ClairCity: Citizen-led air pollution reduction in cities

Deliverable 5.7: City Impact Analysis Report – Liguria Region

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Document Details

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Description	The Deliverable 5.7 collects all results of the full impact analysis, methodological approach and data sources. This report describes the full impact analysis for Liguria Region.

Version History

Version	Updated By	Date	Changes / Comments
V1.0	Kris Vanherle	08/05/2019	Outline
V1.1	Kris Vanherle	12/11/2019	Added content by Peter (TML) and An (DTU)
V2.0	Kris Vanherle	13/01/2020	Incorporation of inputs TECHNE, DTU, PBL
V2.1	Kris Vanherle	18/02/2020	Updated inputs from UAVR 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 Liguria Region.

Contributions and Acknowledgements

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Quality Assurance	Enda Hayes (UWE)
Native Language Check	Enda Hayes (UWE)
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Table of Content

In this document, we elaborate into the methodology and results of the modelling for the Liguria Region case. We first elaborate on any methodological particularity [1] and then report on the specific assumptions, translating the scenarios to model input [2] and report on the results of the modelling [3]. The impact assessment data illustrating the work undertaken can be found on the ClairCity Data Portal, as follow: https://claircitydata.cbs.nl/dataset/d5-5e-assessment-of-impacts-liguria. 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

Transport activity data was available for Liguria region, only on a set of roads concentrated in Genoa. A transport model estimating transport volumes was unavailable. As such, we use following approach to estimate the transport volumes in following steps:

- Road network generation
- Production & Attraction for demand generation
- Mode choice
- Assignment
- Post-processing with scaling to match traffic counting data

Road network generation

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

Demand generation

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

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

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

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

Mode choice

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

Assignment

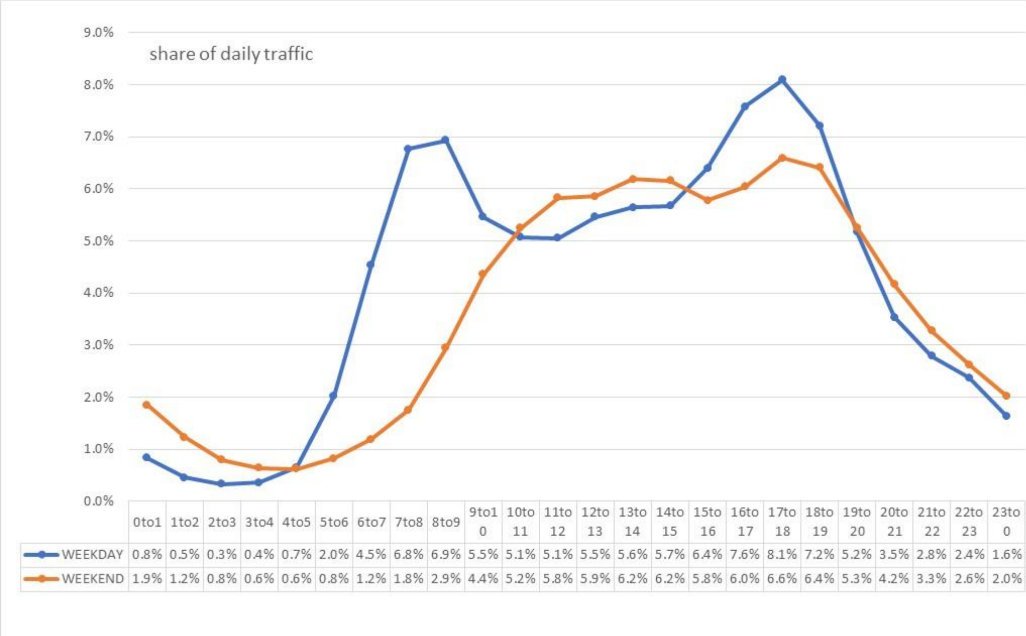
The main idea of assigning demand to the network is based on equilibrium principles. These state that drivers will keep on looking for shorter routes until all drivers unilateral perceive the least resistance. We incorporate a first calibration, scaling the generated demand in such a way the traffic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

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

Post-processing

The initial demand generation and assignment need further refinement. This includes, for Liguria specifically: **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.

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 Figure 1-1 and Figure 1-2 below, the estimates we’ve used, based on observed highway traffic intensity (a good proxy for all roads), making a distinction between weekday and weekend. Note that the sum over all hours is 1 for weekday, but lower for weekend, as traffic generation an assignment is assumed for a weekday with typical peak-profiles.



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

Figure 1-1: 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*

Morandi-bridge collapse

On August 14, 2018 a key road link, the Morandi bridge, collapsed. The unavailability of this main road link will likely have altered traffic flows in Genoa significantly. We simulated the possible effect with the above approach:

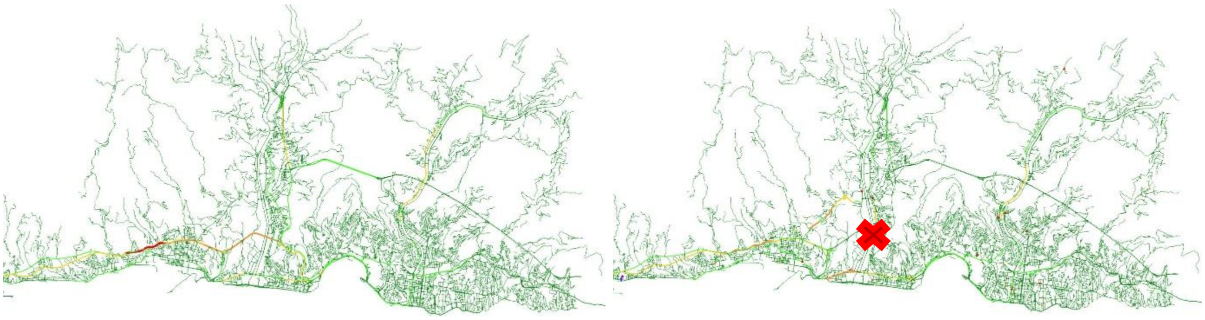


Figure 1-2: Simulation of traffic flows with Morandi bridge intact (left) and not intact (right).

Clearly, the collapse has created knock-on effects on traffic elsewhere in the region.

For consistency purposes, as our baseline was 2015, with the bridge intact, we have kept all simulations for 2025, 2035, 2050 with the road link available.

1.2 Transport: Mode choice model

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

1.3 Air quality modelling

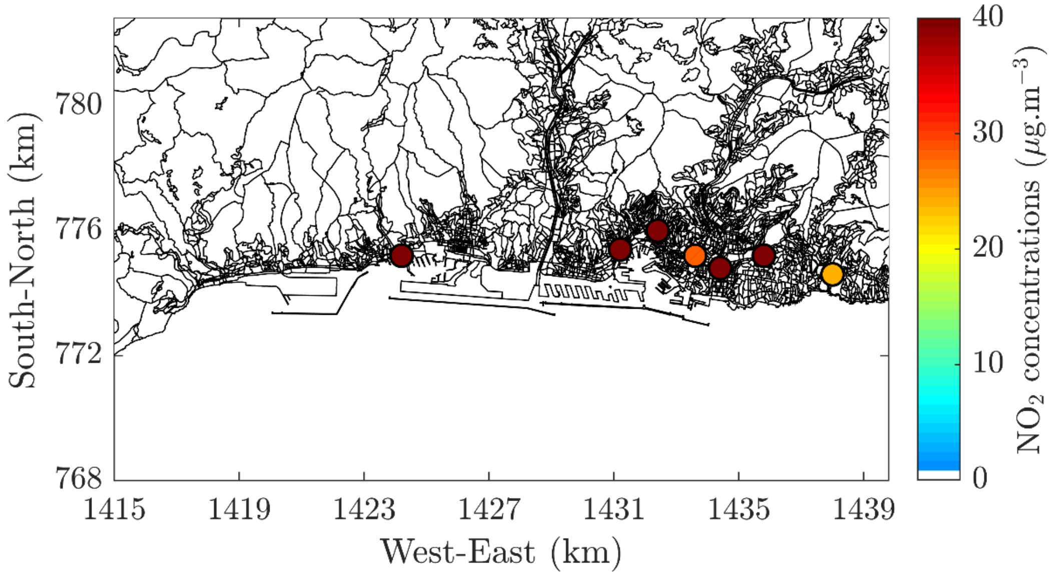
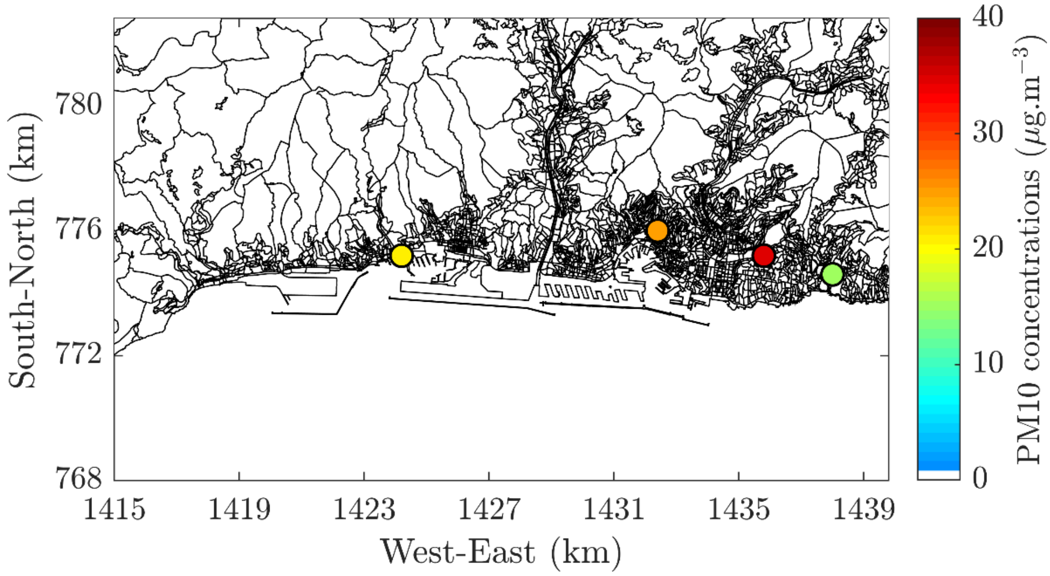
1.3.1 Background concentrations

Based on the source apportionment analysis obtained from the WRF-CAMx and the PSAT tool, it is expected an underestimation of the URBAIR concentrations comparing to measured data results due to the lack of other emission sources contributing to the concentrations within the area, as well as the background concentrations. Therefore, based on the SA, a concentration value for the background concentrations and other sources was used to add on the whole domain. For NO_2 the background added was 0.2 $\mu g.m^{-3}$, for PM_{10} was 15.0 $\mu g.m^{-3}$ and for $PM_{2.5}$ was 13.6 $\mu g.m^{-3}$.

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 be compared with 3 urban traffic, 3 urban background and 1 urban industrial monitoring stations. For PM_{10} concentrations, the modelling results could be compared with 2 urban background, 1 urban traffic and 1 urban industrial monitoring station. For $PM_{2.5}$, the modelling results could only be compared with 1 urban traffic and 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

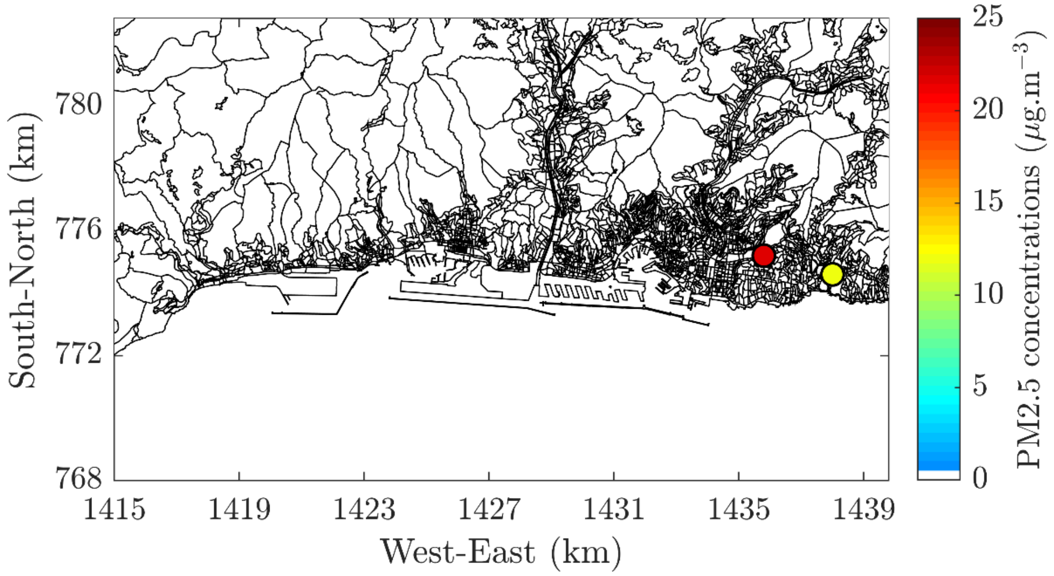


Figure 1-3: Summary data for 2015 with the location of the monitoring stations and respective annual mean concentration for each pollutant in µg.m^{-3}.

The maximum value for NO_2 monitored in 2015 was 58.8 µg.m^{-3} and was measured by the urban background monitoring station. For PM10 the maximum value was 35.1 µg.m^{-3} measured by an urban traffic station and for PM2.5 the maximum value was 21.7 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, due to the large availability of measured data, a separation by AQ station type was applied, originating different factors to be applied to the accounted sectors. From the background stations the factor is 1.91, for the traffic stations the factor is 1.57 and for industrial stations the factor is 1.91.

For PM_{10} and $PM_{2.5}$ no distinction were made between AQ stations type resulting in a factor of 3.0 and 1.63, respectively.

2 Description and modelling of the scenario's

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

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

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

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

Measure #	Main Measures	BAU	High (SDW) scenario	Chosen for UPS
1	Improve the local public transport service (including sharing	Increase in movements in the metropolitan area, on the integrated network of Local Public Transport, from 25,41% to 31.46% by 2029	Increase in movements in the metropolitan area, on the integrated network of Local Public Transport, from 25,41% to 31.46 by 2029 and from 31.46 in 2029 to 45% by 2050	High
2	Improve integration of local public transport service and private transport with new interchange parking lots	No new interchange parking lots	5 new big interchange parking lots	High
3	Ban on most polluting diesel and motorcycle vehicles in the city center	Traffic limits in urban areas for diesel automobiles and light duty vehicles less than or equal to Euro 5 by 2025	Traffic limits in urban areas for diesel automobiles and light duty vehicles less than or equal to Euro 5 by 2025	BAU
4	Promote electric mobility	500 recharging station by 2029 - electric penetration to 15 % and hydrogen penetration to 3%	Replace 50% of vehicles circulating in urban areas with electric automobiles and motorcycles (including sharing) by 2050and installing adequate number of recharging stations	High
5	Promote active mobility (walking, cycling)	increase in % private trips by bicycle or on foot from 22.9% to 23.2% by 2029	increase in % private trips by bicycle or on foot from 22.9% to 23.2% by 2029 and from 23.2% by 2029 to 35% by 2050	High

6	Transfer part of the road freight traffic to railway	30% reduction in heavy traffic at 2035 and 50% at 2050	50% reduction in heavy traffic at 2035 and 70% at 2050	BAU
7	Reduction of energy consumption in the residential, commercial and institutional sector	Reduction of 10% in energy consumtions in residential and 16% in commercial and institutional by 2030	Reduction of 10% in energy consumtions in residential and 16% in commercial and institutional by 2030	BAU
8	Cold ironing in port	IMO Tier2 application and Cold Ironing implementation - BAU scenario for NOx: -15,5% 2025, -24,1% 2050 as a results of IMO Tier2 and cold ironing implementation on specific docks(see files on data portal)	IMO Tier2 application and Cold Ironing implementation	BAU

The Liguria case used a slightly different approach to the scenario modelling:

1. Only a single SDW-scenario was defined compared to a typical high/low combination in the other cases.
2. The BAU scenario was updated after the SDW
3. The UPS is a selection of some of the SDW measures supplemented to the (updated) BAU.

2.1 Transport

2.1.1 Baseline and BAU

The baseline modal split (BAU 2015) is as follows:

- Walk 21.0%[2]
- Bike 1.9%
- Car/van 44%
- Public transport 25%
- Taxi 1%
- Other (including motorbikes): 7.1%

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

ASC_1 = ASC_1-0.1
ASC_2 = ASC_2+0.4
ASC_4 = ASC_4+1

[2] 21% of walking in http://www.epomm.eu/tems/result_city.phtml?city=35 and 1.2% biking for the whole of Liguria in https://www.istat.it/it/files//2014/08/Pendolarismo.pdf which we rounded up to reach the total active number of 22.9 provided by the city.

ASC_5 = ASC_5+1.9
ASC_7 = ASC_7+2.12

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). 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 for Italy this technology time shift is 5 years by default, meaning that Italy is 5 years behind the general, average uptake curve.

This default value was found too optimistic for the BAU by the city, therefore we shifted the expectations 10 years into the pessimistic direction, applying a 15 year time lag in the model, which results in a much lower electric vehicle penetration rate in the BAU fleet evolution. For the Model Scenario, we used the default 5 year value.

Both the BAU and the Model Scenario required to limit traffic in urban areas for diesel automobiles less than or equal to Euro 5 by 2025, so we applied the usual stepwise scrappage scheme: ban of Euro3 and worse at the end of 2020, Euro4 and worse at the end of 2022, and Euro5 and worse at end of 2024. Growth rates did not need changing, as Italy has a non-existent second hand market in our model, with Age0 growth factors at 0.9999 therefore zeroing growth rates later for older vintages does not change the total sum of growth rates significantly.

To scale the number of cars from Italy to the region in question we simply scaled the numbers according to the population of the region relative to the population of the country (assuming that the car ownership rate in Genoa is the same as the Italian average).

For the future BAU and the Model Scenario the provided modal split forecast numbers were extrapolated to the ClairCity reporting years, then we calibrated the ASC values to meet the resulting shares. Below we list the used parameters for the remaining reporting epochs.

- BAU 2025
  - ASC_1 = ASC_1+0.1
  - ASC_2 = ASC_2+0.65
  - ASC_3 = ASC_3-0.05
  - ASC_4 = ASC_4+1.35
  - ASC_5 = ASC_5+2.25
  - ASC_7 = ASC_7+2.15
- BAU 2035 and 2050
  - ASC_1 = ASC_1+0.1
  - ASC_2 = ASC_2+0.7
  - ASC_3 = ASC_3-0.08
  - ASC_4 = ASC_4+1.41
  - ASC_5 = ASC_5+2.32

  - ASC_7 = ASC_7+2.12
- Model Scenario 2035 (as no measures are active in 2025)
  - ASC_1 = ASC_1+0.4
  - ASC_2 = ASC_2+1.61
  - ASC_3 = ASC_3-0.08
  - ASC_4 = ASC_4+1.69
  - ASC_5 = ASC_5+2.62
  - ASC_7 = ASC_7+2.12
- Model Scenario 2050
  - ASC_1 = ASC_1+1.49
  - ASC_2 = ASC_2+3.40
  - ASC_3 = ASC_3-0.08
  - ASC_4 = ASC_4+2.86
  - ASC_5 = ASC_5+3.69

ASC_7 = ASC_7+2.12

2.1.2 Proposed SDW scenario's

Measures 1, 2, 4 and 5 relate to transport specifically, with 1, 2 and 5 specifically affecting the modal share. Given the absence of specific policy measure definitions to achieve the set goals that could be simulated with a mode choice model (e.g. pricing), the target modal share was set as an arbitrary output of the measure.

As for measure 4, promotion of electric vehicles, we update the EV sales share progressively, to achieve the 50% fleet share by 2050.

2.1.3 Final Scenario

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

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 Genova area in Liguria Region.

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);
- Residential fuel energy demand (Table 2-5);
- Census section disaggregation variables (Table 2-6).

Table 2-2: Methodology and source of data for Liguria Region (Genoa Area) fuel consumptions/emissions evaluation - Industrial sources.

Activity	Data availability	Source	Publication	Reference	Note	Disaggregation variable
Industrial sector point sources	Single facility	Regione Liguria	Data on emissions and on plant/stacks characteristics extracted from Regione Liguria Emission Inventory	http://www.banchedati.ambienteinliguria.it/index.php/aria/inventario-emissioni-in-atmosfera?_ga=2.89868251.1763133517.1551799487-742064735.1539778117		None (Point sources)
Industrial sector – other than point sources and natural gas	Single facility	Regione Liguria	Data on emissions extracted from Regione Liguria Emission Inventory	http://www.banchedati.ambienteinliguria.it/index.php/aria/inventario-emissioni-in-atmosfera?_ga=2.89868251.1763133517.1551799487-742064735.1539778117	Allocated to 1kmx1km grid	None (Point sources)
Industrial sector – natural gas	Level 2 (Comune)	Regione Liguria	Regional Energy Balance 2016	https://www.regione.liguria.it/giunta/26-servizi-online/14414-bilancio-energetico-regionale.html	Allocated to 1kmx1km grid	Land Cover Industrial & Commercial areas

Table 2-3: Methodology and source of data for Liguria Region (Genoa Area) consumptions evaluation - Residential and commercial sources.

Activity	Energy vector	Data availability	Source	Publication	Reference	Note	Disaggregation variable
Residential sector	Natural Gas	Level 2 (Comune)	Regione Liguria	Regional Energy Balance 2016	https://www.regione.liguria.it/giunta/26-servizi-online/14414-bilancio-energetico-regionale.html	Original data from regional gas distributors	Dwelling area (Table 2-6)
	Wood	Level 1 (Regione)	Regione Liguria	Regional Energy Balance 2016	https://www.regione.liguria.it/giunta/26-servizi-online/14414-bilancio-energetico-regionale.html	Data at level 1 (regione) allocated to Level 2 with energy demand (Table 2-5)	Dwelling area (Table 2-6)
	LPG	Level 1 (Regione)	Regione Liguria	Regional Energy Balance 2016	https://www.regione.liguria.it/giunta/26-servizi-online/14414-bilancio-energetico-regionale.html	Aggregated Residential & Service sector data at level 1 (regione) subdivided with national (level 0) figure and then allocated to Level 2 with energy demand (Table 2-5)	Dwelling area (Table 2-6)
	Gasoil	Level 1 (Regione)	Regione Liguria	Regional Energy Balance 2016	https://www.regione.liguria.it/giunta/26-servizi-online/14414-bilancio-energetico-regionale.html	Aggregated Residential & Service sector data at level 1 (regione) subdivided with national (level 0) figure and then allocated to Level 2 with energy demand (Table 2-5)	Dwelling area (Table 2-6)

Table 2-3: Methodology and source of data for Liguria Region (Genoa Area) consumptions evaluation - Residential and commercial sources.

