.0	9.6	0	0	0	0%
BAU 2050	2.9	32.9	8.6	0	0	0	0%

BAU scenarios: PM10 concentrations

The slight reductions of PM emissions in the BAU scenario will also lead to reductions of the PM concentrations. Figure 3-55 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 19.3 µg.m^{-3} in 2025 and to 18.8 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 16.3% and 20.0%, when compared to the baseline.

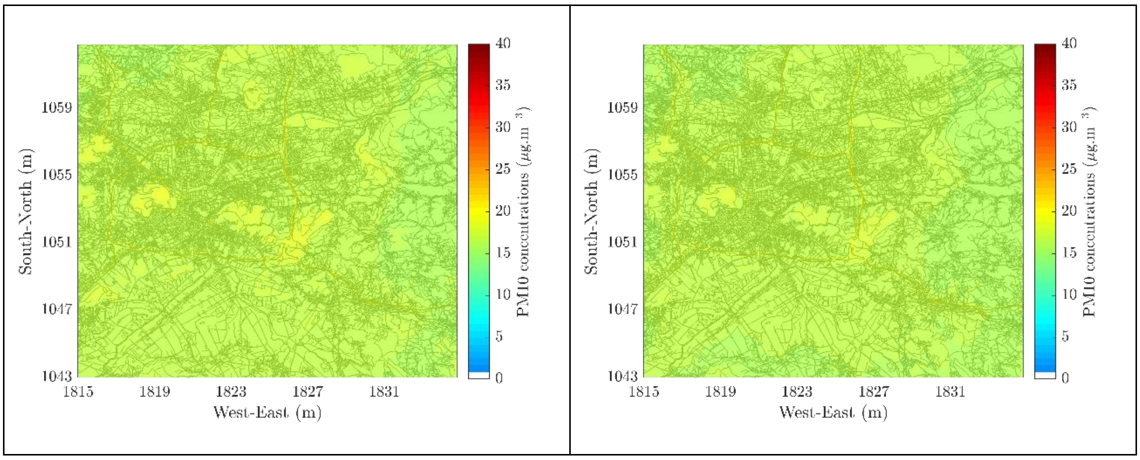


Figure 3-55: PM10 annual average concentrations in the BAU scenario a) in 2025 and b) in 2050.

Figure 3-56 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 3.7 µg.m^{-3} of the PM_{10} concentrations in 2025, corresponding to a reduction of 16.3%, while the spatial average over the entire the domain will reduce 0.8 µg.m^{-3} of PM_{10} concentrations, which corresponds to a reduction of 4.4%. In 2050 the BAU scenario will lead to a maximum reduction of the PM10 concentrations of 4.6 µg.m^{-3} which corresponds to a reduction of 20.0%, while the average over the entire domain will reduce 0.9 µg.m^{-3} (5.3%).

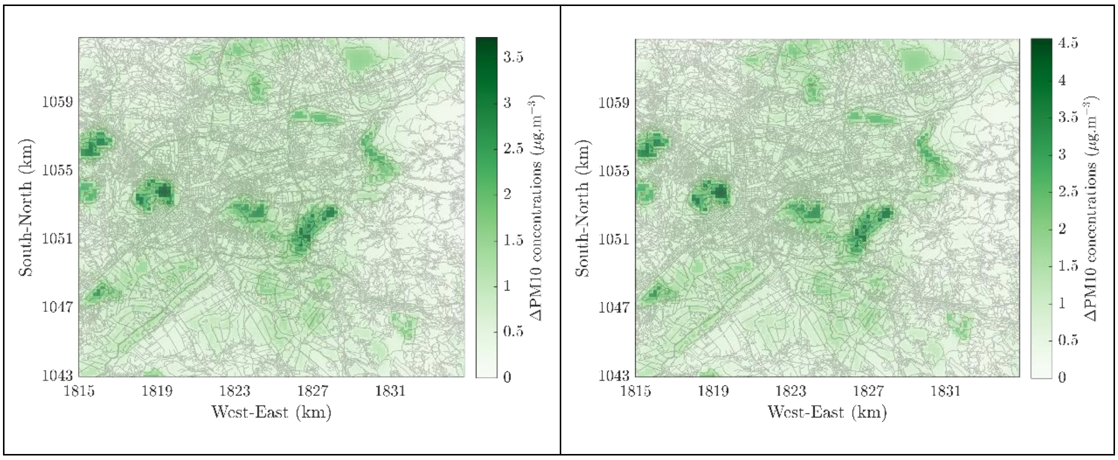


Figure 3-56: Differences of the PM10 annual averaged concentrations in the BAU scenario a) in 2025 and b) in 2050.

Table 3-24 summarize the overall impacts of BAU scenarios on PM_{10} concentrations and population exposure to those concentrations. The simulation results indicate no risk for the population within the urban area of Ljubljana 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 (even if there are 178 grid cells with PM_{10} concentrations above the WHO guideline value, according to Table 3-24). However, we note some difficulties in the spatial distribution of the population over the computational domain, which may affect the accuracy of the analysis of population exposure.

Table 3-24: Summary of results including the annual averages of PM_{10} 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	16.4	22.9	17.5	178	2	129	0%
BAU 2025	16.1	19.3	16.7	0	0	0	0%
BAU 2035	16.1	18.7	16.5	0	0	0	0%
BAU 2050	16.1	18.8	16.5	0	0	0	0%

BAU scenarios: $PM_{2.5}$ concentrations

Figure 3-57 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 17.1 $\mu g.m^{-3}$ in 2025 and to 16.6 $\mu g.m^{-3}$ in 2050, corresponding to an overall reduction of the maximum concentration of 12.5% and 15.4%, when compared to the baseline.