Activity	Energy vector	Data availability	Source	Publication	Reference	Note	Disaggregation variable
Service sector	Natural Gas	Level 2 (Comune)	Regione Liguria	Regional Energy Balance 2016	https://www.regione.liguria.it/giunta/26-servizi-online/14414-bilancio-energetico-regionale.html	Original data from regional gas distributors	Employees (Table 2-6)
	Wood	Single facility	Regione Liguria	Regional Energy Balance 2016	https://www.regione.liguria.it/giunta/26-servizi-online/14414-bilancio-energetico-regionale.html	Original data from Gestore dei Servizi Energetici GSE S.p.A.	None
	LPG	Level 1 (Regione)	Regione Liguria	Regional Energy Balance 2016	https://www.regione.liguria.it/giunta/26-servizi-online/14414-bilancio-energetico-regionale.html	Aggregated Residential & Service sector data at level 1 (regione) subdivided with national (level 0) figure and then allocated to Level 2 with employees (Table 2-6)	Employees (Table 2-6)
	Gasoil	Level 1 (Regione)	Regione Liguria	Regional Energy	https://www.regione.liguria.it/giunta/26-servizi-	Aggregated Residential & Service sector data at level 1 (regione) subdivided with national (level 0) figure	Employees (Table 2-6)

Table 2-3: Methodology and source of data for Liguria Region (Genoa Area) consumptions evaluation - Residential and commercial sources.

Activity	Energy vector	Data availability	Source	Publication	Reference	Note	Disaggregation variable
				Balance 2016	online/14414-bilancio-energetico-regionale.html	and then allocated to Level 2 with employees (Table 2-6)	

Table 2-4: Methodology and source of data for Liguria Region (Genoa Area) fuel consumptions evaluation – Wood statistics.

Variable	Data availability	Sources	Publication	Reference	Note
Technologies split	Level 1 (Liguria Region)	ISTAT ENEA	ISTAT I consumi energetici delle famiglie ENEA Rapporto Energia Ambiente (2005)	https://www.istat.it/it/files/2014/12/Tabelle_appendice_consumi_energetici.zip http://old.enea.it/produzione_scientifica/pdf_volumi/V06_01Analisi_05.pdf	On the basis of available data, the following shares are evaluated: traditional 85% and advanced 15% (ISTAT); fireplaces (2/3) and stoves (1/3) (ENEA) Service sector allocated to boilers.

Table 2-5: Methodology and source of data for Liguria Region (Genoa Area) residential energy demand evaluation.

Variable	Data availability	Sources	Publication	Reference	Note
Energy demand	Level 2 (Comune)	ISTAT ENEA	ISTAT, Censimento Popolazione ed Abitazioni, Abitazioni con impianto di riscaldamento per tipo di combustibile o energia che alimenta l'impianto di riscaldamento) Tabella dei gradi/giorno dei Comuni italiani raggruppati per Regione e Provincia	http://dati-censimentopopolazione.istat.it/Index.aspx?DataSetCode=dica_alloggi http://efficienzaenergetica.acs.enea.it/doc/dpr412-93_allA_tabellagradigiorno.pdf	Energy demand (F) of each comune is computed as: $F_{ij} = 24 \times (N_{ij} \times S_i \times 3) \times G_i \times D_i$ where *j* fuel, *i* comune, N number of dwelling, S average area of occupied dwellings, G degrees days, D volume dispersion coefficient

Table 2-6: Methodology and source of data for Liguria Region (Genoa Area) level 3 fuel consumptions evaluation.

Variable	Data availability	Sources	Publication	Reference	Fields
Dwelling area	Level 3 (CensusSection)	ISTAT	Censimento della popolazione e delle abitazioni 2011	http://www.istat.it/storage/cartografia/variabili-censuarie/dati-sce_2011.zip	Average area of occupied dwellings
Industrial sector employees	Level 3 (CensusSection)	ISTAT	Censimento dell'industria e dei servizi, 2011	http://www.istat.it/storage/cartografia/variabili-censuarie/dati-cpa_2011.zip	Field ADDETTI with field ATECO3 <=400

Table 2-6: Methodology and source of data for Liguria Region (Genoa Area) level 3 fuel consumptions evaluation.

Variable	Data availability	Sources	Publication	Reference	Fields
Service sector employees	Level 3 (CensusSection)	ISTAT	Censimento dell'industria e dei servizi, 2011	http://www.istat.it/storage/cartografia/variabili-censuarie/dati-cpa_2011.zip	Field ADDETTI with field ATECO3 >400

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 Italy 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];
- the new "Proposal for an integrated national energy and climate plan" of 31 December 2018[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.

The **Liguria Region** (Genoa Area) BAU projections consider:

The most important event in the area is the definitive shut-down of Genoa Coal Thermal power plant.

In the residential and commercial sector, due to the structure of the city, the national goal for energy saving is already very ambitious and there are no further objectives at local level. For industrial emissions the national projections for NO_x are too high and local emissions are kept constant while the PM10 emissions are kept constant as the national ones.

Socio-economic drivers' definition is reported in Table 2-7 while technologic drivers' definition is reported in Table 2-8.

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. The NEC reduction are higher that emissions resulting from application of measures of UNFCCC NC. No more reductions are introduced other than NEC ones.

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[3] Ministry for the Environment, Land and Sea, Seventh National Communication under the UN Framework Convention on Climate Change. Italy, December 2017

[4] EEA Eionet, Reporting Obligations Database (ROD), Deliveries for National Emission Ceiling Directive (NECD) - Projected emissions by aggregated NFR sectors, 14 March 2019

[5] Ministero dello Sviluppo Economico, Ministero dell'Ambiente e della Tutela del Territorio e del Mare, Ministero delle Infrastrutture e dei Trasporti, Proposta di piano nazionale integrato per l'energia e il clima, 31/12/2018

Table 2-7: Liguria Region (Genoa Area): Socio-economic drivers used to project emissions in industrial, residential and commercial sector.

Code	Name	Domain
PSClose16	Closure of Plant from 2016	Centrale termoelettrica di Genova (Genoa power plant)

Table 2-8: Liguria Region (Genoa Area): Technological drivers used to project emissions in industrial, residential and commercial sector.

Code	Name	Domain
SOS_NECB_NOx	Liguria NEC Building NOx	all Genova Census Sections
SOS_NECB_PM	Liguria NEC Building PM	all Genova Census Sections

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 2-2);
- Residential and commercial sources (Table 2-3);
- Wood statistics (Table 2-4);
- Residential fuel energy demand (Table 2-5);
- Sezione di censimento disaggregation variables (Table 2-6).

Table 2-9: Methodology and source of data for Liguria Region (Genoa Area) fuel consumptions/emissions evaluation - Industrial sources.

Activity	Energy vector	Data availability	Source	Publication	Reference	Note	Disaggregation variable
Residential sector	Natural Gas	Level 2 (Comune)	Regione Liguria	Regional Energy Balance 2016	https://www.regione.liguria.it/giunta/26-servizi-online/14414-bilancio-energetico-regionale.html	Original data from regional gas distributors	Employees (Table 2-6)
	Electricity	Level 1 (Regione)	Regione Liguria	Regional Energy Balance 2016	https://www.regione.liguria.it/giunta/26-servizi-online/14414-bilancio-energetico-regionale.html	Original data from national electricity transmission grid operator	Employees (Table 2-6)

Table 2-10: Methodology and source of data for Liguria Region (Genoa Area) consumptions evaluation - Residential and commercial sources.

Activity	Energy vector	Data availability	Source	Publication	Reference	Note	Disaggregation variable
Residential sector	Natural Gas	Level 2 (Comune)	Regione Liguria	Regional Energy Balance 2016	https://www.regione.liguria.it/giunta/26-servizi-online/14414-bilancio-energetico-regionale.html	Original data from regional gas distributors	Dwelling area (Table 2-6)

Table 2-10: Methodology and source of data for Liguria Region (Genoa Area) consumptions evaluation - Residential and commercial sources.

Activity	Energy vector	Data availability	Source	Publication	Reference	Note	Disaggregation variable
	Wood	Level 1 (Regione)	Regione Liguria	Regional Energy Balance 2016	https://www.regione.liguria.it/giunta/26-servizi-online/14414-bilancio-energetico-regionale.html	Data at level 1 (regione) allocated to Level 2 with energy demand (Table 2-5)	Dwelling area (Table 2-6)
	LPG	Level 1 (Regione)	Regione Liguria	Regional Energy Balance 2016	https://www.regione.liguria.it/giunta/26-servizi-online/14414-bilancio-energetico-regionale.html	Aggregated Residential & Service sector data at level 1 (regione) subdivided with national (level 0) figure and then allocated to Level 2 with energy demand (Table 2-5)	Dwelling area (Table 2-6)
	Gasoil	Level 1 (Regione)	Regione Liguria	Regional Energy Balance 2016	https://www.regione.liguria.it/giunta/26-servizi-online/14414-bilancio-energetico-regionale.html	Aggregated Residential & Service sector data at level 1 (regione) subdivided with national (level 0) figure and then allocated to Level 2 with energy demand (Table 2-5)	Dwelling area (Table 2-6)
	Electricity	Level 2 (Comune)	Regione Liguria	Regional Energy	https://www.regione.liguria.it/giunta/26-servizi-	Original data from municipal electricity transmission grid operators	Dwelling area (Table 2-6)

Table 2-10: Methodology and source of data for Liguria Region (Genoa Area) consumptions evaluation - Residential and commercial sources.

Activity	Energy vector	Data availability	Source	Publication	Reference	Note	Disaggregation variable
				Balance 2016	online/14414-bilancio-energetico-regionale.html		
Service sector	Natural Gas	Level 2 (Comune)	Regione Liguria	Regional Energy Balance 2016	https://www.regione.liguria.it/giunta/26-servizi-online/14414-bilancio-energetico-regionale.html	Original data from regional gas distributors	Employees (Table 2-6)
	Wood	Single facility	Regione Liguria	Regional Energy Balance 2016	https://www.regione.liguria.it/giunta/26-servizi-online/14414-bilancio-energetico-regionale.html	Original data from Gestore dei Servizi Energetici GSE S.p.A.	None
	LPG	Level 1 (Regione)	Regione Liguria	Regional Energy Balance 2016	https://www.regione.liguria.it/giunta/26-servizi-online/14414-bilancio-energetico-regionale.html	Aggregated Residential & Service sector data at level 1 (regione) subdivided with national (level 0) figure and then allocated to Level 2 with employees (Table 2-6)	Employees (Table 2-6)

Table 2-10: Methodology and source of data for Liguria Region (Genoa Area) consumptions evaluation - Residential and commercial sources.

Activity	Energy vector	Data availability	Source	Publication	Reference	Note	Disaggregation variable
	Gasoil	Level 1 (Regione)	Regione Liguria	Regional Energy Balance 2016	https://www.regione.liguria.it/giunta/26-servizi-online/14414-bilancio-energetico-regionale.html	Aggregated Residential & Service sector data at level 1 (regione) subdivided with national (level 0) figure and then allocated to Level 2 with employees (Table 2-6)	Employees (Table 2-6)
	Electricity	Level 2 (Comune)	Regione Liguria	Regional Energy Balance 2016	https://www.regione.liguria.it/giunta/26-servizi-online/14414-bilancio-energetico-regionale.html	Original data from municipal electricity transmission grid operators	Employees (Table 2-6)

Table 2-11: Methodology and source of data for Liguria Region (Genoa Area) fuel consumptions evaluation – Wood statistics.

Variable	Data availability	Sources	Publication	Reference	Note
Technologies split	Level 1 (Liguria Region)	ISTAT ENEA	ISTAT I consumi energetici delle famiglie ENEA Rapporto Energia Ambiente (2005)	https://www.istat.it/it/files/2014/12/Tabelle_appendice_consumi_energetici.zip http://old.enea.it/produzione_scientifica/pdf_volumi/V06_01Analisi_05.pdf	On the basis of available data, the following shares are evaluated: traditional 85% and advanced 15% (ISTAT); fireplaces (2/3) and stoves (1/3) (ENEA) Service sector allocated to boilers.

Table 2-12: Methodology and source of data for Liguria Region (Genoa Area) residential energy demand evaluation.

Variable	Data availability	Sources	Publication	Reference	Note
Energy demand	Level 2 (Comune)	ISTAT ENEA	ISTAT, Censimento Popolazione ed Abitazioni, Abitazioni con impianto di riscaldamento per tipo di combustibile o energia che alimenta l'impianto di riscaldamento) Tabella dei gradi/giorno dei Comuni italiani raggruppati per Regione e Provincia	http://dati-censimentopopolazione.istat.it/Index.aspx?DataSetCode=dica_alloggi http://efficienzaenergetica.acs.enea.it/doc/dpr412-	Energy demand (F) of each comune is computed as: $F_{ij} = 24 \times (N_{ij} \times S_i \times 3) \times G_i \times D_i$ where *j* fuel, *i* comune, N number of dwelling, S average area of occupied

				93_allA_tabellagradigiorno.pdf	dwellings, G degrees days, D volume dispersion coefficient

Table 2-13: Methodology and source of data for Liguria Region (Genoa Area) level 3 fuel consumptions evaluation.

Variable	Data availability	Sources	Publication	Reference	Fields
Dwelling area	Level 3 (CensusSection)	ISTAT	Censimento della popolazione e delle abitazioni 2011	http://www.istat.it/storage/cartografia/variabili-censuarie/dati-sce_2011.zip	Average area of occupied dwellings
Industrial sector employees	Level 3 (CensusSection)	ISTAT	Censimento dell'industria e dei servizi, 2011	http://www.istat.it/storage/cartografia/variabili-censuarie/dati-cpa_2011.zip	Field ADDETTI with field ATECO3 <=400
Service sector employees	Level 3 (CensusSection)	ISTAT	Censimento dell'industria e dei servizi, 2011	http://www.istat.it/storage/cartografia/variabili-censuarie/dati-cpa_2011.zip	Field ADDETTI with field ATECO3 >400

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[6] up to 2030. In a conservative way, taking into consideration the uncertainty of national projections behind 2030 and the outlines of policy workshop no further reductions are foreseen for 2050.

For electricity emission factors an additional driver was introduced to take into consideration the evolution of carbon footprint from electricity generation. The driver is defined using official Italy projection data up to 2050[7].

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.

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[6] Ministero dello Sviluppo Economico Ministero dell'Ambiente e della Tutela del Territorio e del Mare Ministero delle Infrastrutture e dei Trasporti Proposta di Piano Nazionale Integrato per l'Energia ed il Clima, 31 Dicembre 2018

[7] Ministero dello sviluppo economico, Ministero dell'Ambiente e per la Tutela del Territorio e del Mare, Strategia Energetica Nazionale, 10 Novembre 2017

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 for various reporting years in for various scenarios. As mentioned earlier, in the model of Genoa modal shift is already assumed in the business as usual case, therefore we provide multiple snapshots of that scenario too.

Mode	Trip share (%)
1|Walk	20.79
2|Bicycle	1.76
3|Car/van	44.38
4|Bus/metro	16.54
5|Train/surface rail	8.52
6|Taxi	0.83
7|Other (incl. motorbike)	7.18

Figure 3-1: Trip shares in the calibrated mode choice model for the Baseline (BAU 2016).

Mode	Mileage change	Trip share (%)
1|Walk	1.044	21.4
2|Bicycle	▲ 1.145	1.9
3|Car/van	▼ 0.913	39.3
4|Bus/metro	▲ 1.213	19.9
5|Train/surface rail	▲ 1.191	10.4
6|Taxi	▼ 0.884	0.7
7|Other (incl. motorbike)	▼ 0.909	6.4

Figure 3-2: Trip shares in the calibrated mode choice model for the Baseline (BAU 2025).

Mode	Mileage change	Trip share (%)
1|Walk	1.024	21.0
2|Bicycle	1.177	2.0
3|Car/van	0.891	38.3
4|Bus/metro	1.257	20.9
5|Train/surface rail	1.252	11.0
6|Taxi	0.885	0.7
7|Other (incl. motorbike)	0.879	6.1

Figure 3-3: Trip shares in the calibrated mode choice model for the Baseline (BAU 2050).

Mode	Mileage change	Trip share (%)
1|Walk	1.110	22.4
2|Bicycle	2.460	4.0
3|Car/van	0.814	33.6
4|Bus/metro	1.364	22.3
5|Train/surface rail	1.409	12.1
6|Taxi	0.740	0.6
7|Other (incl. motorbike)	0.738	5.1

Figure 3-4: Model Scenario (2035).

Mode	Mileage change	Trip share (%)
1|Walk	1.319	25.4
2|Bicycle	6.886	9.9
3|Car/van	0.514	18.3
4|Bus/metro	1.898	29.1
5|Train/surface rail	1.925	15.0
6|Taxi	0.355	0.3
7|Other (incl. motorbike)	0.376	2.2

Figure 3-5: Model 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]	47.38%	46.73%	34.22%	28.08%
[HPETROL]	0.73%	0.80%	0.34%	0.26%
[LDIESEL]	35.50%	36.28%	48.96%	45.46%
[HDIESEL]	8.26%	2.81%	3.79%	3.52%
[ELECTRIC]	0.04%	0.53%	1.68%	8.01%
[FUELCELL]	0.00%	0.03%	0.20%	1.15%
[HYBRID]	0.10%	0.78%	1.69%	5.98%
[HYBDIS]	0.01%	0.46%	0.99%	3.05%
[CNG]	2.09%	3.35%	2.66%	2.06%
[LPG]	5.89%	8.22%	5.46%	2.42%
[E85]	0.00%	0.00%	0.00%	0.00%

VENSIM model in percentage of total fleet per reporting year				
Scenario	2016	2025	2035	2050
[LPETROL]	47.38%	46.53%	31.92%	15.35%
[HPETROL]	0.73%	0.79%	0.32%	0.14%
[LDIESEL]	35.50%	35.93%	45.22%	24.85%
[HDIESEL]	8.26%	2.78%	3.50%	1.93%
[ELECTRIC]	0.04%	0.68%	3.96%	19.89%
[FUELCELL]	0.00%	0.13%	1.31%	7.59%
[HYBRID]	0.10%	1.05%	4.37%	24.21%
[HYBDIS]	0.01%	0.55%	1.43%	2.49%
[CNG]	2.09%	3.34%	2.50%	1.13%
[LPG]	5.89%	8.22%	5.46%	2.43%
[E85]	0.00%	0.00%	0.00%	0.00%

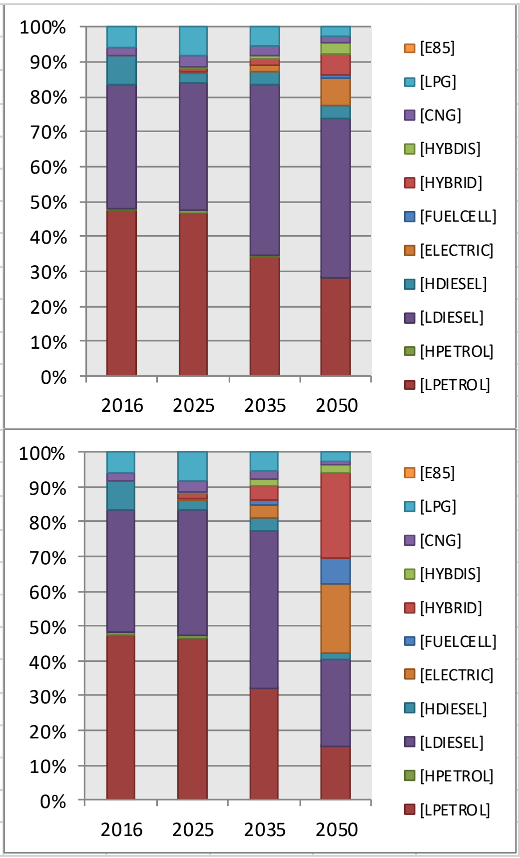

Figure 3-6: Passenger car fleet composition in the BAU and in the Model Scenario.

Table 3-1: relative emissions in the BAU and SDW scenario for Liguria.

MIDZWVR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	63.80%	36.14%	21.79%
SCEN		63.80%	36.14%	21.79%

PM

Year	2015	2025	2035	2050
BAU	100.00%	67.51%	40.85%	38.53%
SCEN		67.51%	40.85%	38.53%

PM_NE

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

MOTO

Nox

Year	2015	2025	2035	2050
BAU	100.00%	99.79%	63.08%	37.76%
SCEN		85.53%	45.06%	18.88%

PM

Year	2015	2025	2035	2050
BAU	100.00%	73.07%	45.61%	42.70%
SCEN		62.63%	32.58%	21.35%

PM_NE

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

ZWVR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	24.16%	12.52%	7.44%
SCEN		24.16%	6.26%	2.23%

PM

Year	2015	2025	2035	2050
BAU	100.00%	33.81%	24.73%	22.98%
SCEN		33.81%	12.36%	6.89%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	109.92%	120.82%	139.23%
SCEN		109.92%	60.41%	41.77%

CAR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	19.12%	16.73%	7.57%
SCEN		19.12%	15.29%	4.37%

PM

Year	2015	2025	2035	2050
BAU	100.00%	14.60%	14.70%	10.82%
SCEN		14.60%	13.43%	6.25%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	96.97%	99.94%	104.88%
SCEN		96.97%	91.28%	60.55%

BUS

Nox

Year	2015	2025	2035	2050
BAU	100.00%	119.07%	90.99%	54.46%
SCEN		144.48%	124.07%	103.36%

PM

Year	2015	2025	2035	2050
BAU	100.00%	41.21%	27.45%	25.70%
SCEN		50.00%	37.44%	48.78%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	134.03%	153.36%	178.05%
SCEN		162.63%	209.13%	337.91%

VAN

Nox

Year	2015	2025	2035	2050
BAU	100.00%	41.46%	26.44%	14.68%
SCEN		41.46%	25.71%	13.08%

PM

Year	2015	2025	2035	2050
BAU	100.00%	41.05%	27.77%	24.67%
SCEN		41.05%	27.14%	22.39%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	103.99%	111.58%	124.51%
SCEN		103.99%	107.26%	102.35%

Table 3-2: Relative emissions in the (updated) BAU and UPS scenario for Liguria.