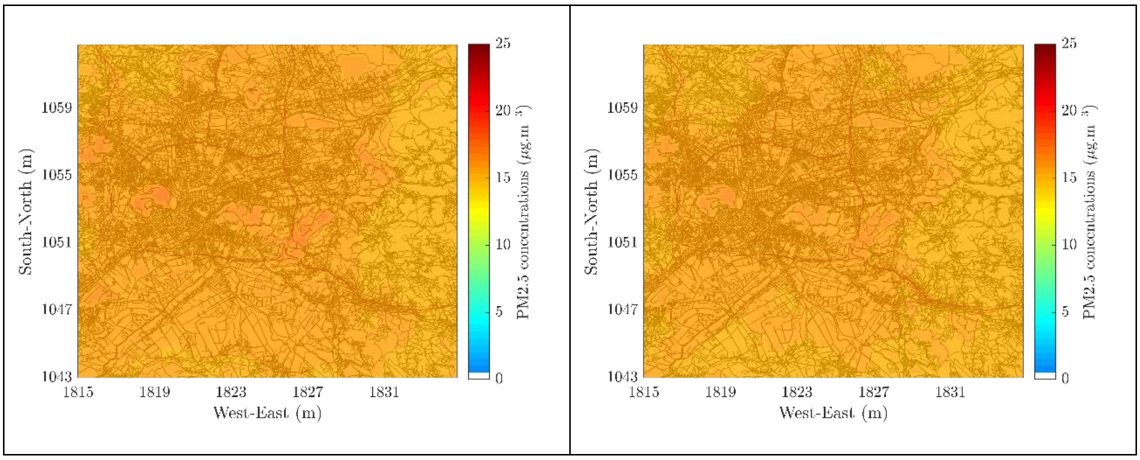


Figure 3-57: PM2.5 annual average concentrations in the BAU scenario a) in 2025 and b) in 2050.

Figure 3-58 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 2.5 μg.m^{-3} of the $PM_{2.5}$ concentrations in 2025, corresponding to a reduction of 12.5%, while the spatial average over the entire the domain will reduce 0.5 μg.m^{-3} of $PM_{2.5}$ concentrations, which corresponds to a reduction of 3.1%. In 2050 the BAU scenario will lead to a maximum reduction of the $PM_{2.5}$ concentrations of 3.0 μg.m^{-3} which corresponds to a reduction of 15.4%, while the average over the entire domain will reduce 0.6 μg.m^{-3} (3.7%).

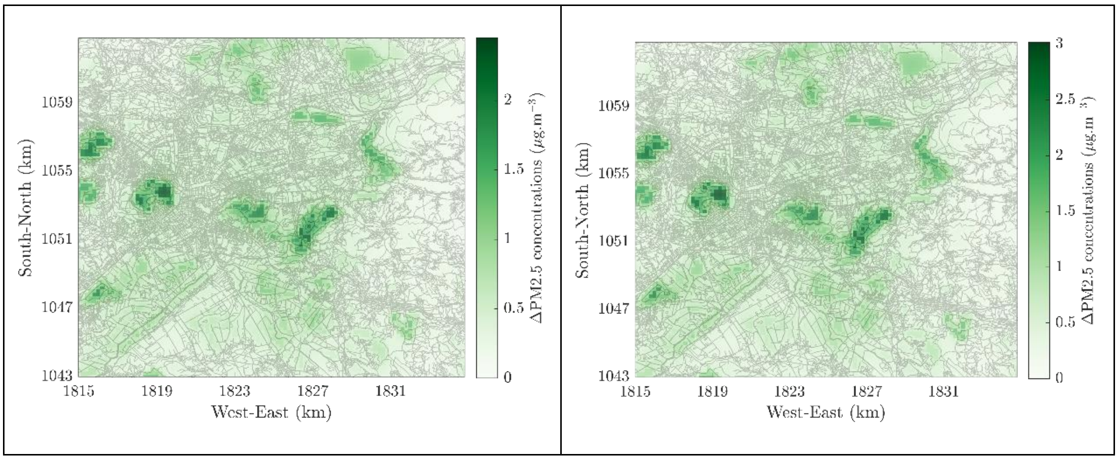


Figure 3-58: Differences of the PM2.5 annual averaged concentrations in the BAU scenario a) in 2025 and b) in 2050.

Table 3-25 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 within all the grid cells of the domain in 2050. The simulation results indicate no risk for the population within the urban area of Ljubljana to be potentially exposed to $PM_{2.5}$ concentrations above the EU annual legal limit value, but, on contrary all the 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.).

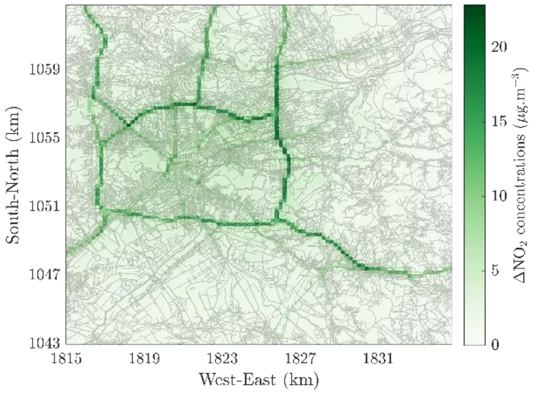
	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	15.3	19.6	16.0	10000	3792	314691	100%
BAU 2025	15.1	17.1	15.5	10000	3792	314691	100%
BAU 2035	15.1	16.6	15.4	10000	3792	314691	100%
BAU 2050	15.1	16.6	15.4	10000	3792	314691	100%