MIDZWVR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	63.80%	36.14%	21.79%
UPS		63.80%	36.14%	21.79%

PM

Year	2015	2025	2035	2050
BAU	100.00%	67.51%	40.85%	38.53%
UPS		67.51%	40.85%	38.53%

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%	99.79%	63.08%	37.76%
UPS		85.53%	45.06%	18.88%

PM

Year	2015	2025	2035	2050
BAU	100.00%	73.07%	45.61%	42.70%
UPS		62.63%	32.58%	21.35%

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%	21.98%	7.25%	2.67%
UPS		21.98%	7.25%	2.67%

PM

Year	2015	2025	2035	2050
BAU	100.00%	30.76%	14.33%	8.25%
UPS		30.76%	14.33%	8.25%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	100.00%	70.00%	50.00%
UPS		100.00%	70.00%	50.00%

CAR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	19.24%	18.14%	15.18%
UPS		19.12%	15.29%	4.37%

PM

Year	2015	2025	2035	2050
BAU	100.00%	14.66%	15.58%	15.06%
UPS		14.60%	13.43%	6.25%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	96.97%	99.94%	104.88%
UPS		96.97%	91.28%	60.55%

BUS

Nox

Year	2015	2025	2035	2050
BAU	100.00%	119.07%	90.99%	54.46%
UPS		144.48%	124.07%	103.36%

PM

Year	2015	2025	2035	2050
BAU	100.00%	41.21%	27.45%	25.70%
UPS		50.00%	37.44%	48.78%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	134.03%	153.36%	178.05%
UPS		162.63%	209.13%	337.91%

VAN

Nox

Year	2015	2025	2035	2050
BAU	100.00%	41.52%	27.14%	18.49%
UPS		41.46%	25.71%	13.08%

PM

Year	2015	2025	2035	2050
BAU	100.00%	41.09%	28.21%	26.80%
UPS		41.05%	27.14%	22.39%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	103.99%	111.58%	124.51%
UPS		103.99%	107.26%	102.35%

3.2 Spatial-temporal

- Data pre-processing

The temperature dataset is shared by Claircity's local partner via a local meteorology website and obtained from the Alpe Goretto station. It is available as a .csv file and has five variables, translated as start date and time of detection, end date and time of detection, temperature value in Celsius to one decimal place, dataset and validity. The temperature data are presented in hourly resolutions, though only 8724 valid observations are provided. Therefore, we found missing values here. First, we reduced some unnecessary variables such as "end date and time of detection", "dataset" and "validity". We eliminated the dataset and validity variables because the values of 8724 observations of the "dataset" variable are all marked

“Tutti i dati” (“all the data”) in Italian. Likewise, the values of 8724 observations of the “validity” variable are all marked “Si” (“Yes”). Thus, we can assume that all values are valid and therefore that it will be more efficient to reduce these variables in the dataset. Regarding the missing values here, which are typically the missing unknown observations, we performed a simple screening and cleaning solution in the spreadsheet. We filled in the complete hourly observations, which should total 8760 observations for the variables start date, time of detection and end date and time of detection and value of temperature, making it possible identify and interpolate the missing values. We then transformed the hourly values into daily average values as required.

Table 3-3: Resulting intra-day profiles.

Typical days (TD)	Pattern (%)		
	Commercial	Residential	
	NOX and PM10	NOX	PM10
11-02-2015	0,33842676	0,350310424	0,714876483
15-02-2015	0,356294179	0,368805247	0,752618764
12-08-2015	0,245993462	0,240889631	0,084314725
16-08-2015	0,27364912	0,267971494	0,093793755

3.3 IRCI

3.3.1 Baseline

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

- Liguria Region (Genoa Area) Residential, Commercial & Institutional NOx emissions for all sectors and fuels (Figure 3-7**: Liguria Region (Genoa Area) Residential, Commercial & Institutional NOx emissions – all sectors and fuels.**

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- Liguria Region (Genoa Area) Residential, Commercial & Institutional PM10 emissions for all sectors and fuels (Figure 3-8: **Liguria Region (Genoa Area) Residential, Commercial & Institutional PM10 emissions – all sectors and fuels.**

- Liguria Region (Genoa Area) Residential, Commercial & Institutional PM10 emissions from solid biomass (Figure 3-9: Liguria **Region (Genoa Area) Residential, Commercial & Institutional PM10 emissions – solid biomass.**

- Liguria Region (Genoa Area) Industry NOx point emissions (Figure 3-10: Liguria **Region (Genoa Area) Industry NOx point emissions.**

- Liguria Region (Genoa Area) Industry NOx area emissions (Figure 3-11: Liguria **Region (Genoa Area) Industry NOx area emissions.**

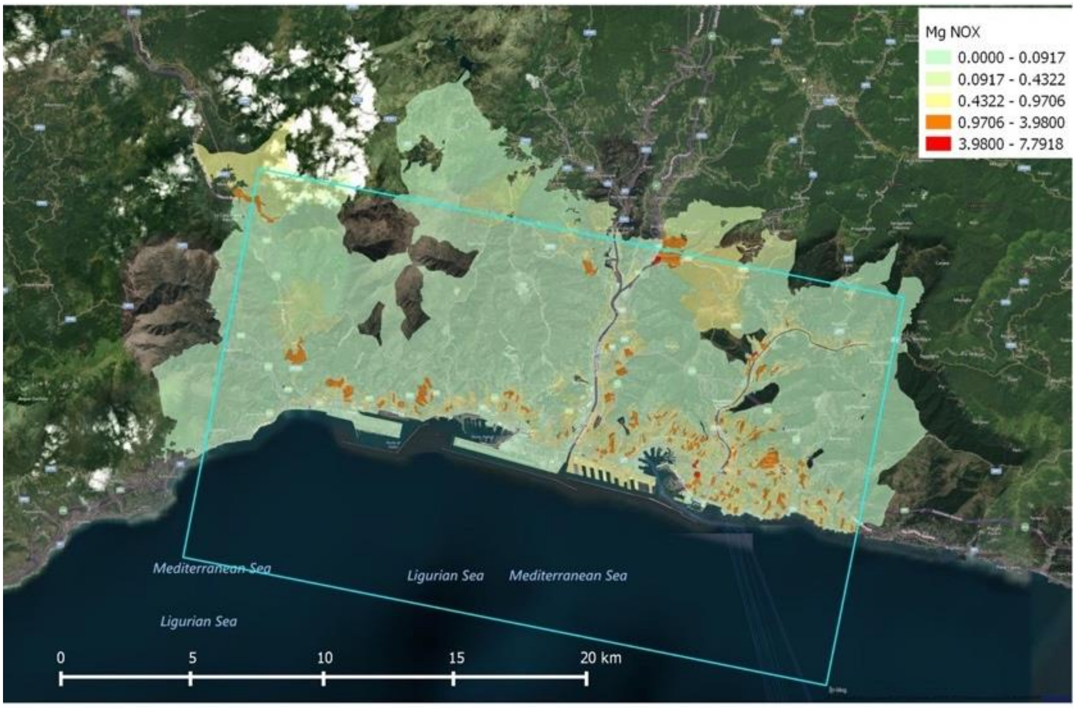


Figure 3-7: Liguria Region (Genoa Area) Residential, Commercial & Institutional NOx emissions – all sectors and fuels.

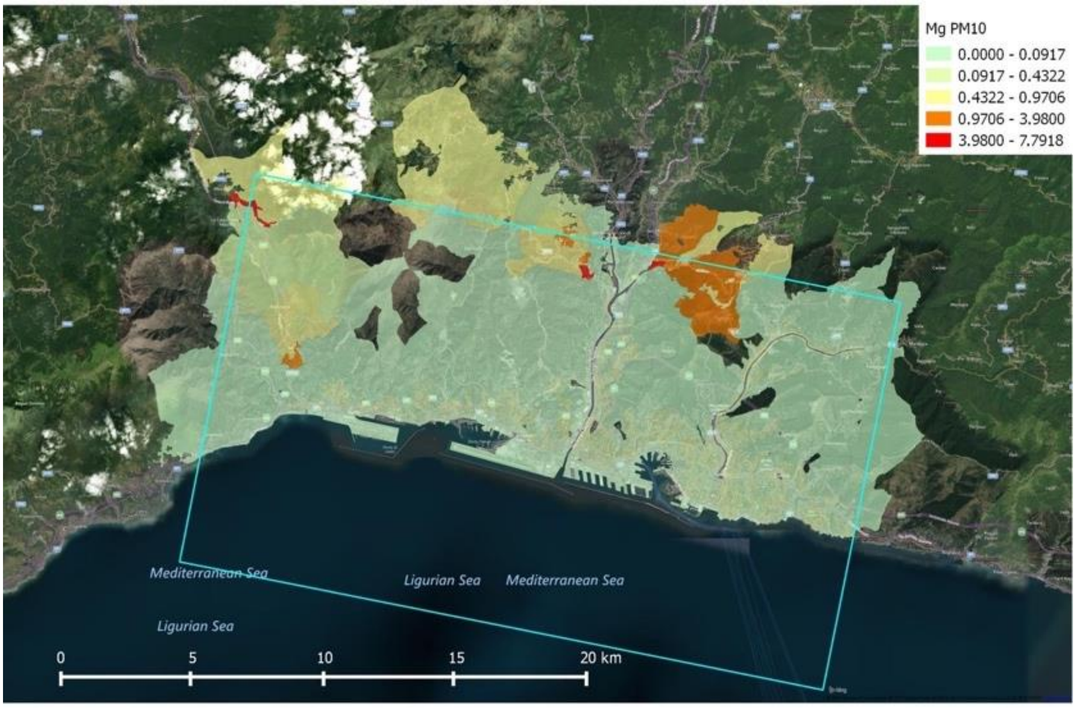


Figure 3-8: Liguria Region (Genoa Area) Residential, Commercial & Institutional PM10 emissions – all sectors and fuels.

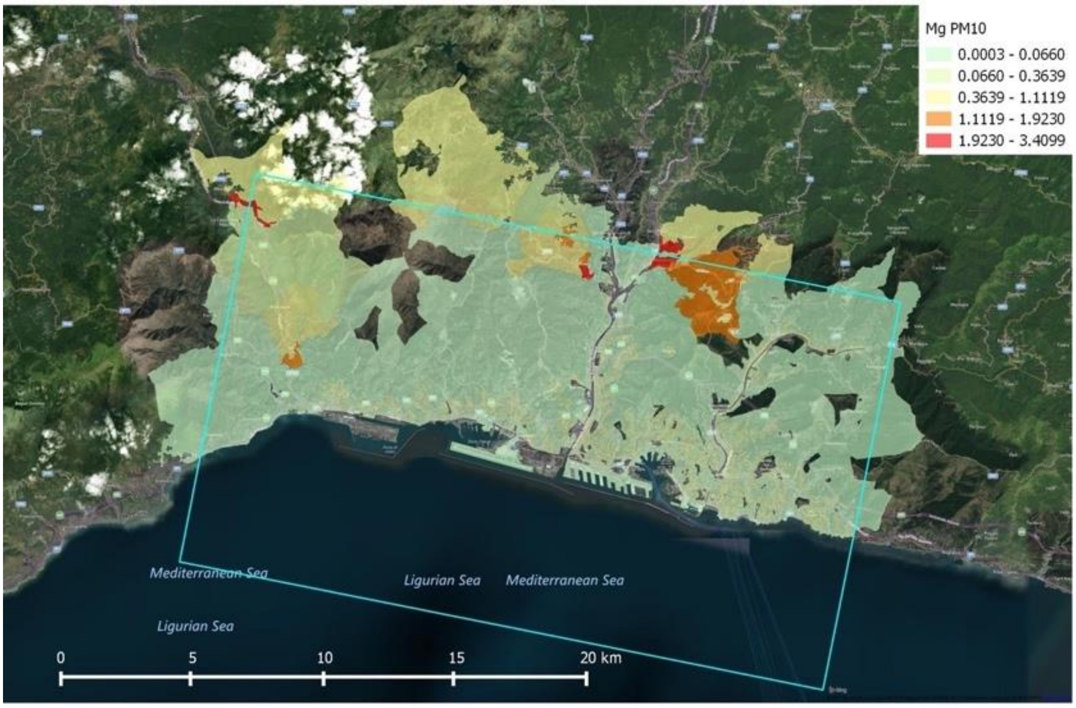


Figure 3-9: Liguria Region (Genoa Area) Residential, Commercial & Institutional PM10 emissions – solid biomass.

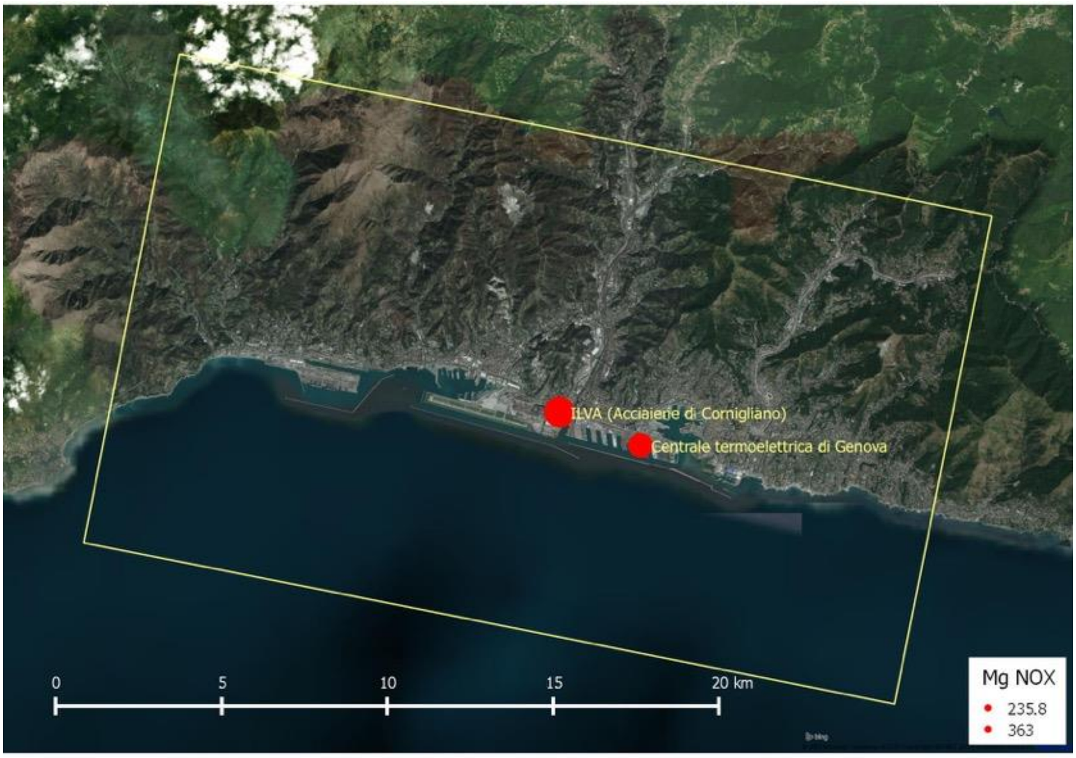


Figure 3-10: Liguria Region (Genoa Area) Industry NOx point emissions.

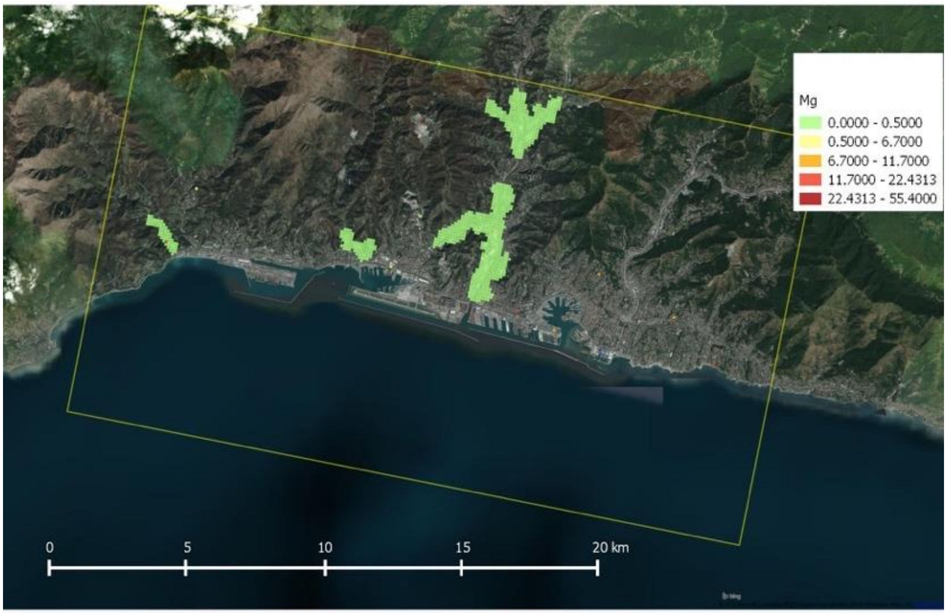


Figure 3-11: Liguria Region (Genoa Area) Industry NOx area emissions.

Finally, in the following Figure 3-12**: Liguria Region Genoa Comune Residential, Commercial & Institutional NOx emissions** and Figure 3-13: **Liguria Region Genoa Comune Residential, Commercial & Institutional PM10 emissions** the emissions for the different activities & fuels in the only *Genova Comune* are reported.

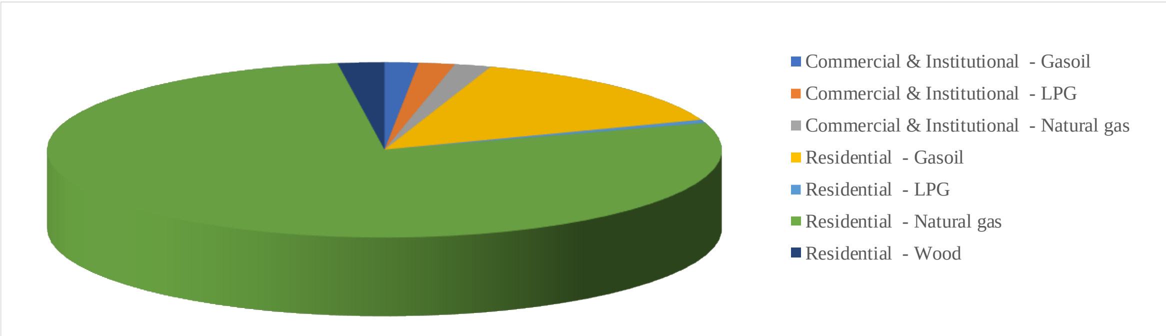


Figure 3-12: Liguria Region Genoa Comune Residential, Commercial & Institutional NOx emissions

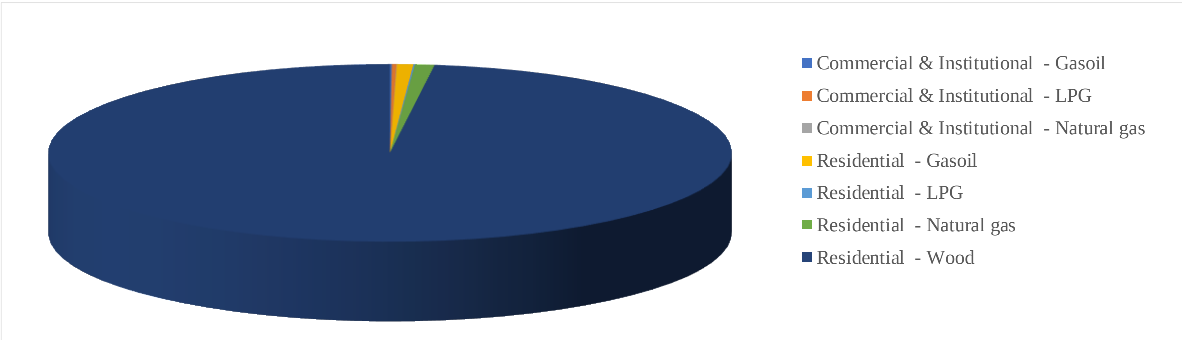


Figure 3-13: Liguria Region Genoa Comune Residential, Commercial & Institutional PM10 emissions.

3.3.2 BAU

The evolutions of industrial emissions are reported in Figure 3-14 for nitrogen oxides (NO_x) and for suspended particles with diameter less than 10µ (PM_{10}). The only significant modification comes from the definitive shut-down of Genoa Coal Thermal power plant.

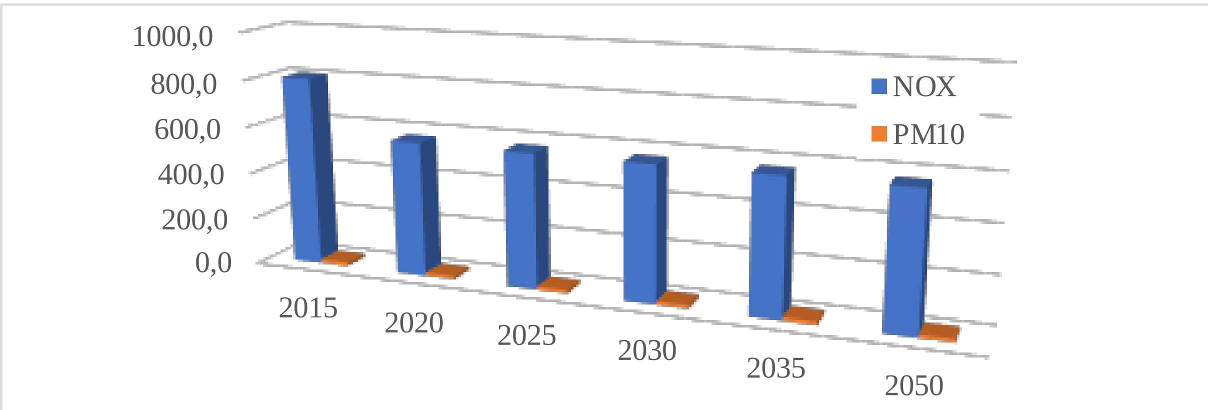


Figure 3-14: Liguria Region (Genoa Area) BAU Industrial main point sources NOx emissions.

The evolutions of residential, commercial and institutional emissions in Genoa Area of Liguria Region are reported in Figure 3-15 for nitrogen oxides (NO_x) and for suspended particles with diameter less than 10μ (PM_{10}).