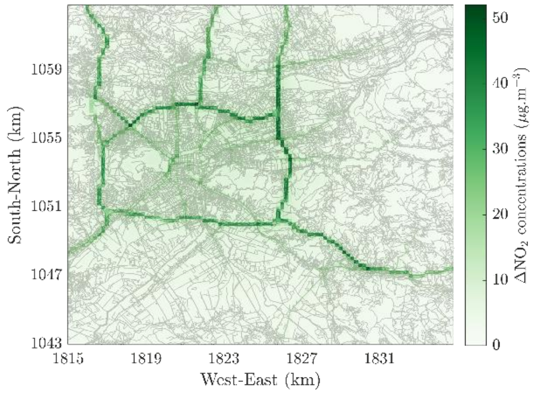
SDW scenarios: NO_2 concentrations

The two proposed scenarios from the SDW – low and high ambition scenarios – will impact the air quality over the urban area of Ljubljana. Figure 3-59 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 54.9 µg.m^{-3} to 33.3 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 52.5 µg.m^{-3} to 33.4 µg.m^{-3}. Figure 3-59 also points out that the maximum reductions of the NO_2 concentrations are simulated over the city centre and over the main roads, denoting a relevant 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 32.7% over the entire computational domain in 2025, and of 75.9% in 2050. While the high ambition scenario will lead to an averaged reduction over the entire area of the NO_2 concentrations of 37.5% in 2025, and of 75.1% in 2050.

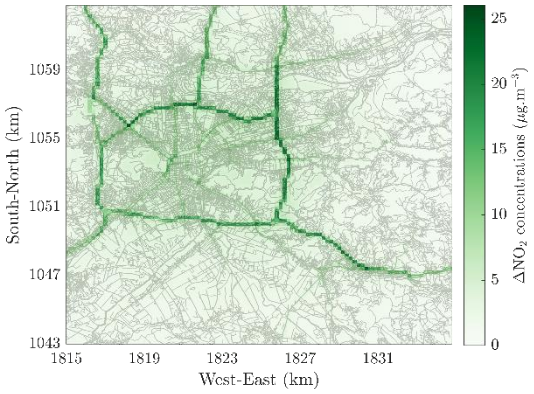
	2025	2050

Low ambition scenario





High ambition scenario



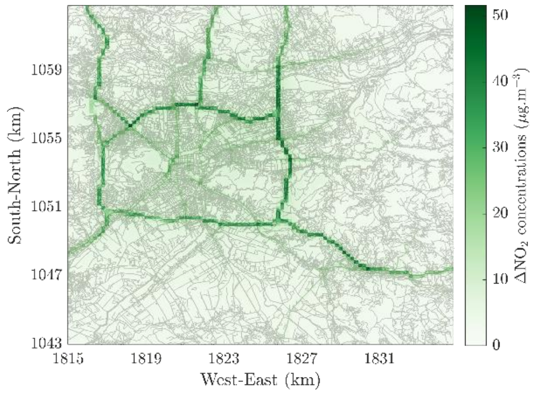


Figure 3-59: Differences of the NO2 annual averaged concentrations in the SDW scenarios a) in 2025 and b) in 2050.

Table 3-26 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 2035, and already in 2025 there is only a small group of inhabitants (less than 1%) potentially exposed to those concentrations.

Table 3-26: Summary of the SDW impacts including the annual averages of NO_2 concentrations, together with the number of exceedances to the EU legal limit value, the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit, and the corresponding % of population.

	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	5.1	76.8	15.9	304	170	14141	4.5%
Low 2025	4.1	54.9	12.5	63	40	2632	0.8%

Low 2035	3.3	40.1	10.1	1	0	0	0%
Low 2050	3.0	33.3	8.9	0	0	0	0%
High 2025	4.0	52.5	12.2	40	26	1706	0.5%
High 2035	3.4	41.1	10.2	1	0	0	0%
High 2050	3.0	33.4	9.0	0	0	0	0%

SDW scenarios: PM_{10} concentrations

The overall measures impacting the PM_{10} emissions will also promote reductions of PM_{10} concentrations over the urban area of Ljubljana as indicated in Figure 3-60. The differences contour maps of the annual PM_{10} concentrations point out a maximum concentration ranging from 19.3 µg.m^{-3} to 18.9 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 18.9 µg.m^{-3} in 2050. The simulation results denote the same impact of both scenarios, independently on the level of ambition.

	2025	2050
Low ambition scenario		

High ambition scenario		

Figure 3-60: Differences of the PM10 annual averaged concentrations in the SDW scenario a) in 2025 and b) in 2050.

Table 3-27 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 4.4% over the entire computational domain in 2025, and of 5.2% in 2050. While the high ambition scenario will lead to a reduction of 4.5% in 2025, and of 5.2% in 2050. The low and high ambition scenarios will lead to similar impacts on PM_{10} concentrations reductions.

Table 3-27: Summary of results including the annual averages of PM10 concentrations.

	Min.	Max.	Aver.
2015	16.4	22.9	17.5
Low 2025	16.1	19.3	16.7
Low 2035	16.1	18.8	16.5
Low 2050	16.1	18.9	16.6
High 2025	16.1	19.2	16.7
High 2035	16.1	18.7	16.5
High 2050	16.1	18.9	16.6

The simulation results indicate no risk for the population within the urban area of Ljubljana 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 3-61 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 17.1 µg.m^{-3} to 16.7 µg.m^{-3} between 2025 and 2050 with the implementation of the low ambition scenario, and ranging from 17.1 µg.m^{-3} to 16.6 µg.m^{-3} between 2025 and 2050 with the implementation of the high ambition scenario. The simulation results denote the same impact of both scenarios, independently on the level of ambition.

	2025	2050
Low ambition scenario		
High ambition scenario		

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

Table 3-28 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 3.0% of the $PM_{2.5}$ concentrations over the entire computational domain in 2025, and of 3.7% in 2050. While the high ambition scenario will lead to a reduction of 3.1% of the $PM_{2.5}$ concentrations in 2025, and of 3.7% 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 all the 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 urban area of Ljubljana to be potentially exposed to $PM_{2.5}$ concentrations above the EU annual legal limit value, but, on contrary all the inhabitants will be potential exposed to the stricter WHO guideline values even in 2050, independently of the level ambition.

Table 3-28: 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	15.3	19.6	16.0	10000	3792	314691	100%
Low 2025	15.1	17.1	15.5	10000	3792	314691	100%
Low 2035	15.1	16.6	15.4	10000	3792	314691	100%
Low 2050	15.1	16.7	15.4	10000	3792	314691	100%
High 2025	15.1	17.1	15.5	10000	3792	314691	100%
High 2035	15.1	16.6	15.4	10000	3792	314691	100%
High 2050	15.1	16.6	15.4	10000	3792	314691	100%

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 3-62 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 55.3 $\mu g.m^{-3}$ in 2025 and to 33.3 $\mu g.m^{-3}$ in 2050, corresponding to an overall reduction of the maximum concentration of 31.9% and 76.2%, when compared to the baseline.

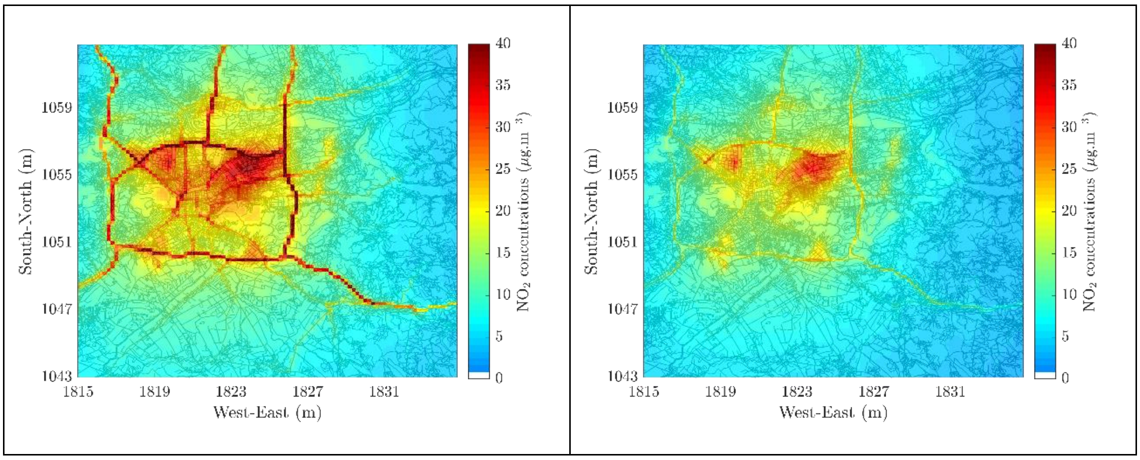


Figure 3-62: NO_2 annual average concentrations in the FUPS scenario a) in 2025 and b) in 2050.

Figure 3-63 shows the differences of the NO_2 annual concentrations with the implementation of the FUPS scenarios compared to the baseline year. Figure 3-63 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 20.9% over the entire computational domain in 2025, and of 43.2% in 2050.

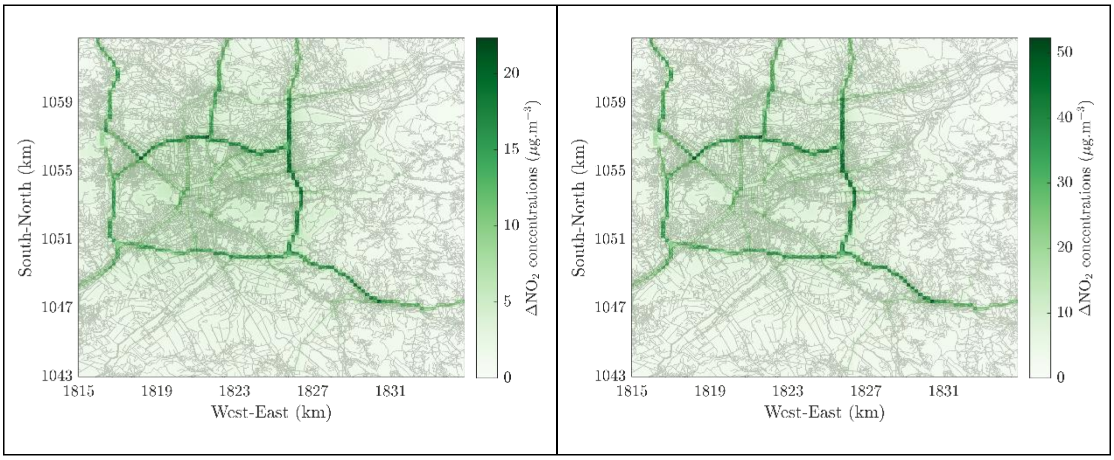


Figure 3-63: Differences of the NO_2 annual averaged concentrations in the FUPS scenario a) in 2025 and b) in 2050.

Table 3-29 shows the summary of the overall impact of the FUPS scenario on the NO_2 concentrations, indicating low risk of population exposure to those concentrations already in 2025, and no risk at all in 2035. The FUPS scenario in 2025 will led to a reduction of 3.6% of the population within the Ljubljana computational domain potentially exposed to NO_2 concentrations above the EU annual legal limit value.

Table 3-29: Summary of the FUPS impacts including the annual averages of NO_2 concentrations, together with the number of exceedances to the EU annual legal limit value, the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit, and the corresponding % of population.

	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	5.1	76.8	15.9	304	170	14141	4.5%
FUPS 2025	4.1	55.3	12.6	69	45	2663	0.9%
FUPS 2035	3.3	40.0	10.1	0	0	0	0%
FUPS 2050	3.0	33.3	8.9	0	0	0	0%

FUPS scenarios: PM_{10} concentrations

Figure 3-64 and Figure 3-65 present the impact of the FUPS scenario on PM10 concentrations. The contour maps with the differences of the annual PM10 concentrations point out a maximum concentration ranging from 19.3 µg.m-3 to 18.9 µg.m-3 between 2025 and 2050 with the implementation of the FUPS scenario.