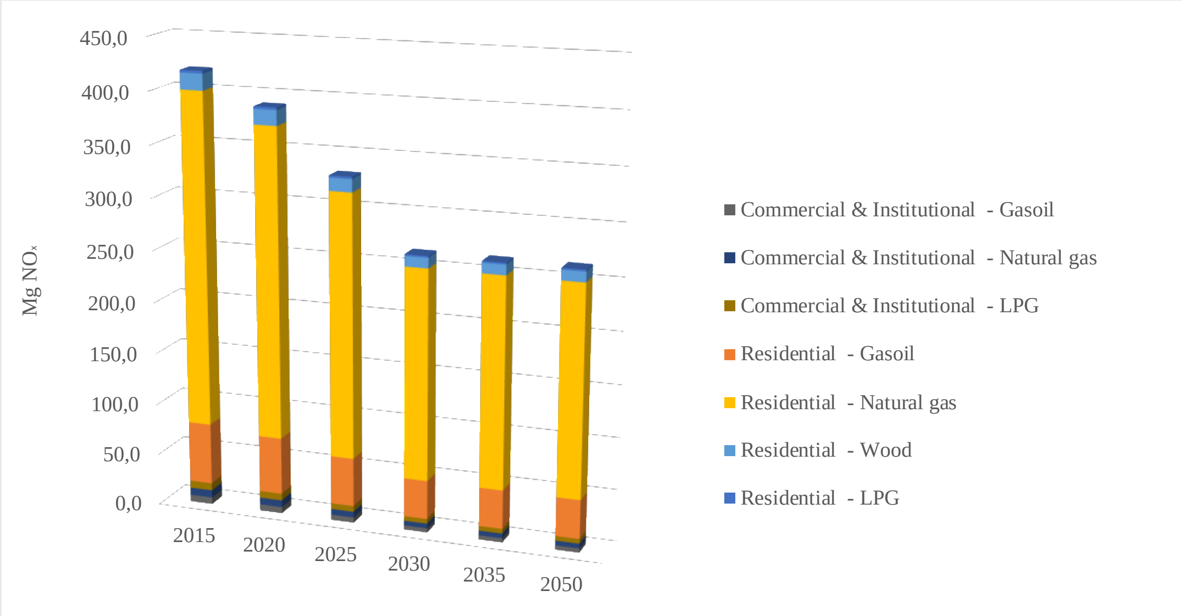


Figure 3-15: Liguria Region (Genoa Area) BAU total Residential, Commercial & Institutional NOx emissions.

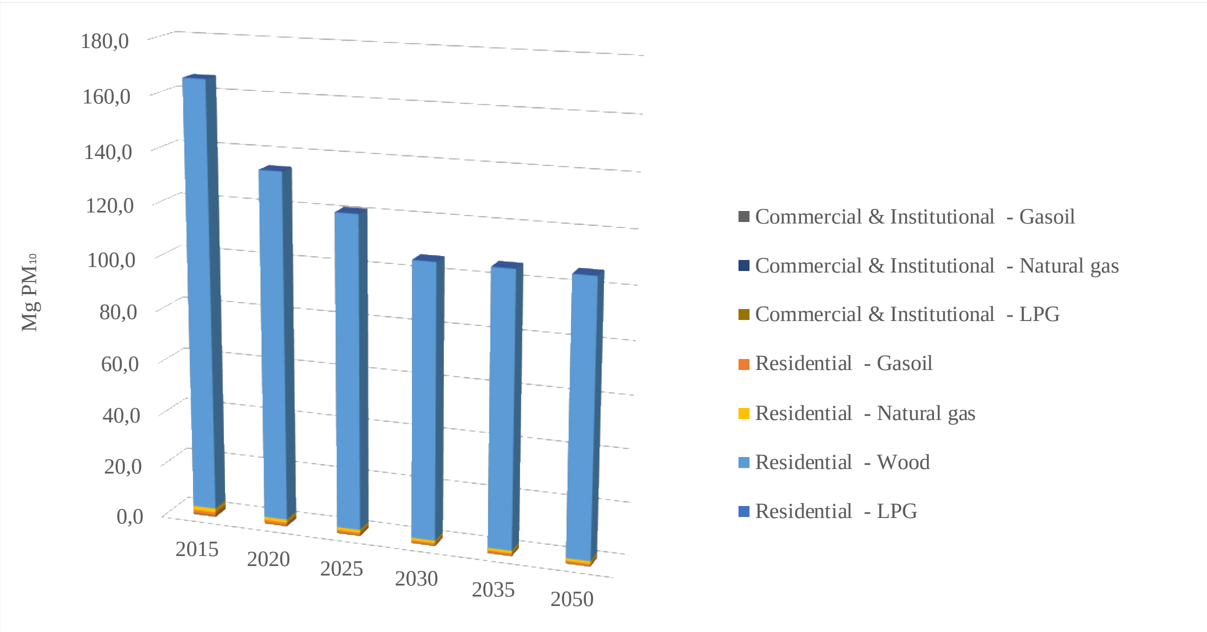


Figure 3-16: Liguria Region (Genoa Area) BAU Residential, Commercial & Institutional PM10 emissions.

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 3-4 Carbon Footprint by fuel is reported for Genoa expressed as CO_2, CO_2 equivalent and CO_2 equivalent on Life Cycle.

Table 3-4: Genoa Carbon Footprint by Fuel (Mg).

Energy Vector	CO_2	CO_{2eq}	$CO_{2eq,LCA}$
Biomass	-	487	1.204
Gasoil/diesel	192.266	192.785	220.251
Gasoline	100.700	100.991	126.893
LPG	15.313	15.313	18.953
Natural gas	556.601	556.601	661.770
Electricity	655.926	657.991	810.788
Total	**1.520.806**	**1.524.167**	**1.839.859**

In Figure 3-17 Carbon Footprint expressed as CO_2 equivalent on Life Cycle is reported by fuel and sector.

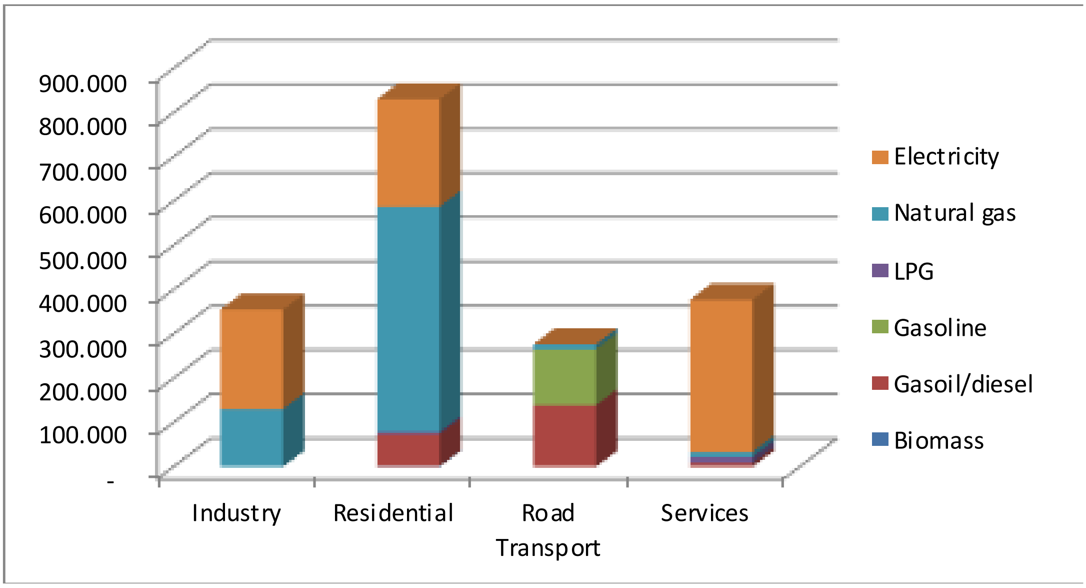


Figure 3-17: Genoa Carbon Footprint (Mg CO2 equivalent on Life Cycle).

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

- Genoa Census Sections Carbon Footprint for all sectors and fuel (Figure 3-18),
- Genoa Census Sections Carbon Footprint for Industrial sector (Figure 3-19);
- Genoa Census Sections Carbon Footprint for Residential sector (Figure 3-20);
- Genoa Census Sections Carbon Footprint for Services sector (Figure 3-21);
- Genoa Census Sections Carbon Footprint for Road Transport sector (Figure 3-22).

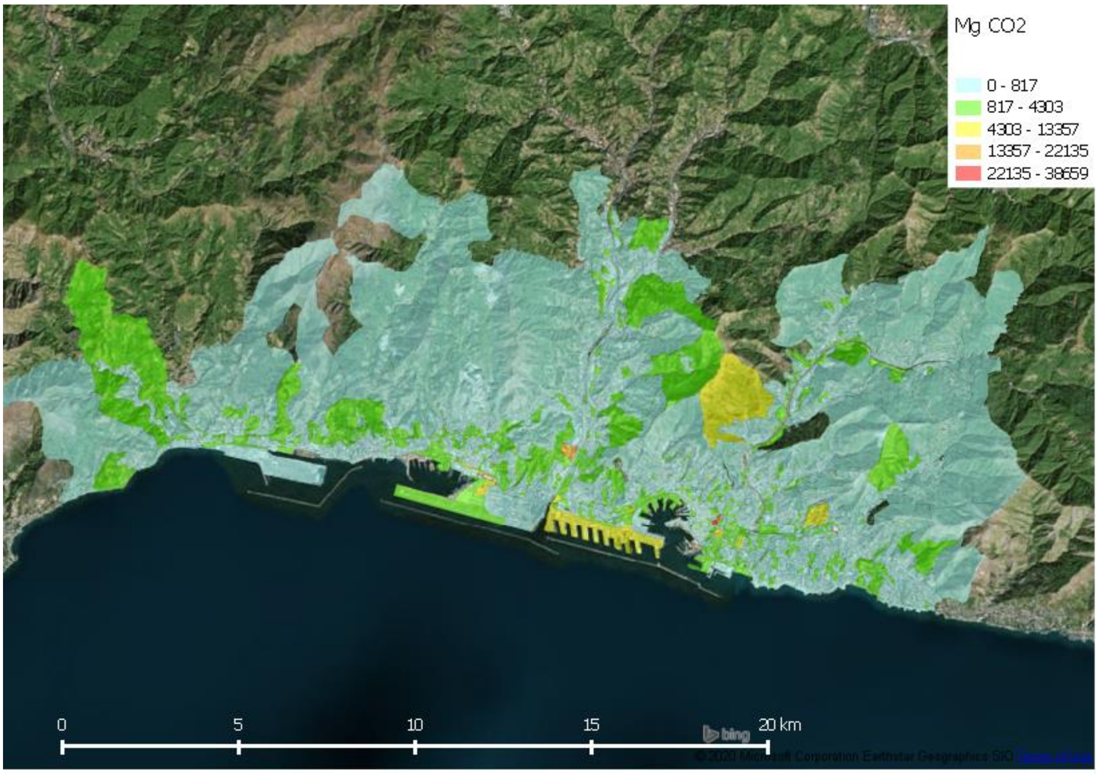


Figure 3-18: Genoa Census Sections Carbon Footprint – all sectors.

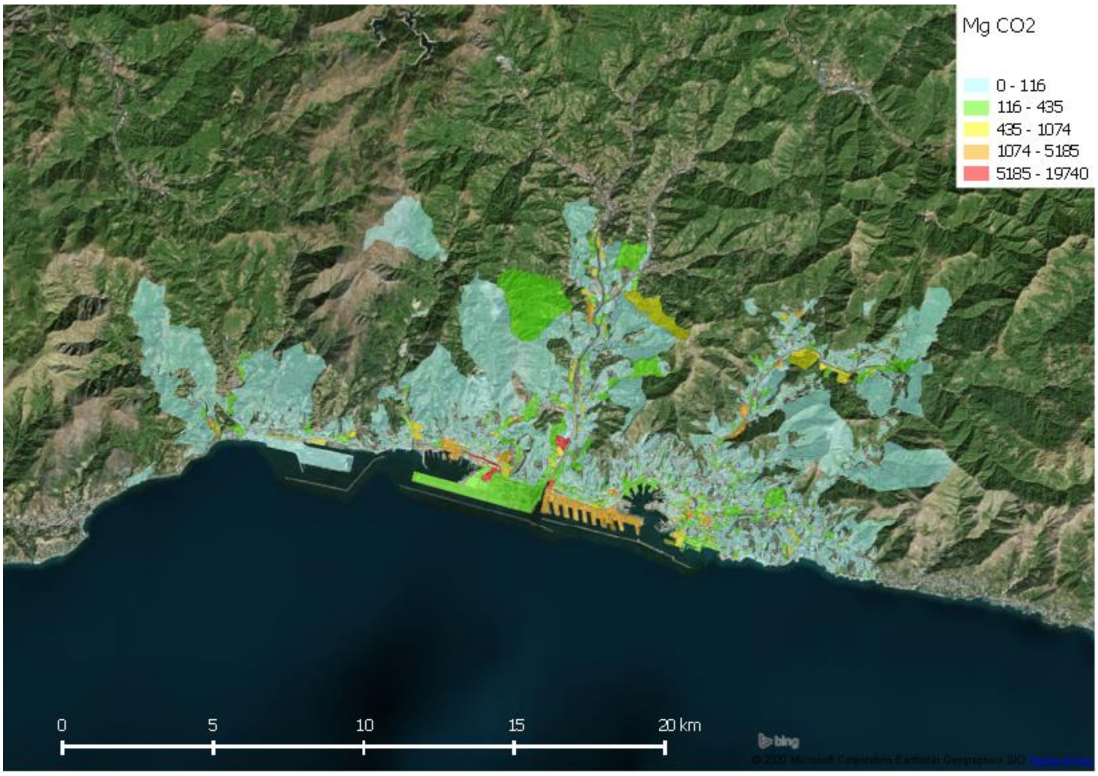


Figure 3-19: Genoa Census Sections Carbon Footprint – industry sector.

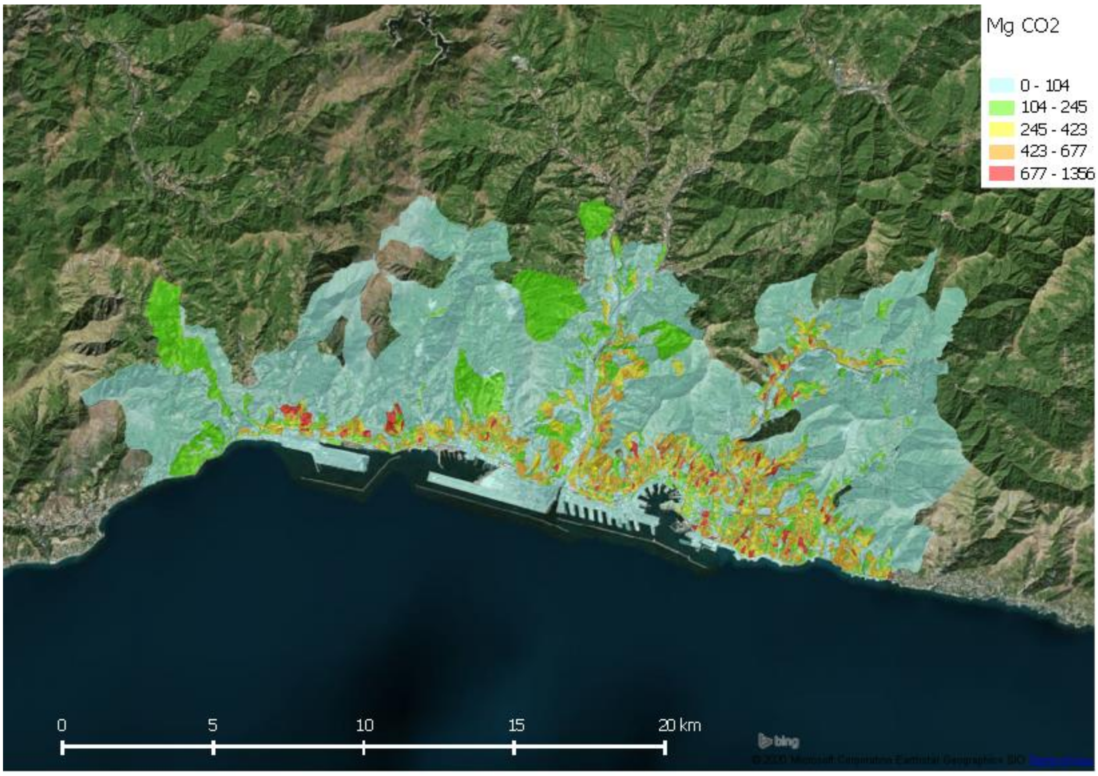


Figure 3-20: Genoa Census Sections Carbon Footprint – residential sector.

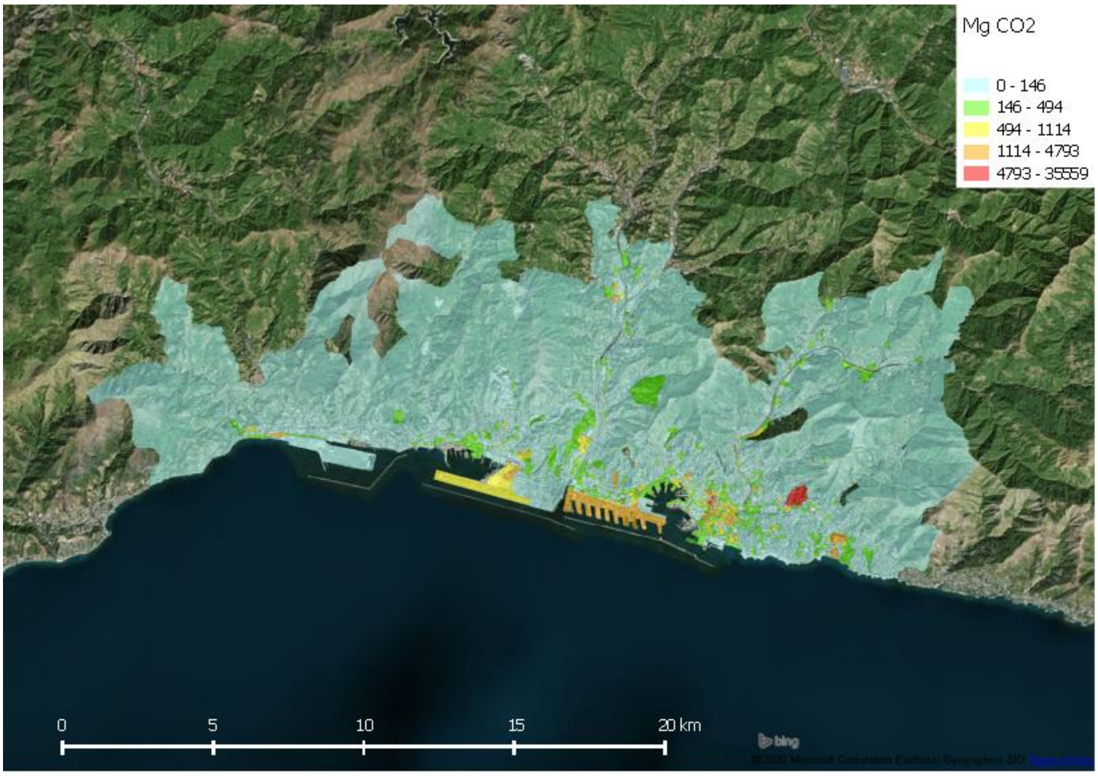


Figure 3-21: Genoa Census Sections Carbon Footprint – services sector.

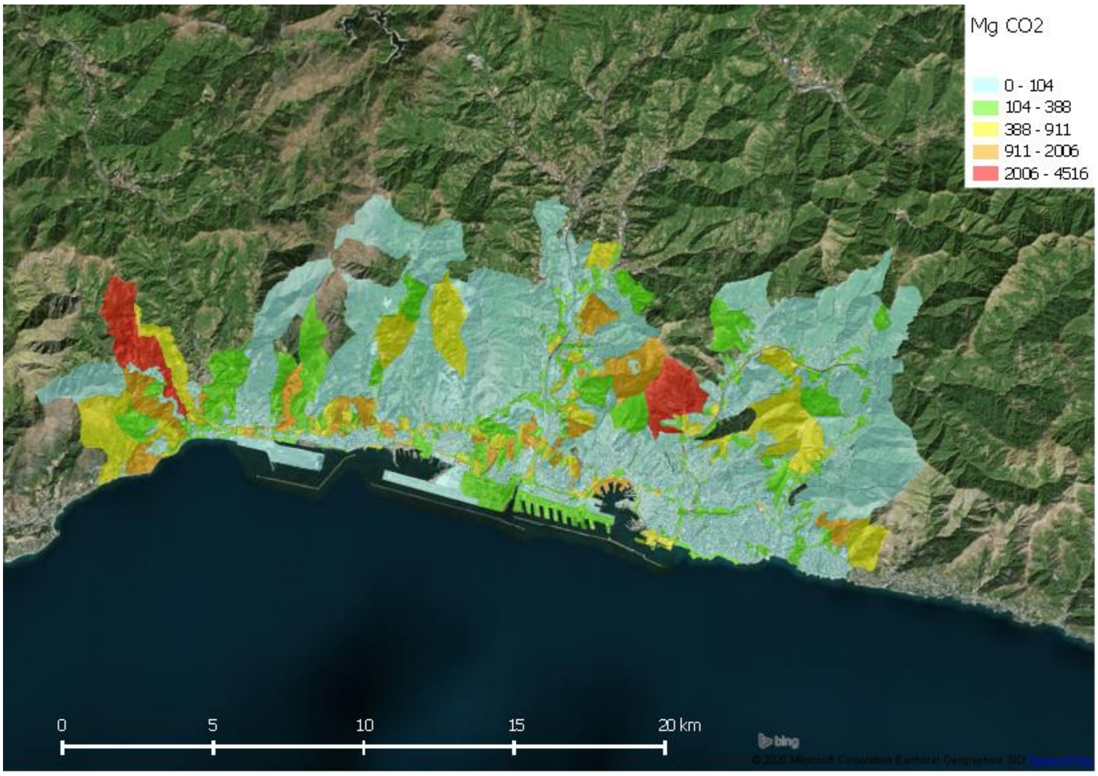


Figure 3-22: Genoa Census Sections Carbon Footprint – road transport.

3.4.2 BAU

In Table 3-5 Carbon Footprint by sector is reported for Genoa BAU expressed as CO_2, CO_2 equivalent and CO_2 equivalent on Life Cycle. In Table 3-5 CO2 equivalent on Life Cycle reductions on 2015 are reported.