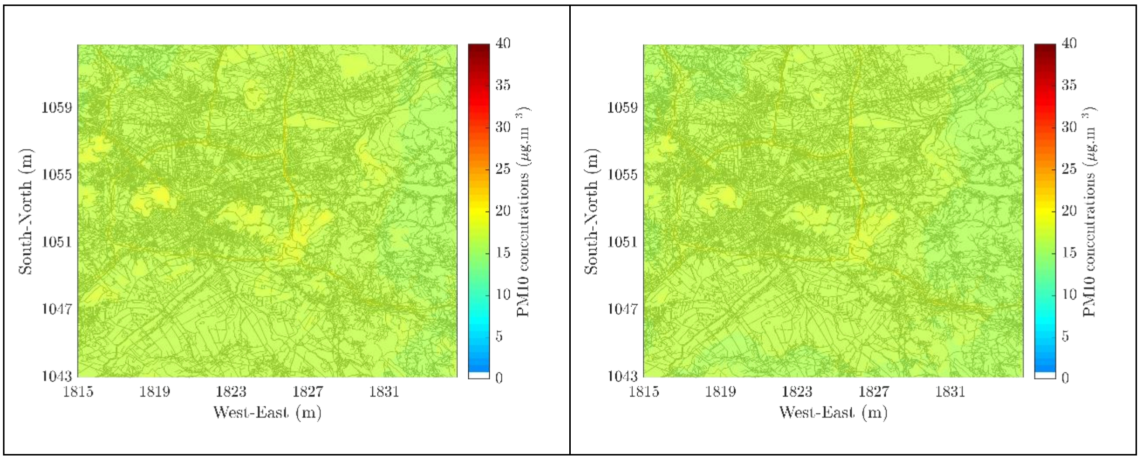


Figure 3-64: PM10 annual average concentrations in the FUPS scenario a) in 2025 and b) in 2050.

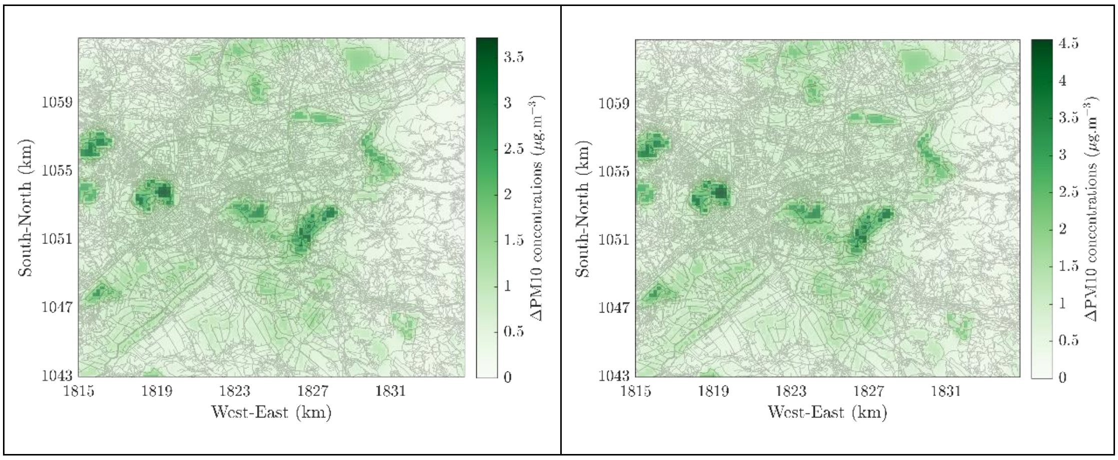


Figure 3-65: Differences of the PM10 annual averaged concentrations in the FUPS scenario a) in 2025 and b) in 2050.

Table 3-30 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 4.4% over the entire computational domain in 2025, and of 5.2% in 2050.

Table 3-30: Summary of results including the annual averages of PM10 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 urban area of Ljubljana 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 3-66 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 17.1 µg.m^{-3} in 2025 and to 16.6 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 12.5% and 15.4%, when compared to the baseline.

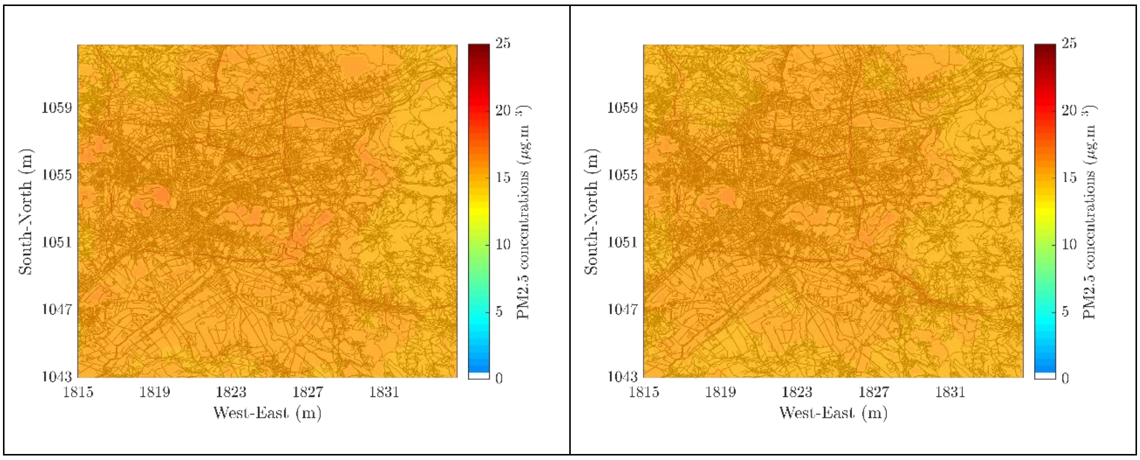


Figure 3-66: PM2.5 annual average concentrations in the FUPS scenario a) in 2025 and b) in 2050.

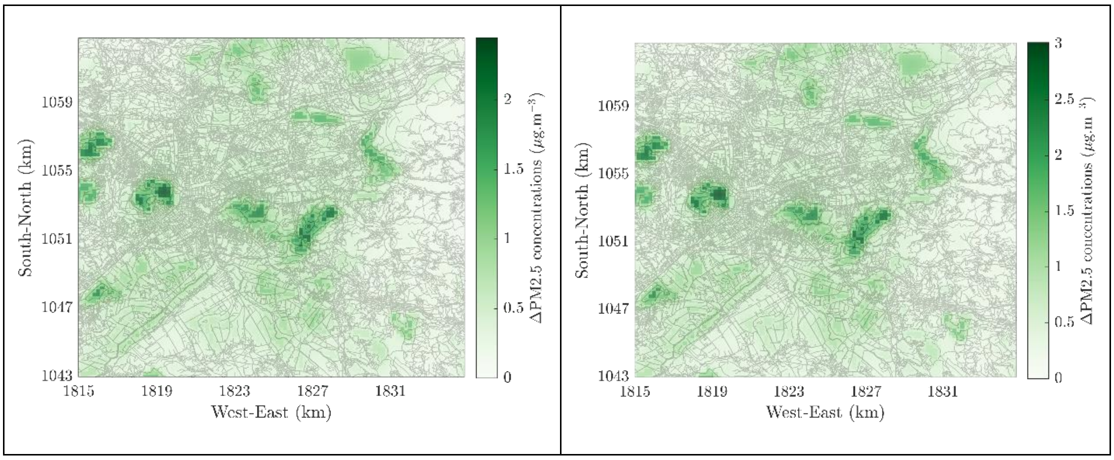


Figure 3-67: Differences of the PM2.5 annual averaged concentrations in the FUPS scenario a) in 2025 and b) in 2050.

Table 3-31 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 3.0% of the $PM_{2.5}$ concentrations over the entire computational domain in 2025, and of 3.7% in 2050. It is of notice that the FUPS 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 all the grid cells of the domain in 2050. The simulation results indicate no risk for the population within the urban area of Ljubljana to be potentially exposed to $PM_{2.5}$ concentrations above the EU annual legal limit value, but, on contrary all the inhabitants will be potential exposed to the stricter WHO guideline values even in 2050.

Table 3-31: 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.).

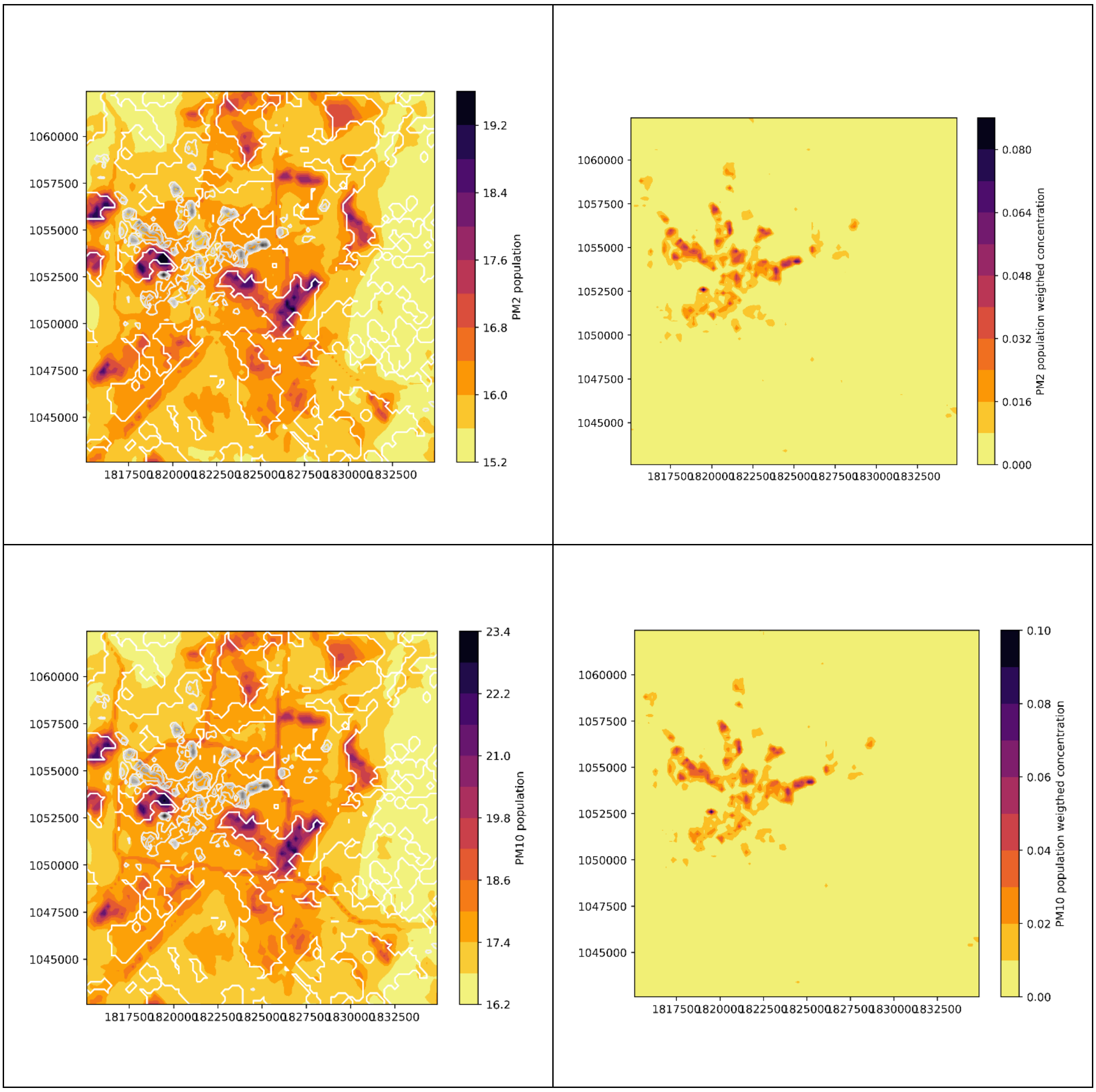
	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	15.3	19.6	16.0	10000	3792	314691	100%
FUPS 2025	15.1	17.1	15.5	10000	3792	314691	100%
FUPS 2035	15.1	16.6	15.4	10000	3792	314691	100%
FUPS 2050	15.1	16.6	15.4	10000	3792	314691	100%