Table 3-5: Genoa BAU Carbon Footprint by Sector (Gg).

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide (CO_2)						
Residential	691,7	626,0	521,6	413,3	392,1	326,3
Services	306,4	267,1	228,7	181,1	149,8	48,2

Transport	231,3	212,6	194,5	186,9	179,6	140,1
Industry	291,5	265,3	221,0	173,1	153,1	93,2
Total	***1.520,8***	***1.371,1***	***1.165,8***	***954,4***	***874,6***	***607,8***
Carbon dioxide equivalent (CO_{2eq})						
Industry	693,0	627,1	522,6	414,0	392,8	326,8
Services	307,3	267,9	229,4	181,6	150,2	48,3
Transport	231,9	213,2	195,0	187,4	180,1	140,5
Residential	292,0	265,8	221,4	173,4	153,4	93,3
Total	***1.524,2***	***1.374,1***	***1.168,3***	***956,5***	***876,4***	***608,8***
Carbon dioxide equivalent on life cycle (CO_{2eq})						
Residential	830,3	751,0	625,7	495,5	469,3	388,1
Services	377,6	329,2	281,8	223,1	184,4	58,8
Transport	276,9	254,6	233,0	222,7	212,8	165,3
Industry	355,1	323,1	268,9	210,4	185,7	111,6
Total	***1.839,9***	***1.658,0***	***1.409,5***	***1.151,7***	***1.052,2***	***723,8***

Table 3-6: Genoa 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	90	75	60	57	47
Services	100	87	75	59	49	16
Transport	100	92	84	80	77	60
Industry	100	91	76	59	52	31
Total	***100***	***90***	***77***	***63***	***57***	***39***

Carbon Footprint, expressed as CO_2 equivalent on Life Cycle, is reported in Figure 3-23 by sector and in Figure 3-24 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.

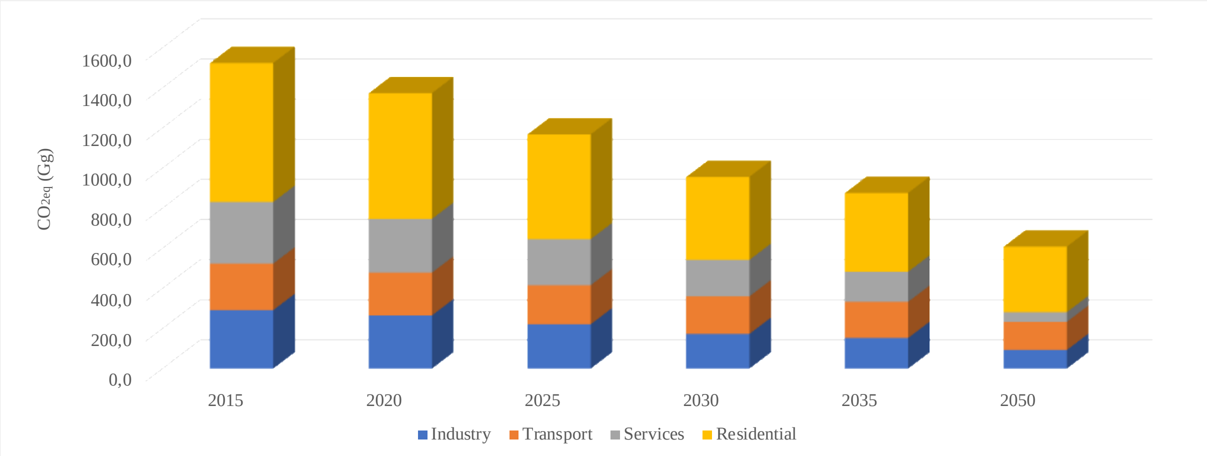


Figure 3-23: Genoa BAU Carbon Footprint by sector (Gg CO2 equivalent on Life Cycle).

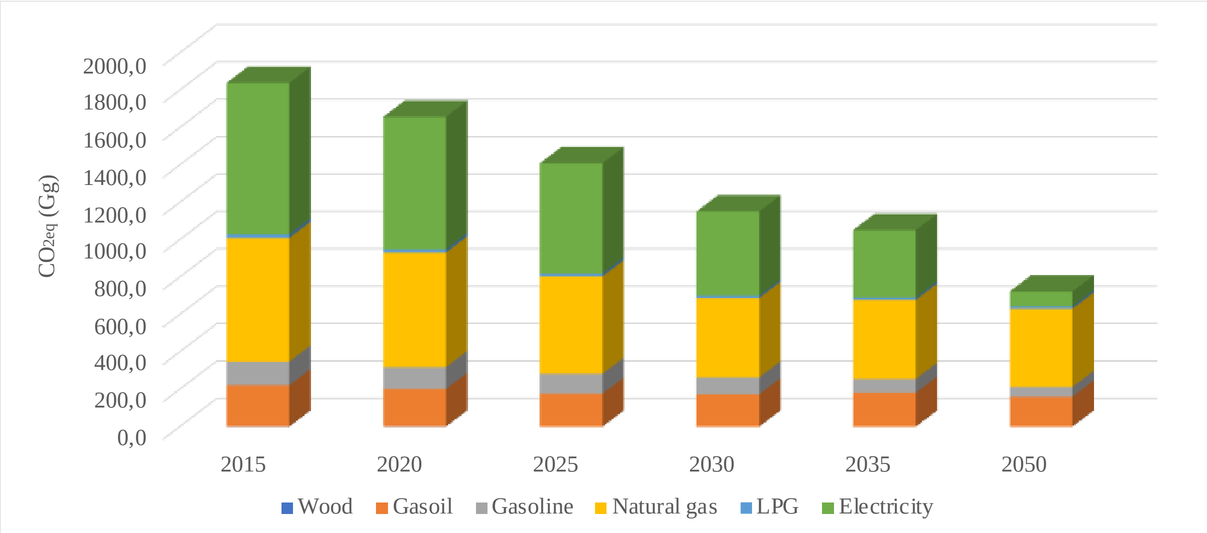


Figure 3-24: Genoa BAU Carbon Footprint by fuel (Gg CO_2 equivalent on Life Cycle).

3.4.3 Stakeholder dialog workshop Scenarios

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

Table 3-7: Genoa Scenario Carbon Footprint by Sector (Gg).

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide (CO_2)						
Residential	691,7	626,0	521,6	413,3	392,1	326,3
Services	306,4	267,1	228,7	181,1	149,8	48,2

Transport	231,3	215,7	198,8	180,9	163,1	78,9
Industry	291,5	265,3	221,0	173,1	153,1	93,2
Total	***1.520,8***	***1.374,1***	***1.170,1***	***948,4***	***858,1***	***546,7***
Carbon dioxide equivalent (CO_{2eq})						
Residential	693,0	627,1	522,6	414,0	392,8	326,8
Services	307,3	267,9	229,4	181,6	150,2	48,3
Transport	231,9	216,3	199,3	181,4	163,5	79,1
Industry	292,0	265,8	221,4	173,4	153,4	93,3
Total	***1.524,2***	***1.377,1***	***1.172,6***	***950,4***	***859,9***	***547,5***
Carbon dioxide equivalent on life cycle (CO_{2eq})						
Residential	830,3	751,0	625,7	495,5	469,3	388,1
Services	377,6	329,2	281,8	223,1	184,4	58,8
Transport	276,9	258,3	238,2	215,8	193,5	93,1
Industry	355,1	323,1	268,9	210,4	185,7	111,6
Total	***1.839,9***	***1.661,6***	***1.414,7***	***1.144,8***	***1.032,9***	***651,6***

Table 3-8: Genoa 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	90	75	60	57	47
Services	100	87	75	59	49	16
Transport	100	93	86	78	70	34
Industry	100	91	76	59	52	31
Total	***100***	***90***	***77***	***62***	***56***	***35***

For the Scenario, Carbon Footprint, expressed as CO_2 equivalent on Life Cycle, is reported in Figure 3-25 by sector and in Figure 3-26 by fuel.

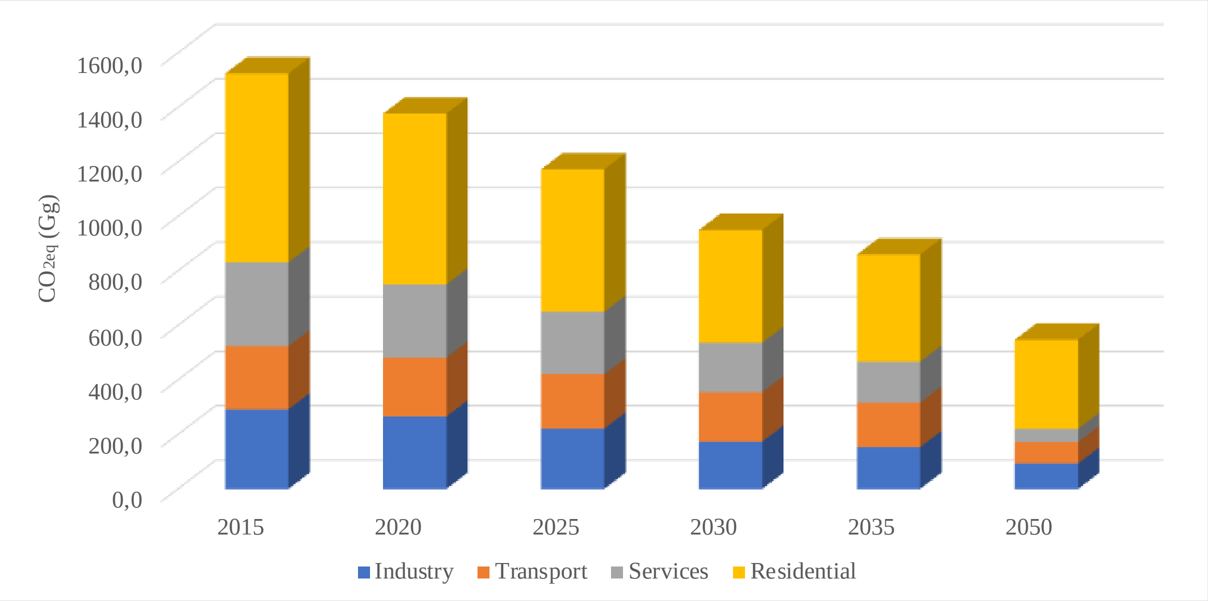


Figure 3-25 – Genoa Scenario Carbon Footprint by sector (Gg CO2 equivalent on Life Cycle)

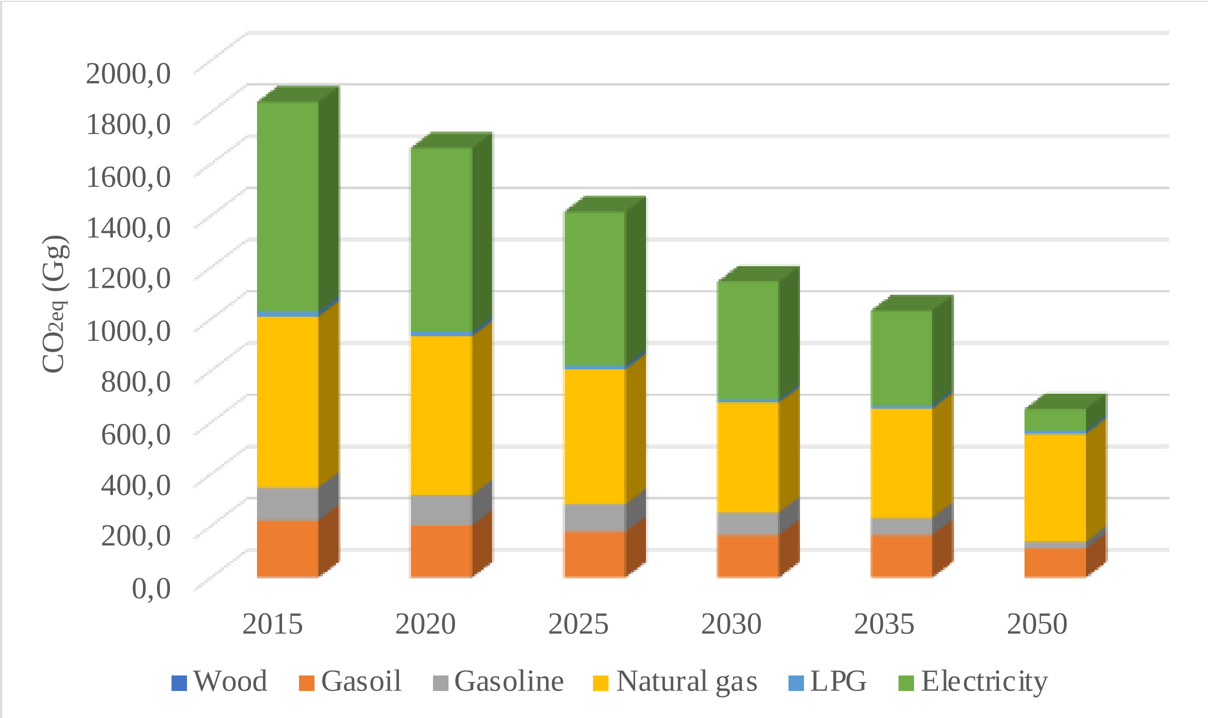


Figure 3-26 – Genoa Scenario Carbon Footprint by fuel (Gg CO_2 equivalent on Life Cycle)

Total Carbon Footprint in the different scenarios is compared in Figure 3-27 expressed as CO_2 equivalent on Life Cycle.

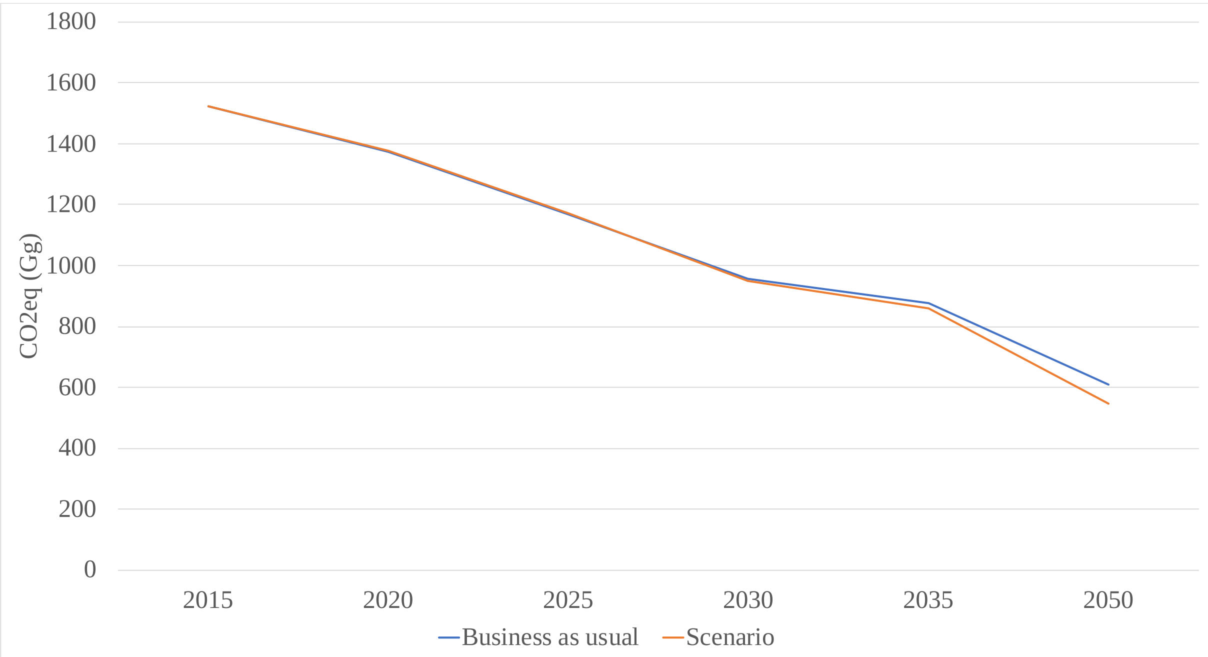


Figure 3-27 – Genoa Carbon Footprint (Mg CO2 equivalent on Life cycle) by scenario

3.4.4 Unified Policy Scenario

Unified Policy Scenario is the same as the Scenario from the Stakeholder dialog workshop.

In Figure 3-28 results are reported by sector and in Figure 3-29 by sector and fuel. Finally, in Figure 3-30 Carbon Footprint on life cycle generated by citizens' activities is reported in BAU and UPS scenario.

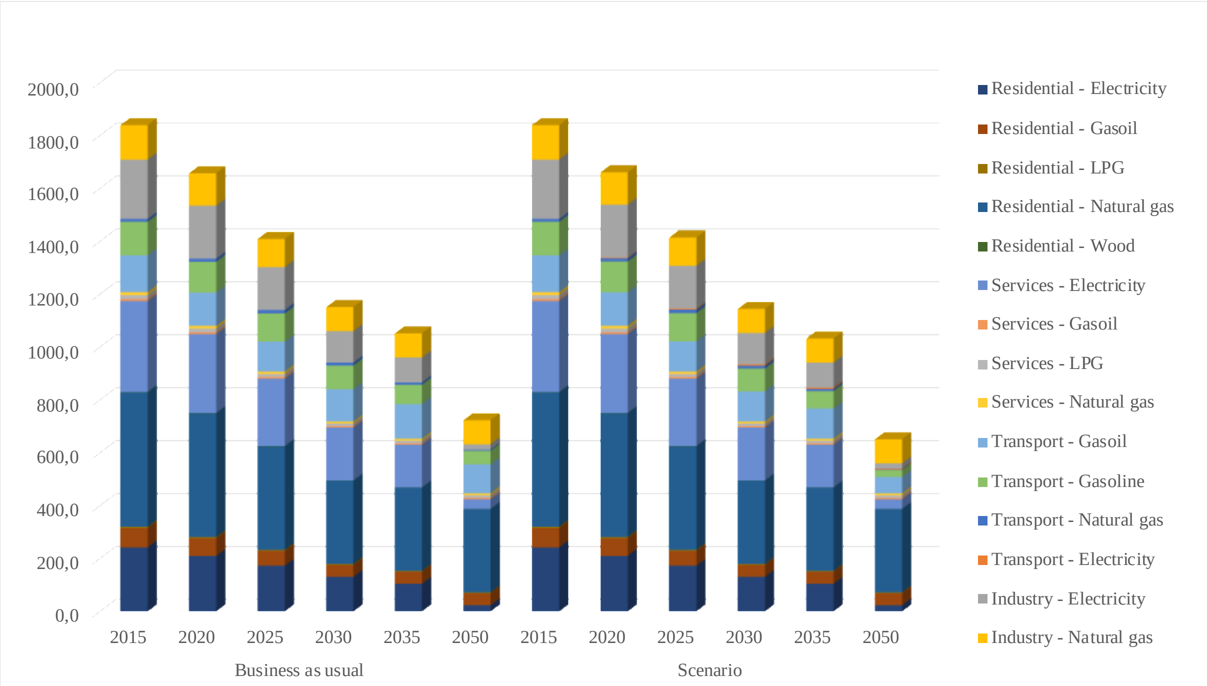


Figure 3-28 – Genoa Carbon Footprint on life cycle BAU and UPS comparison by sector ($Mg\ CO_2$ equivalent)

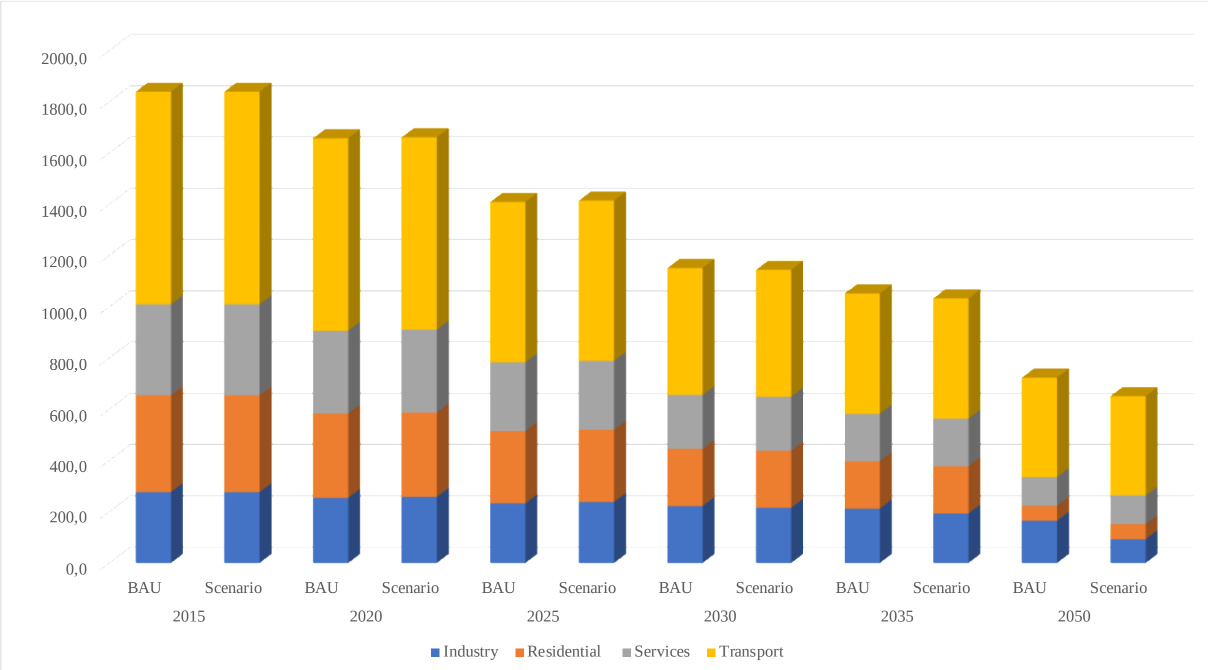


Figure 3-29 – Genoa Carbon Footprint on life cycle BAU and UPS comparison by sector and fuel (Mg CO_2 equivalent)