3.6 Health impacts

3.6.1 Baseline

The health impacts related to exposure to NO_2, PM_{10}, and $PM_{2.5}$ 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 Ljubljana, for individual pollutants. The population weighted concentration maps indicate that exposure is the highest closer to the city centre.

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 255, 185, and 219 premature deaths, and 2687, 1950, 2306 years of life potentially lost attributed to $PM_{2.5}$, PM_{10}, and NO_2 pollution levels in Ljubljana in 2015, respectively.


PM2 population
PM2 population weigthed concentration
PM10 population
PM10 population weigthed concentration
1060000
1057500
1055000
1052500
1050000
1047500
1045000
1817500
1820000
1822500
1825000
1827500
1830000
1832500
19.2
18.4
17.6
16.8
16.0
15.2
0.080
0.064
0.048
0.032
0.016
0.000
23.4
22.2
21.0
19.8
18.6
17.4
16.2
0.10
0.08
0.06
0.04
0.02
0.00

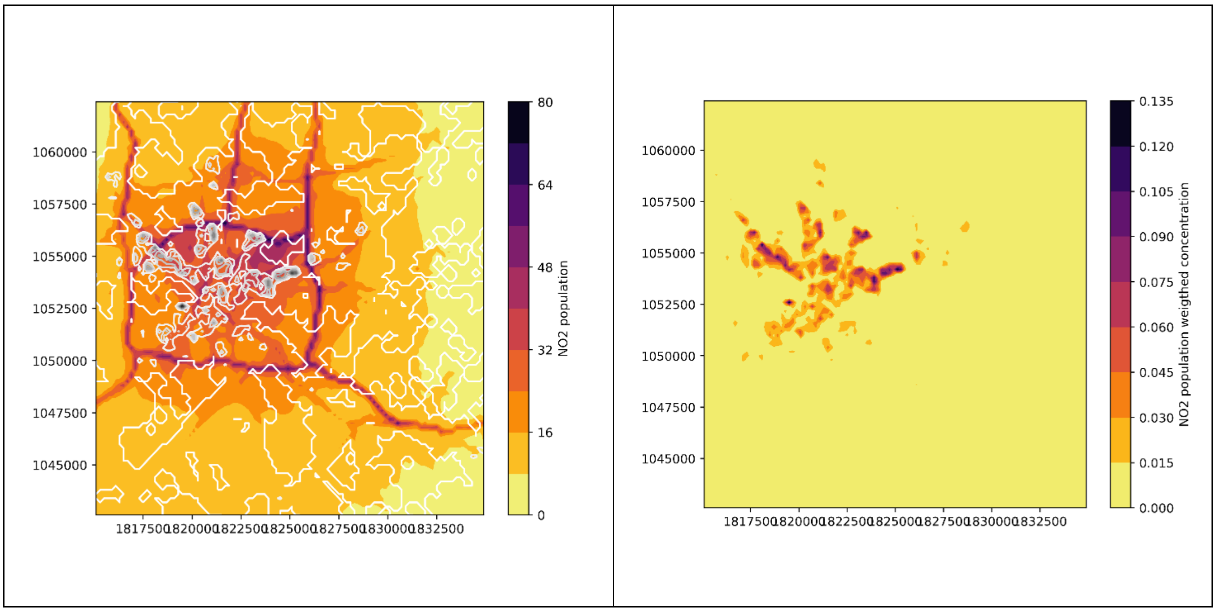


Figure 3-68: Concentration maps overlaid with population density contours (left), population weighted concentration maps (right) for PM2.5 (top), PM10 (centre), and NO_2 (bottom) based on the baseline emission scenario (2015), for Ljubljana.

3.6.1.1 BAU and UPS

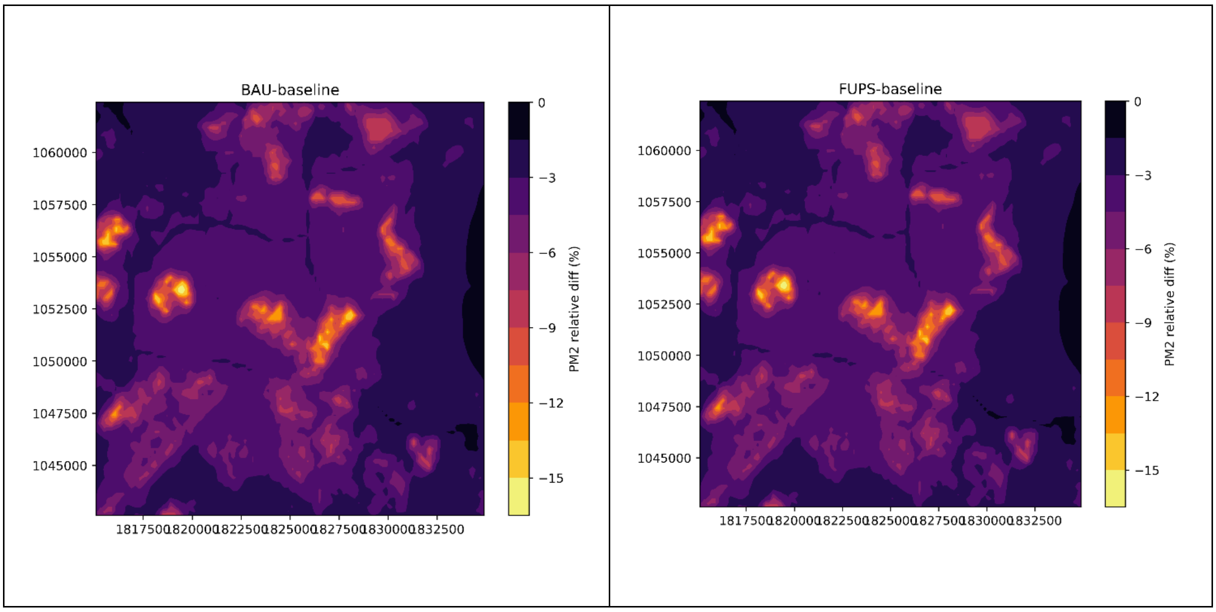
The analysis of the health impact benefits of implementing emission control measures can be quantified by benchmarking the health indicators estimated based on the BAU and UPS emission scenarios. The results in relative terms (%) are described in the table below. Note that independently of the indicators,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