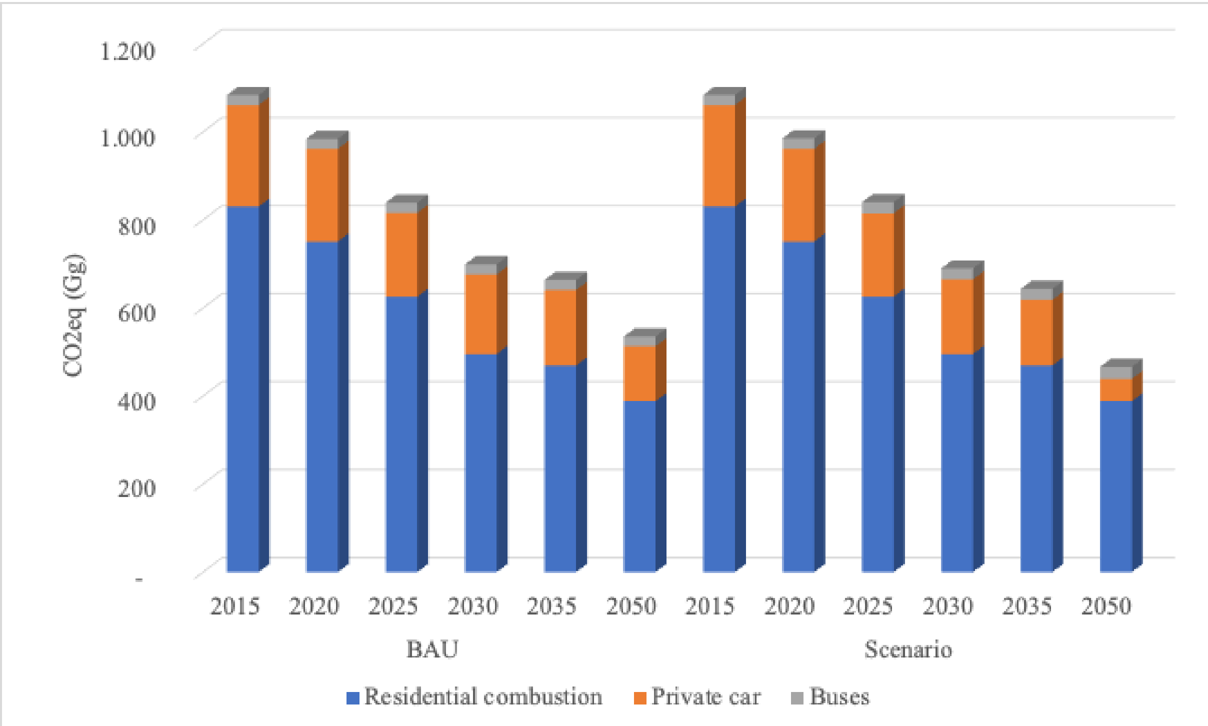
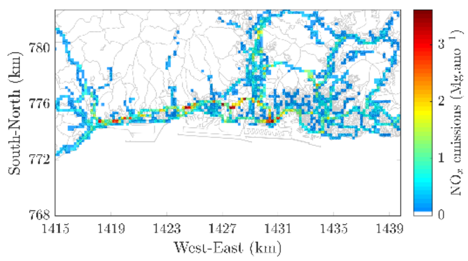
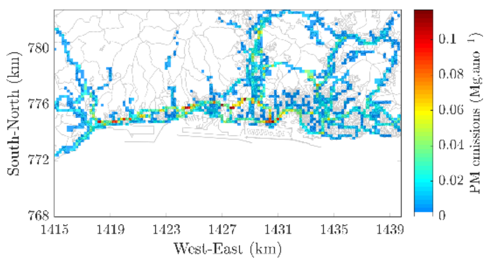


Figure 3-30 – Genoa Carbon Footprint on life cycle generated by citizens' activities in BAU and UPS scenario (Mg CO_2 equivalent)

3.5 Air quality impacts

3.5.1 Annual emissions input

Air quality simulations, start from the spatiotemporally distributed emissions from all the sources described in the previous section. Figure 3-31 shows the emission values for NO_x and PM in $Mg.year^{-1}$ for each sector.

<table>
<tr><th></th><th>NOx</th><th>PM</th></tr>
<tr><td>Transport</td><td>
</td><td>
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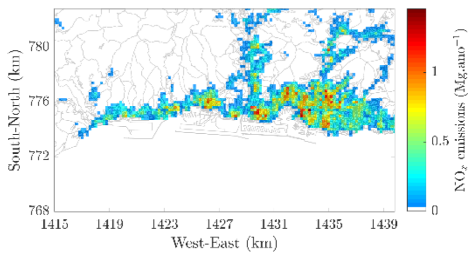
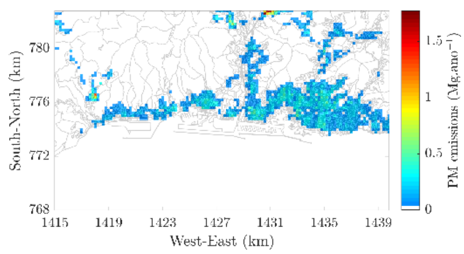
<tr><td>Commercial and Residential</td><td>
</td><td>
</td></tr>
</table>

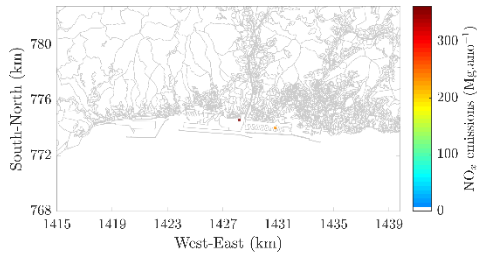
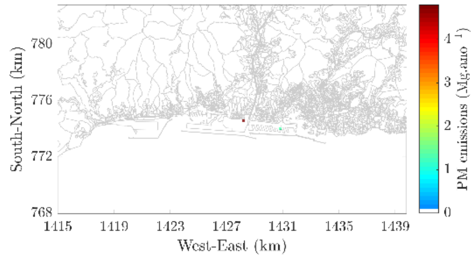
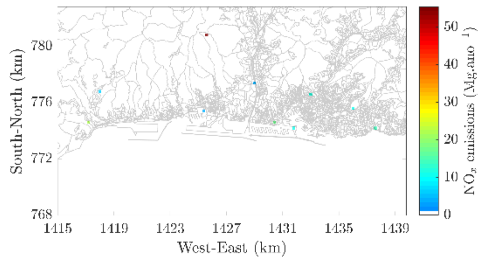
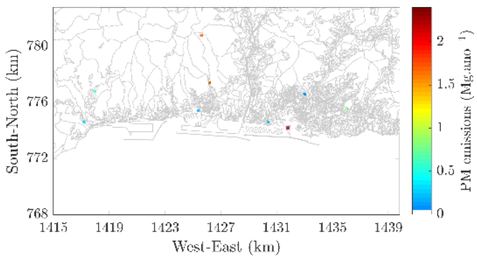
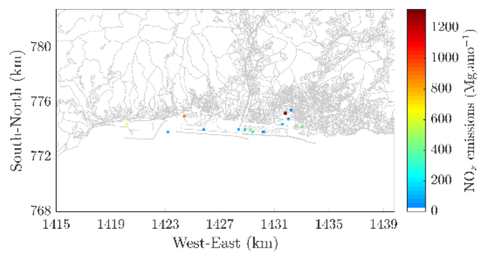
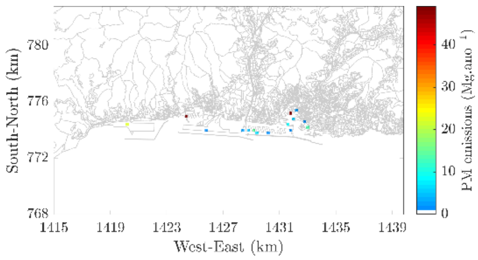
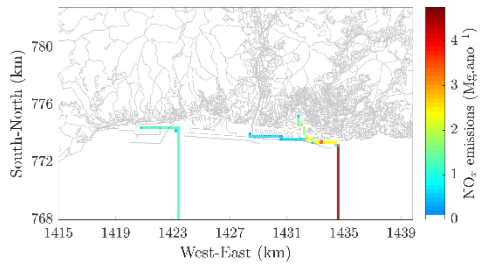
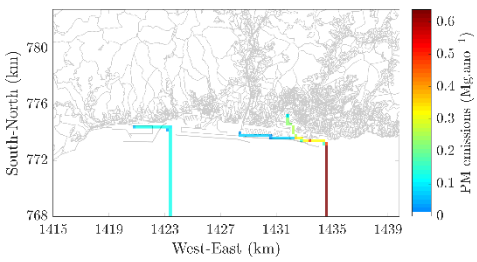
<table>
<tr><td>Industrial Point</td><td></td><td></td></tr>
<tr><td>Industrial Area</td><td></td><td></td></tr>
<tr><td>Shipping Point</td><td></td><td></td></tr>
<tr><td>Shipping Area</td><td></td><td></td></tr>
</table>

Figure 3-31: 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 the Liguria Region, at the mesoscale, was based on the analysis of the spatial average of the following variables: temperature, precipitation and wind speed and direction. The mean air temperatures and accumulated temperature, for each month, are presented in Figure 3-32.

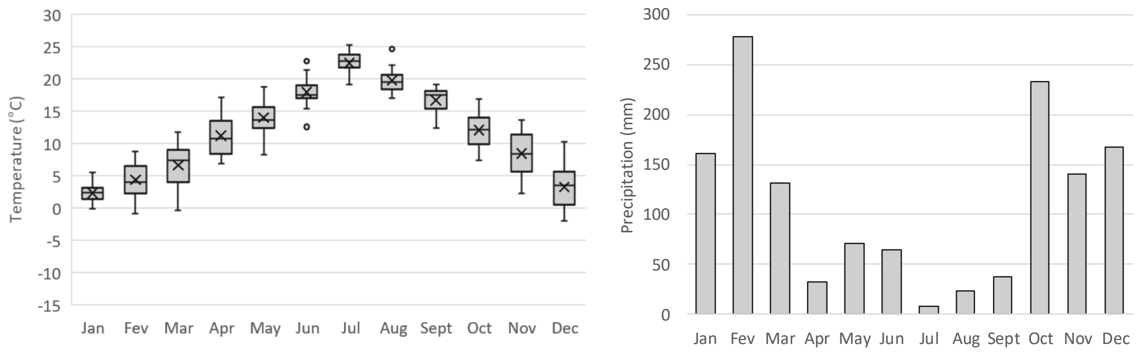
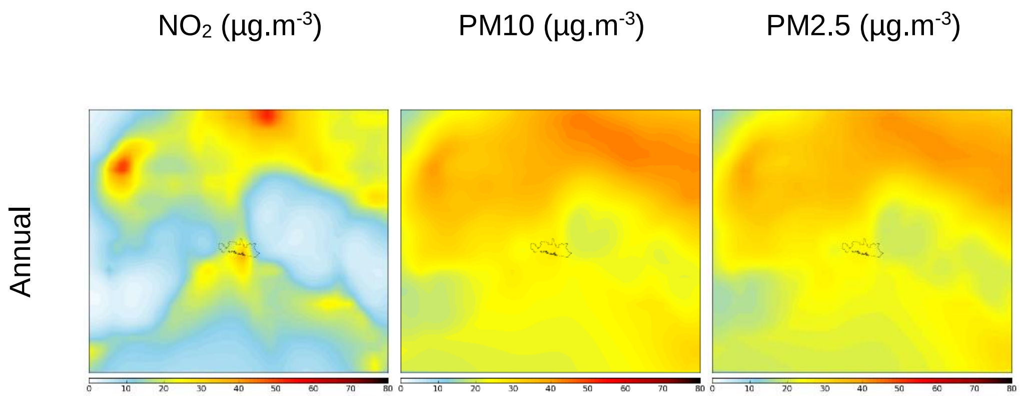


Figure 3-32: (Left) Box and whisker plot of temperature by month; boxes indicate the lower and upper quartile; horizontal line in each box represents the median temperature; the mean temperature for each month is indicated by a x; vertical lines extending from each box represent the minimum and maximum temperature recorded for that month. (Right) Column graph of total precipitation by month.

According to Figure 3-32, in Liguria Region, the minimum mean temperatures are obtained in January and December, with 2.4°C and 3.3°C, respectively. The month where the highest mean temperature is recorded is July, with 22.5°C, followed by July, with 19.7°C. Regarding precipitation, the months with the highest accumulated precipitation go from October to March (with values up to 270mm), while the driest month is July with 8 mm. During almost the whole year, the wind blows predominantly from the 2nd (SE) and 4th (NW) quadrants, with a wind speed between 4 and 12 $m.s^{-1}$.

The air quality characterization in Genoa, 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 3-33).



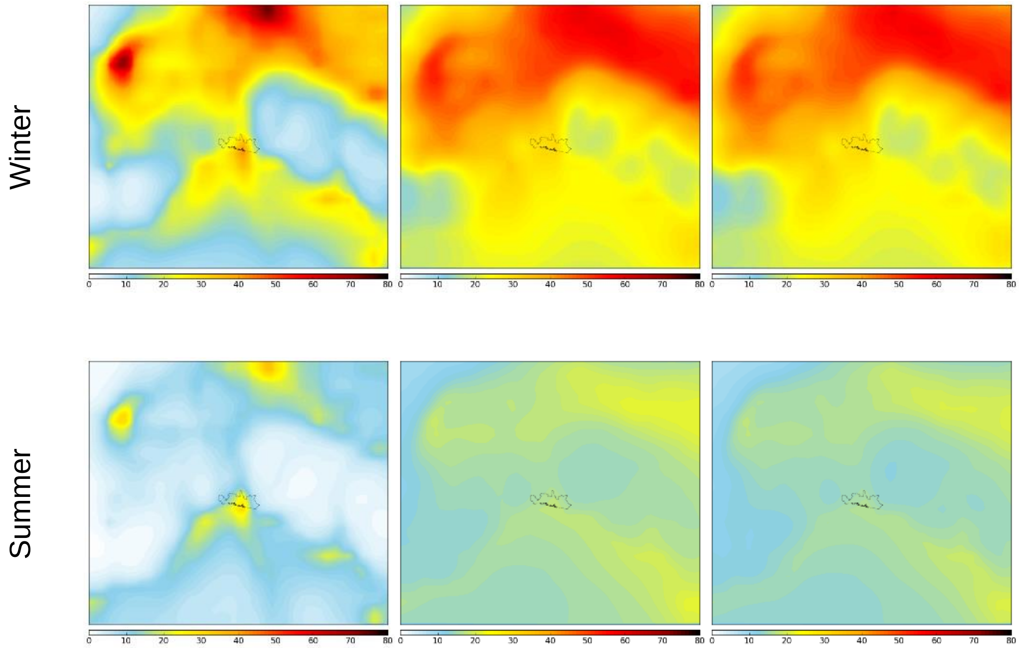


Figure 3-33: Spatial distribution of NO_2, PM10 and PM2.5 concentrations, for the different periods analysed (annual, winter and summer) in Liguria Region.

For each pollutant, NO_2, PM10 and PM2.5, results presented in Figure 3-34 show similar spatial patterns for the different periods and pollutants analysed. For all pollutants, the highest concentration values are found in Genoa seaport and in other urban areas in the northern region of the domain like Milan and Turin.

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 53 $\mu g.m^{-3}$, 74 $\mu g.m^{-3}$ and 35 $\mu g.m^{-3}$, respectively. For PM10, the maximum concentration values are close to 44 $\mu g.m^{-3}$, for the annual average, 59 $\mu g.m^{-3}$ in winter and 22 $\mu g.m^{-3}$ in summer. For PM2.5, the highest concentration values are 42 $\mu g.m^{-3}$, 57 $\mu g.m^{-3}$ and 21 $\mu g.m^{-3}$ 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 Genoa, 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 Liguria for the three periods previously defined, are analysed in Figure 3-34.

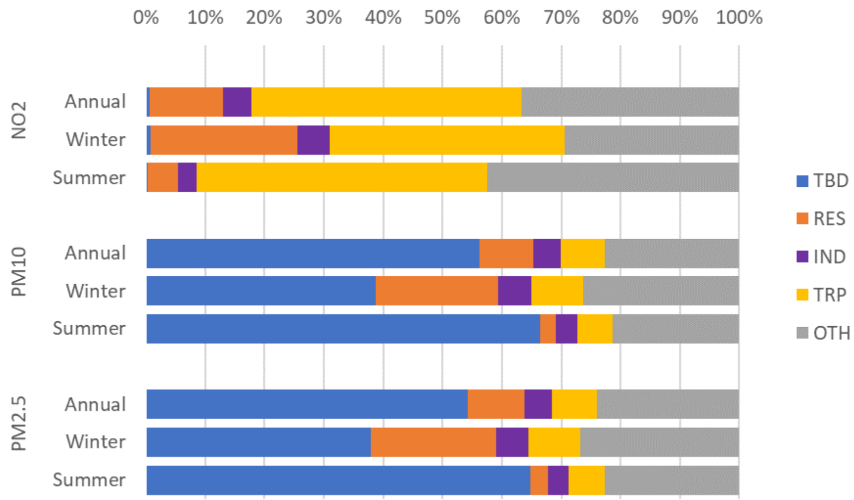


Figure 3-34: Annual, winter and summer averages contribution for each source group for NO_2, PM10 and PM2.5 concentrations, for Liguria Region; (TBD- transboundary transport, RES - residential and commercial combustion, IND - industrial combustion and processes, TRP - road transport and OTH - all the remaining sources).

The average annual contributions of each source group reveal that, for NO_2, the largest contribution is from TRP (between 40% and 50%), followed by RES (between 5%, in summer, and 25%, in winter).

For PM10, the annual average contributions of each source group reveal that one of the major contributions is from TBD (56%), 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 65%. Source contribution results also point to a great influence of the contribution of different human activities, such as residential and commercial combustion to the PM10 levels, with higher values during winter. For PM2.5, the analysis is similar to that of PM10.

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

3.5.3 Assessment of air quality at urban scale: baseline year

Figure 3-35 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.

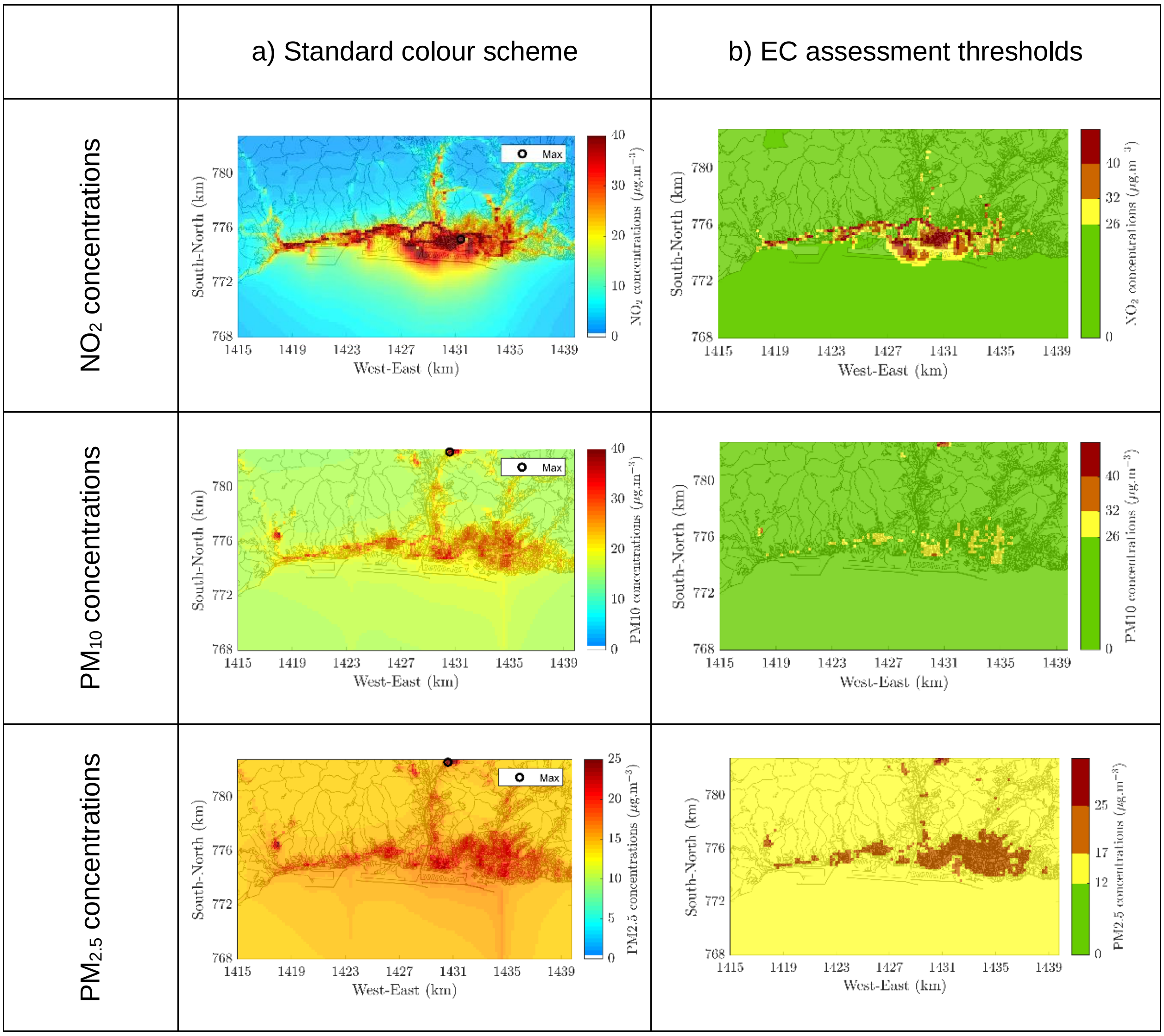


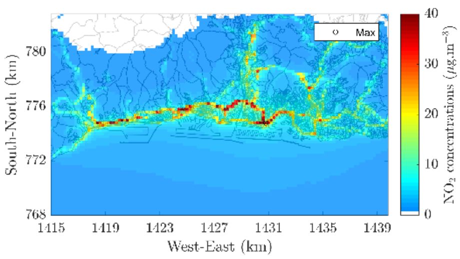
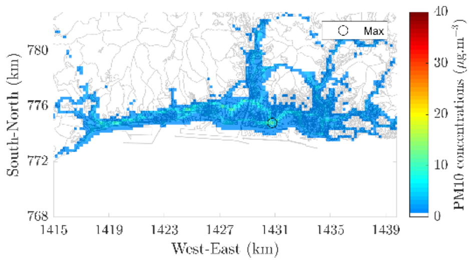
Figure 3-35: Annual average of the NO2, PM10 and PM2.5 concentrations, including the background concentrations and the adjustment factor. a) using a standard color scheme, and b) using a customized color scheme based on the EC assessment thresholds

The maximum value of the annual NO_2 concentrations in 2015 is equal to 84.9 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 shipping sector, with a contribution of 53.4%, followed by the road transport sector with 38.7%, the commercial and residential sector with a contribution of 6.2%, and the industrial sector with a contribution of 1.8 %. These contributions are obtained from the source apportionment analysis. The average value of the NO_2 concentrations over the entire domain is equal to 10.1 and the source apportionment analysis indicates that transport is contributing with 33.2%, shipping sector with 34.2%, industrial sector with 12.6% and the residential and commercial sector with 19.9% to the simulated concentrations.

The maximum value of the annual PM_{10} concentrations in 2015 is equal to 50.2 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 major contribution 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 all the domain a source apportionment analysis indicates that transport is contributing with 23.1%, shipping sector with 13.0%, industrial sector with 1.3% and the residential and commercial sector with 62.6% to the simulated concentrations.

The maximum value of the annual $PM_{2.5}$ concentrations in 2015 is equal to 32.5 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 major contribution from the residential and commercial sector. The average value over the entire domain is equal to 14.9 µg.m^{-3}. For $PM_{2.5}$ concentrations average over all the domain a source apportionment analysis indicates that transport is contributing with 11.7%, shipping sector with 24.2%, industrial sector with 1.3% and the residential and commercial sector with 62.8% to the simulated concentrations.

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 3-36 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	PM10 concentrations
Transport sector		

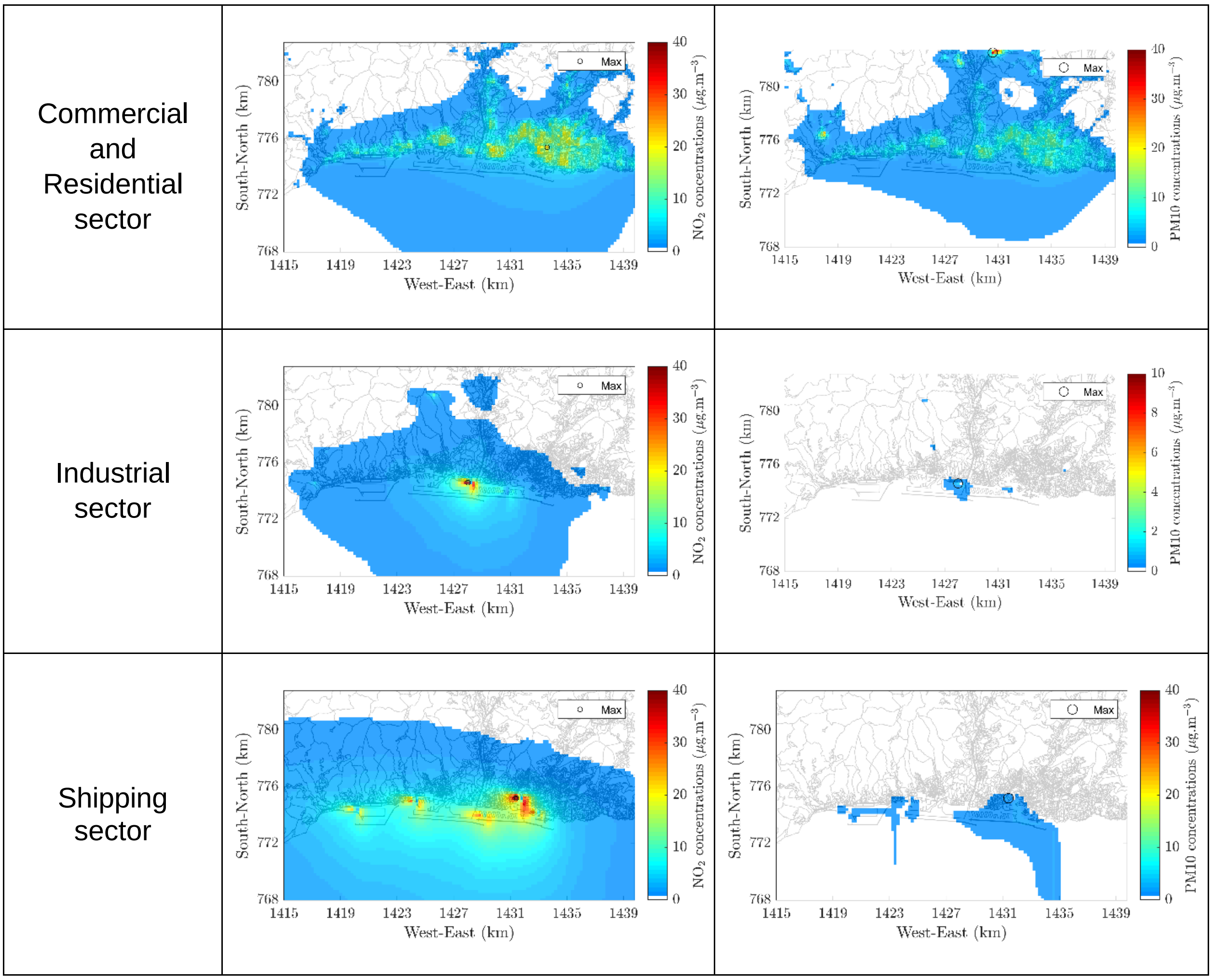


Figure 3-36: Air quality maps for NO_2 and PM adjusted concentrations by sector without the added background.

For the emission sectors considered, the emissions of particulate matter are assumed to be equal 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 (Section 2.1). 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 10.8 $\mu g.m^{-3}$ and for $PM_{2.5}$ is 2.9 $\mu g.m^{-3}$.

The final air quality results are then compared with the measuring data. Table 3-9: Comparison between the measurements and the simulated NO_2 concentrations (with the background concentrations and the adjustment factor) and contribution of each sector to the simulated values.presents the comparison between the measurements and the simulated

NO_2 concentrations (with the background concentrations and the adjustment factor) for all the monitoring sites.

Table 3-9: Comparison between the measurements and the simulated NO_2 concentrations (with the background concentrations and the adjustment factor) and contribution of each sector to the simulated values.

Station		NO_2 concentrations	
ID	Station type	Measured	Simulated
IT0852A	Urban Industrial	41.7	56.9
IT0854A	Urban Background	26.2	42.6
IT0858A	Urban Background	15.4	23.9
IT1698A	Urban Traffic	29.8	53.4
IT1884A	Urban Traffic	37.9	46.7
IT1887A	Urban Traffic	52.5	50.5
IT0856A	Urban Background	33.5	58.8

Table 3-10 shows the contribution of each sector to the simulated NO_2 concentration values for the location of each monitoring station.

Table 3-10: Contribution of each sector to the simulated NO_2 concentrations values for each measuring location.

Station		Contribution by sector for the corresponding cell (%)			
Station	Station type	Transport sector	Shipping sector	Industrial sector	Com. and Res. Sector
IT0852A	Urban Industrial	57.4	26.7	6.6	9.3

IT0854A	Urban Background	26.9	14.2	3.7	55.2
IT0858A	Urban Background	31.1	9.4	3.5	56
IT1698A	Urban Traffic	60.6	6.7	2.8	29.8
IT1884A	Urban Traffic	54.7	10.7	2.3	32.3
IT1887A	Urban Traffic	20.7	53.7	2.8	22.9
IT0856A	Urban Background	27.3	14.3	2.9	55.4

The SA analysis shows that for the background stations the major contribution comes from commercial and residential sector. For the urban traffic the major contribution, as expected, comes from the transport sector, except in one measuring location where the biggest contribution comes from the industrial sector (53.7%).

Table 3-11 presents the comparison between the measurements and the simulated PM_{10} concentrations (with the background concentrations and the adjustment factor) and the sector contribution to the simulated values of each monitoring location. The SA analysis shows a major contribution from the commercial and residential sector for all the locations, except for the IT0852A station in which the main contribution comes from the transport sector (57.4%).

Table 3-11: Comparison between the measurements and the simulated PM_{10} concentrations (with the background concentrations and the adjustment factor) and the sector contribution to the simulated values of each monitoring location.

Station		PM_{10} concentrations		Contribution by sector for the corresponding cell (%)			
ID	Station type	Measured	Simulated	Transport sector	Shipping sector	Industrial sector	Com. and Res. Sector
IT0852A	Urban Industrial	20.7	23	56.6	10.1	0.8	32.5
IT0854A	Urban Background	25.0	26.0	11.3	2.1	0.2	86.4
IT0858A	Urban Background	14.7	21.3	12.5	1.8	0.2	85.5
IT1698A	Urban Traffic	35.1	24.3	36.3	1.7	0.5	61.5

Table 3-12 presents the comparison between the measurements and the simulated PM_{10} concentrations (with the background concentrations and the adjustment factor) and the sector contribution to the simulated values of each monitoring location.

Table 3-12: Comparison between the measurements and the simulated $PM_{2.5}$ concentrations (with the background concentrations and the adjustment factor) and the sector contribution to the simulated values of each monitoring location.

Station		PM2.5 concentrations		Contribution by sector for the corresponding cell (%)			
ID	Station type	Measured	Simulated	Transport sector	Shipping sector	Industrial sector	Com. and Res. Sector

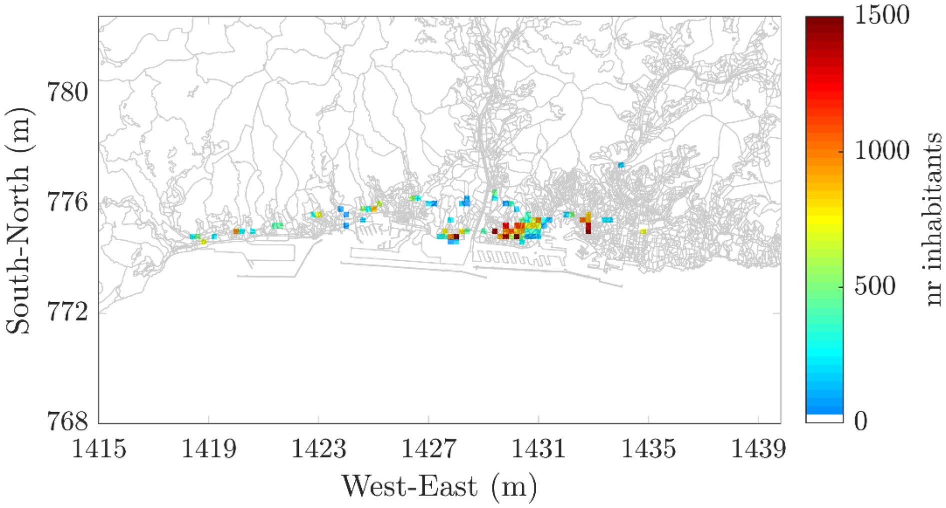
Station		PM2.5 concentrations		Contribution by sector for the corresponding cell (%)			
IT0858A	Urban Background	12.1	16.9	6.6	3.5	0.3	89.6
IT1698A	Urban Traffic	21.7	17.8	22.0	3.7	0.6	73.7

The SA analysis shows a major contribution from the commercial and residential sector for both monitoring station locations, although for the urban traffic station the transport sector has also a significant impact (22%) for that location.

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 3-37 shows the population exposure to NO_2, PM_{10} and $PM_{2.5}$ baseline concentration values.

	EU annual limit value	WHO guideline value
NO_2 concentrations		

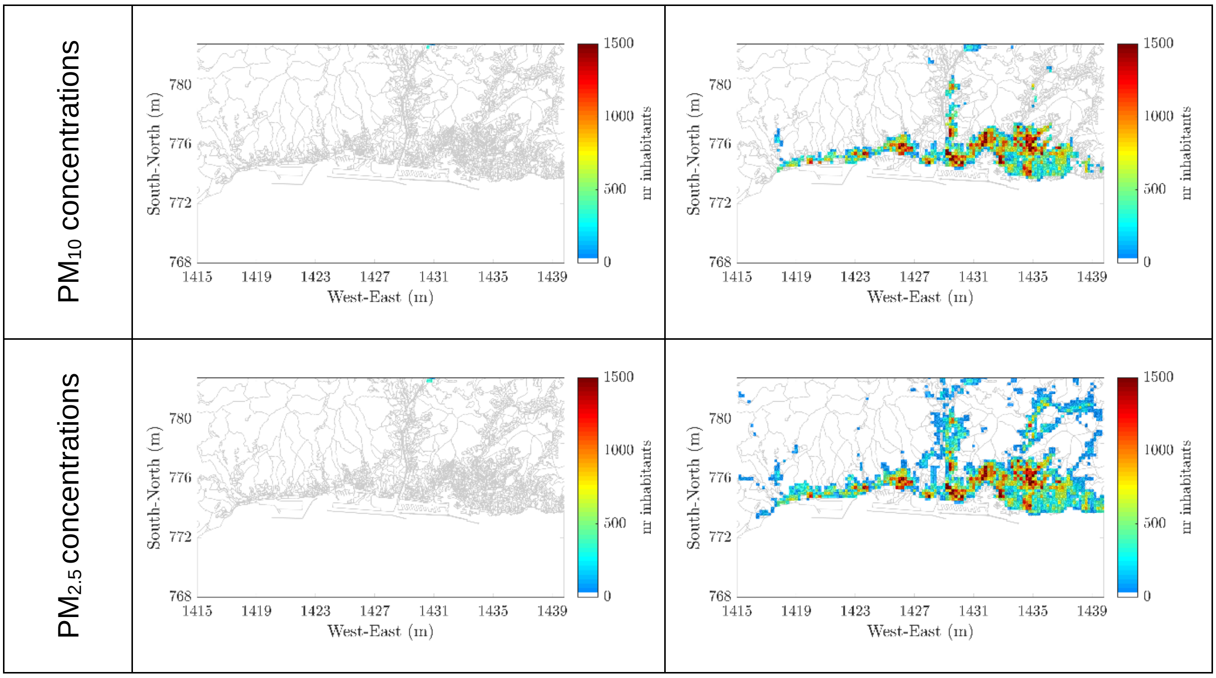


Figure 3-37: Population potentially exposed to values above the EU limits and WHO guideline values for NO_2, PM_{10} and $PM_{2.5}$ baseline concentrations.

For NO_2 the limits established by the EU and the WHO are equivalent, being 40 µg.m^{-3} for the annual mean. In the Liguria Region, the NO_2 annual limits are exceeded in 123 cells corresponding to 8% 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}. The PM10 and PM2.5 concentrations contour maps indicate only a few exceedances to the EU legal limit value, respectively, with 3 and 5 grid cells above the annual limit value. However, the results for PM10 concentrations indicate several exceedances to the WHO guidelines with 999 cells above the WHO annual guideline value, corresponding to 77.6% of the population within the simulation area potentially exposed. For PM2.5, 9375 cells are exceeding the WHO guideline value, which represents the entire population within the simulation area 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 3-38 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 62.2 µg.m^{-3} in 2025 and to 59.5 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 62.0% and 80.1%, when compared to the baseline.

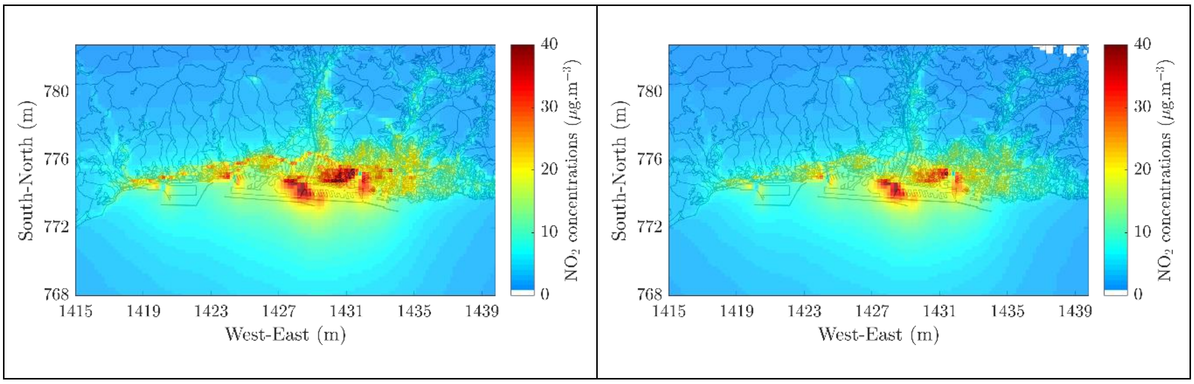


Figure 3-38 - NO_2 annual average concentrations in the BAU scenario a) in 2025 and b) in 2050.

Figure 3-39 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 41.8 µg.m^{-3} of the NO_2 concentrations in 2025, corresponding to a reduction of 62.0%, while the spatial average over the entire the domain will reduce 3.4 µg.m^{-3} of NO_2 concentrations, which corresponds to a reduction of 33.3%. In 2050 the BAU scenario will lead to a maximum reduction of the NO_2 concentrations of 55.0 µg.m^{-3} which corresponds to a reduction of 80.1%, while the average over the entire domain will reduce 4.6 µg.m^{-3} (45.0%).

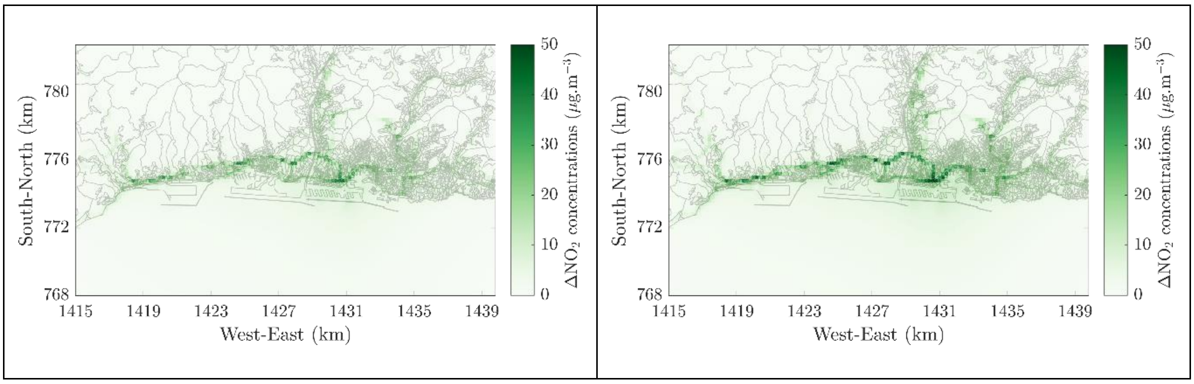


Figure 3-39: Differences of the NO_2 annual averaged concentrations in the BAU scenario a) in 2025 and b) in 2050.

Table 3-13 summarizes the overall impacts of BAU scenarios on air quality and population exposure. The population within the Liguria Region potentially exposed to NO_2 concentrations will diminish from 8% to less than 1% of inhabitants potentially at risk of exposure with the implementation of the BAU scenario already in 2025. Therefore, the simulation results indicate full compliance with the EU annual limits almost everywhere in Liguria Region with the BAU scenario.

Table 3-13 – Summary of results including the annual averages of NO_2 concentrations, together with the number of exceedances to the EU annual legal limit value (Exc.), as well as the number of exceedances to the EU annual legal limit value in grid cells with inhabitants allocated to (Exc. Inhabit.), the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit (Inhabit.), and the corresponding % of population (Pop.).

	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	1.2	84.9	10.1	123	97	45150	8.0%
BAU 2025	0.9	62.2	6.6	12	7	1394	0.3%
BAU 2035	0.8	60.9	6.0	7	3	307	0.1%
BAU 2050	0.7	59.5	5.4	6	2	199	0.1%

BAU scenarios: PM_{10} concentrations

The slight reductions of PM emissions in the BAU scenario will also lead to minor reductions of the PM concentrations. Figure 3-40 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 40.7 µg.m^{-3} in 2025 and to 37.6 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 18.9% and 25.1%, when compared to the baseline.

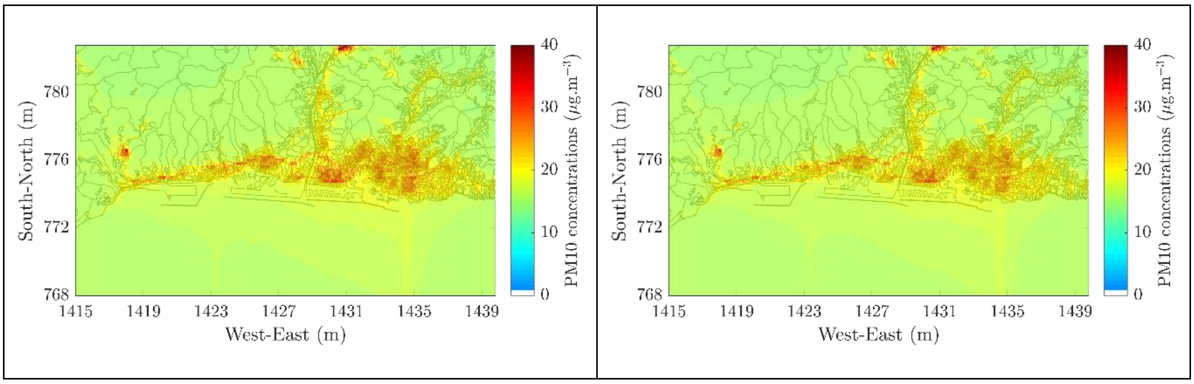


Figure 3-40 – PM_{10} annual average concentrations in the BAU scenario a) in 2025 and b) in 2050.

Figure 3-41 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 9.5 µg.m^{-3} of the PM_{10} concentrations in 2025, corresponding to a reduction of 18.9%, while the spatial average over the entire the domain will reduce 0.5 µg.m^{-3} of PM_{10} concentrations, which corresponds to a reduction of 2.7%. In 2050, the BAU scenario will lead to a maximum reduction of 12.6 µg.m^{-3} of the PM_{10} concentrations, corresponding to a reduction of 25.1%, while the spatial average over the entire the domain will reduce 0.7 µg.m^{-3} of PM_{10} concentrations, which corresponds to a reduction of 3.4%.