Table 3-32: Health impact benefits of implementing emission control measures in Ljubljana (%).

	PM2.5			PM10			NO2		
	2025	2035	2050	2025	2035	2050	2025	2035	2050
BAU	-3	-3	-3	-4	-5	-5	-34	-58	-67
UPS	-3	-3	-3	-4	-5	-5	-31	-54	-65

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 3-67 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 city, reducing the impact of NO_2 on human health of the people living in Ljubljana. 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, an increase on the health impact benefit across the years is expected due to the implementation of the emissions control measures for both emissions scenarios. For particulate matter there is little or no change across the years.



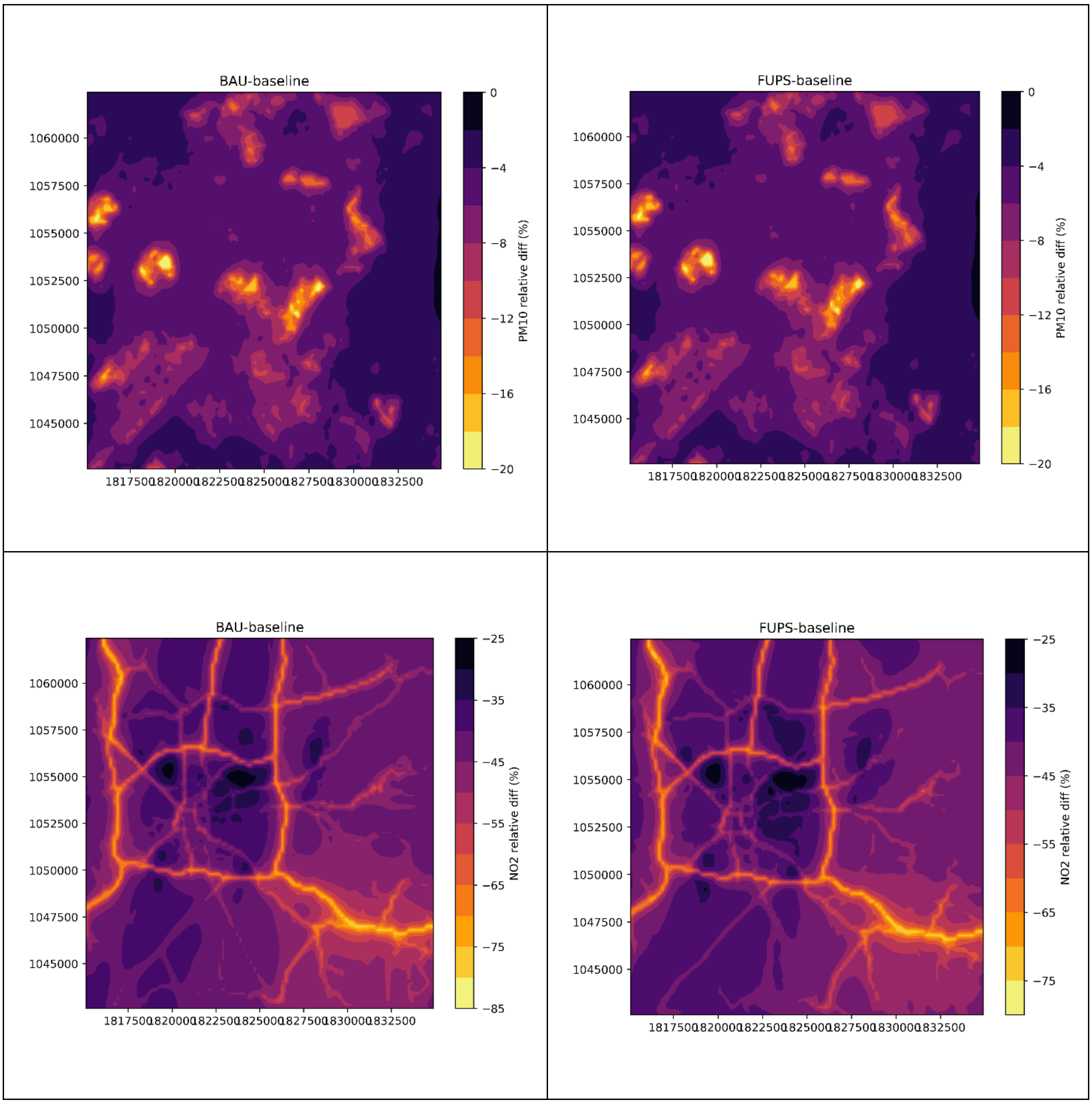


Figure 3-69: Air quality impact benefits of implementing emission control measures in 2050 for Ljubljana, BAU vs baseline on the left and UPS vs baseline on the right for PM2.5 (top), PM10 (centre), and NO_2 (bottom).

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 Amsterdam. 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/d5-5a-assessment-of-impacts-ljubljana. 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.