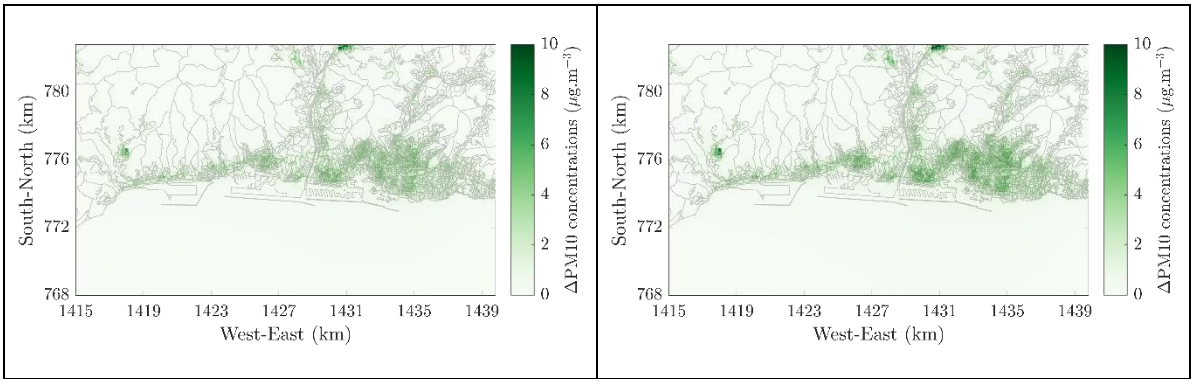


Figure 3-41 - Differences of the PM_{10} annual averaged concentrations in the BAU scenario a) in 2025 and b) in 2050.

Table 3-14 summarizes the overall impacts of BAU scenarios on PM_{10} concentrations. The simulation results indicate low risk for the population within the Liguria Region to be potentially exposed to PM_{10} concentrations above the EU legal limit value already in 2015. However, there are still significant potential risks of population exposure over the region to the stricter limits recommended by the WHO even n 2050, with 55% of the population potentially exposed to those levels in 2050.

Table 3-14: Summary of the BAU impacts on the annual averages of PM_{10} concentrations, together with the number of exceedances to the EU annual legal limit value (Exc.), as well as the number of exceedances to the EU annual legal limit value in grid cells with inhabitants allocated to (Exc. Inhabit.), the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit (Inhabit.), and the corresponding % of population (Pop.).

	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	15.2	50.2	17.4	3	3	487	0.1%
BAU 2025	15.2	40.7	16.9	1	1	325	0.1%
BAU 2035	15.2	37.5	16.7	0	0	0	0%
BAU 2050	15.2	37.6	16.8	0	0	0	0%

Table 3-15: Summary of the BAU impacts on the annual averages of PM_{10} concentrations, together with the number of exceedances to the WHO annual guideline value (Exc.), as well as the number of exceedances to the WHO annual guideline value in grid cells with inhabitants allocated to (Exc. Inhabit.), the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit (Inhabit.), and the corresponding % of population (Pop.).

	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	15.2	50.2	17.4	1000	925	439376	77.6%
BAU 2025	15.2	40.7	16.9	682	656	359497	63.5%
BAU 2035	15.2	37.5	16.7	561	541	307777	54.3%
BAU 2050	15.2	37.6	16.8	574	553	313467	55.3%

BAU scenarios: $PM_{2.5}$ concentrations

Figure 3-42 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 27.4 µg.m^{-3} in 2025 and to 25.7 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 15.6% and 20.8%, when compared to the baseline.

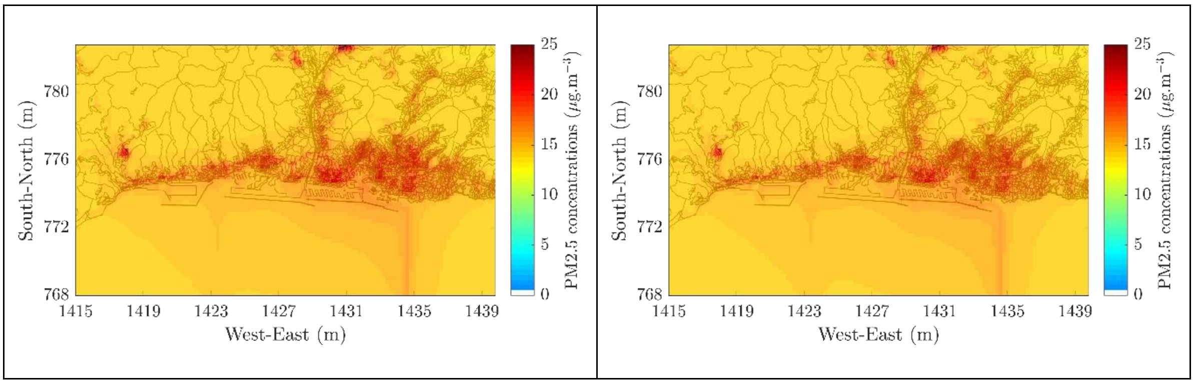


Figure 3-42 – $PM_{2.5}$ annual average concentrations in the BAU scenario a) in 2025 and b) in 2050.

Figure 3-43 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 5.1 µg.m^{-3} of the $PM_{2.5}$ concentrations in 2025, corresponding to a reduction of 15.6%, while the spatial average over the entire the domain will reduce 0.2 µg.m^{-3} of $PM_{2.5}$ concentrations, which corresponds to a reduction of 1.3%. In 2050 the BAU scenario will lead to a maximum reduction of the $PM_{2.5}$ concentrations of 6.8 µg.m^{-3} which corresponds to a reduction of 20.8%, while the average over the entire domain will reduce 0.3 µg.m^{-3} (1.8%).

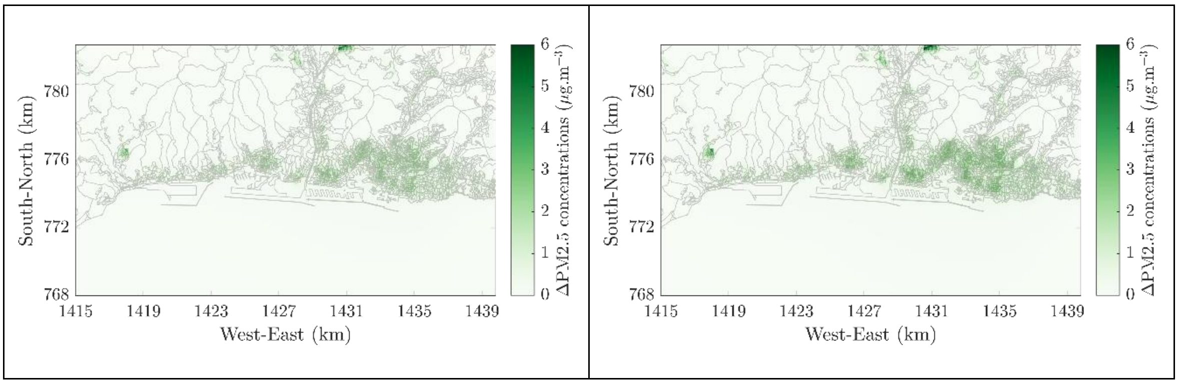


Figure 3-43: Differences of the $PM_{2.5}$ annual averaged concentrations in the BAU scenario a) in 2025 and b) in 2050.

Table 3-16 and Table 3-17 summarize an overview of the overall impact of the BAU scenarios on the $PM_{2.5}$ concentrations. The simulation results indicate full compliance with the EU annual limit value almost everywhere in the computational domain already in the baseline. However, all the population of the region will be potentially exposed to $PM_{2.5}$ concentrations above the stricter, but still voluntary, WHO guideline values even in 2050 with the implementation of the BAU scenario.

Table 3-16: Summary of results including the annual averages of $PM_{2.5}$ concentrations, together with the number of exceedances to the EU annual legal limit value (Exc.), as well as the number of exceedances to the EU annual legal limit value in grid cells with inhabitants allocated to (Exc. Inhabit.), the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit (Inhabit.), and the corresponding % of population (Pop.).

	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	13.7	32.5	14.9	5	5	840	0.2%

BAU 2025	13.7	27.4	14.7	3	3	487	0.1%
BAU 2035	13.7	25.7	14.6	1	1	325	0.1%
BAU 2050	13.7	25.7	14.6	1	1	325	0.1%

Table 3-17: 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	13.7	32.5	14.9	9375	2637	566483	100%
BAU 2025	13.7	27.4	14.7	9375	2637	566483	100%
BAU 2035	13.7	25.7	14.6	9375	2637	566483	100%
BAU 2050	13.7	25.7	14.6	9375	2637	566483	100%

SDW scenarios

Following citizen engagement, the top 10 policies were presented to regional stakeholders for their reflections. This process led to the proposed scenarios from the SDW – low and high ambition scenarios. On contrary to other case studies, Liguria Region chose the current policy level as low level ambition. Therefore, the impact of the low ambition scenario on air quality is the same as the BAU impacts on air quality. On the other side, the high ambition scenario from the SDW corresponds to the same level of ambition as the final Unified Policy Scenario, and it will have the same impacts on air quality over the Liguria Region. Therefore, we will only discuss the impacts of the Unified Policy Scenario.

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 3-44 presents the NO_2 annual averaged concentrations considering the impacts of FUPS scenario in 2025 and 2050. The maximum annual averaged NO2 concentrations will be equal to 62.4 µg.m^{-3} in 2025 and to 59.5 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 59.9% and 80.2%, when compared to the baseline. It is of notice that the implementation of the FUPS will led to no further reductions of the maximum annual averaged NO_2 concentrations compared to the BAU scenario.

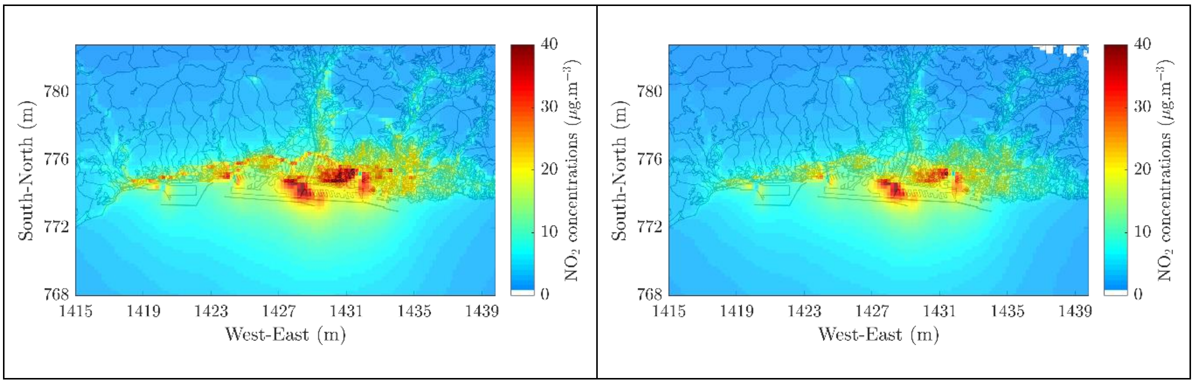


Figure 3-44 - NO_2 annual average concentrations in the FUPS scenario a) in 2025 and b) in 2050.

Figure 3-45 shows the differences of the NO_2 annual concentrations with the implementation of the FUPS scenarios compared to the baseline year. Figure 3-45 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 32.6% over the entire computational domain in 2025, and of 45.0% in 2050.

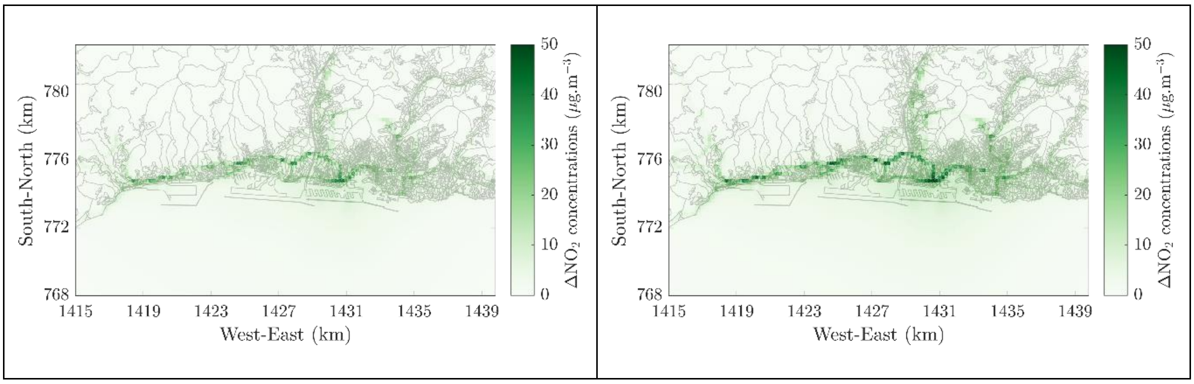


Figure 3-45: Differences of the NO_2 annual averaged concentrations in the FUPS scenario a) in 2025 and b) in 2050.

Table 3-18 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 above the EU annual legal limit value already in 2025.

Table 3-18 – Summary of results including the annual averages of NO_2 concentrations, together with the number of exceedances to the EU annual legal limit value (Exc.), as well as the number of exceedances to the EU annual legal limit value in grid cells with inhabitants allocated to (Exc. Inhabit.), the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit (Inhabit.), and the corresponding % of population (Pop.).

	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	1.2	84.9	10.1	123	97	45150	8.0%
FUPS 2025	0.9	62.4	6.7	12	7	1394	0.3%
FUPS 2035	0.8	61.1	6.0	7	3	307	0.1%
FUPS 2050	0.7	59.5	5.4	6	2	199	0.1%

FUPS scenarios: PM_{10} concentrations

Figure 3-46 and Figure 3-47 present the impact of the FUPS scenario on PM_{10} concentrations. The contour maps with the differences of the annual PM_{10} concentrations point out a maximum concentration ranging from 40.7 µg.m^{-3} to 37.5 µg.m^{-3} between 2025 and 2050 with the implementation of the FUPS scenario.

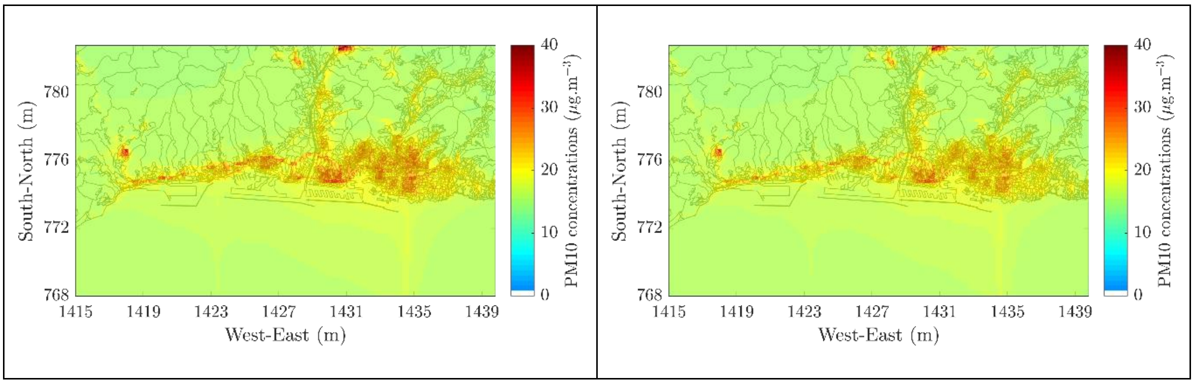


Figure 3-46: PM_{10} annual average concentrations in the FUPS scenario a) in 2025 and b) in 2050.

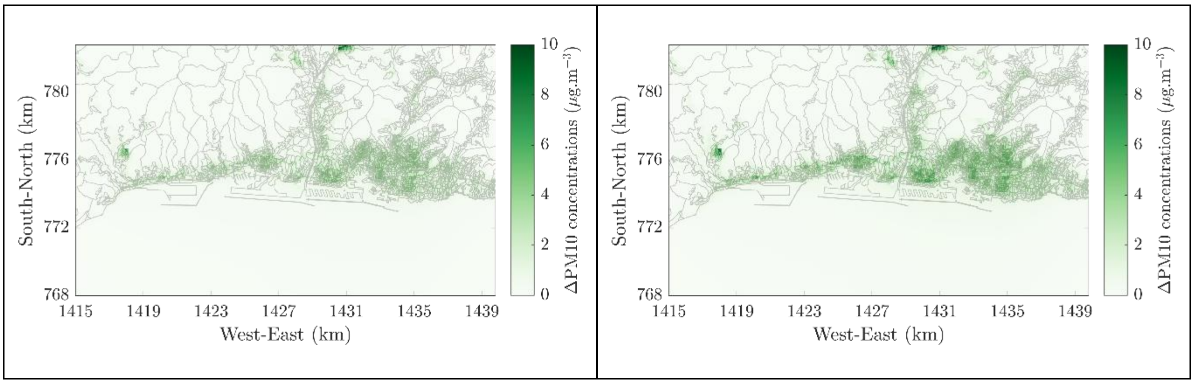


Figure 3-47 - Differences of the PM_{10} annual averaged concentrations in the FUPS scenario a) in 2025 and b) in 2050.

Table 3-19 presents an overview of the overall impact of the FUPS scenario on PM_{10} concentrations. The simulation results indicate low risk for the population within the Liguria Region to be potentially exposed to PM_{10} concentrations above the EU legal limit value already in 2015. However, there are still significant potential risks of population exposure over the region to the stricter limits recommended by the WHO even n 2050, with 55% of the population potentially exposed to those levels in 2050.

Table 3-19: Summary of the FUPS impacts on the annual averages of PM_{10} concentrations, together with the number of exceedances to the EU annual legal limit value (Exc.), as well as the number of exceedances to the EU annual legal limit value in grid cells with inhabitants allocated to (Exc. Inhabit.), the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit (Inhabit.), and the corresponding % of population (Pop.).

	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	15.2	50.2	17.4	3	3	487	0.1%
FUPS 2025	15.2	40.7	16.9	1	1	325	0.1%
FUPS 2035	15.1	37.5	16.7	0	0	0	0%
FUPS 2050	15.1	37.5	16.7	0	0	0	0%

Table 3-20: Summary of the FUPS impacts on the annual averages of PM_{10} concentrations, together with the number of exceedances to the WHO annual guideline value (Exc.), as well as the number of exceedances to the WHO annual guideline value in grid cells with inhabitants allocated to (Exc. Inhabit.), the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit (Inhabit.), and the corresponding % of population (Pop.).

	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	15.2	50.2	17.4	1000	925	439376	77.6%
FUPS 2025	15.2	40.7	16.9	687	661	362138	63.9%
FUPS 2035	15.1	37.5	16.7	555	536	305908	54.0%
FUPS 2050	15.1	37.5	16.7	531	514	297190	52.5%

FUPS scenarios: $PM_{2.5}$ concentrations

Figure 3-48 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 27.4 µg.m^{-3} in 2025 and to 25.7 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 15.6% and 20.8%, when compared to the baseline.

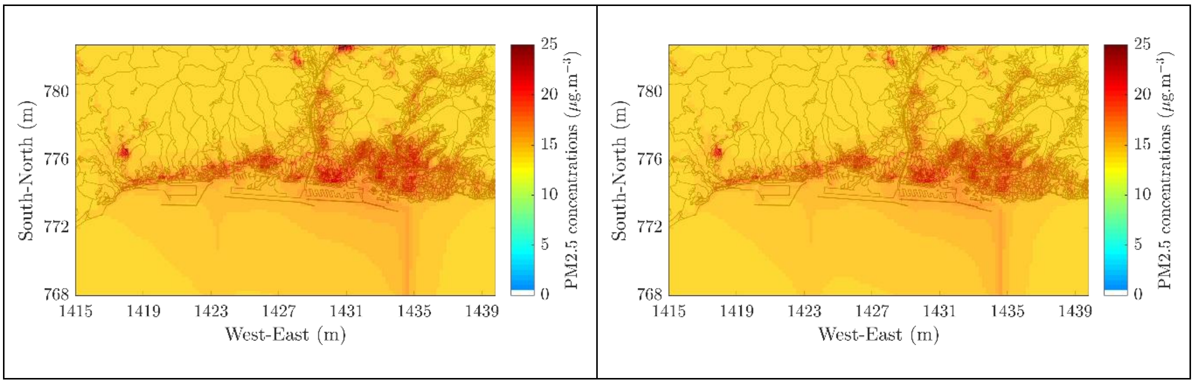


Figure 3-48 – PM2.5 annual average concentrations in the FUPS scenario a) in 2025 and b) in 2050.

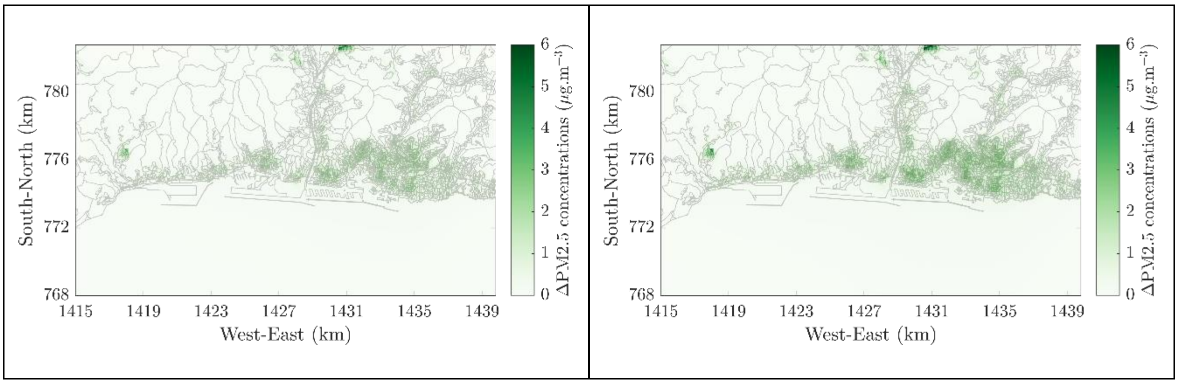


Figure 3-49: Differences of the $PM_{2.5}$ annual averaged concentrations in the FUPS scenario a) in 2025 and b) in 2050.

Table 3-21 and Table 3-22 summarize 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 1.3% of the $PM_{2.5}$ concentrations over the entire computational domain in 2025, and of 1.9% in 2050. The simulation results indicate full compliance with the EU annual limit value almost everywhere in the computational domain already in the baseline. However, all the population of the region will be potentially exposed to $PM_{2.5}$ concentrations above the stricter, but still voluntary, WHO guideline values even in 2050 with the implementation of the FUPS scenario.

Table 3-21: Summary of results including the annual averages of $PM_{2.5}$ concentrations, together with the number of exceedances to the EU annual legal limit value (Exc.), as well as the number of exceedances to the EU annual legal limit value in grid cells with inhabitants allocated to (Exc. Inhabit.), the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit (Inhabit.), and the corresponding % of population (Pop.).

	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	13.7	32.5	14.9	5	5	840	0.2%
FUPS 2025	13.7	27.4	14.7	3	3	487	0.1%
FUPS 2035	13.7	25.7	14.6	1	1	325	0.1%
FUPS 2050	13.7	25.7	14.6	1	1	325	0.1%

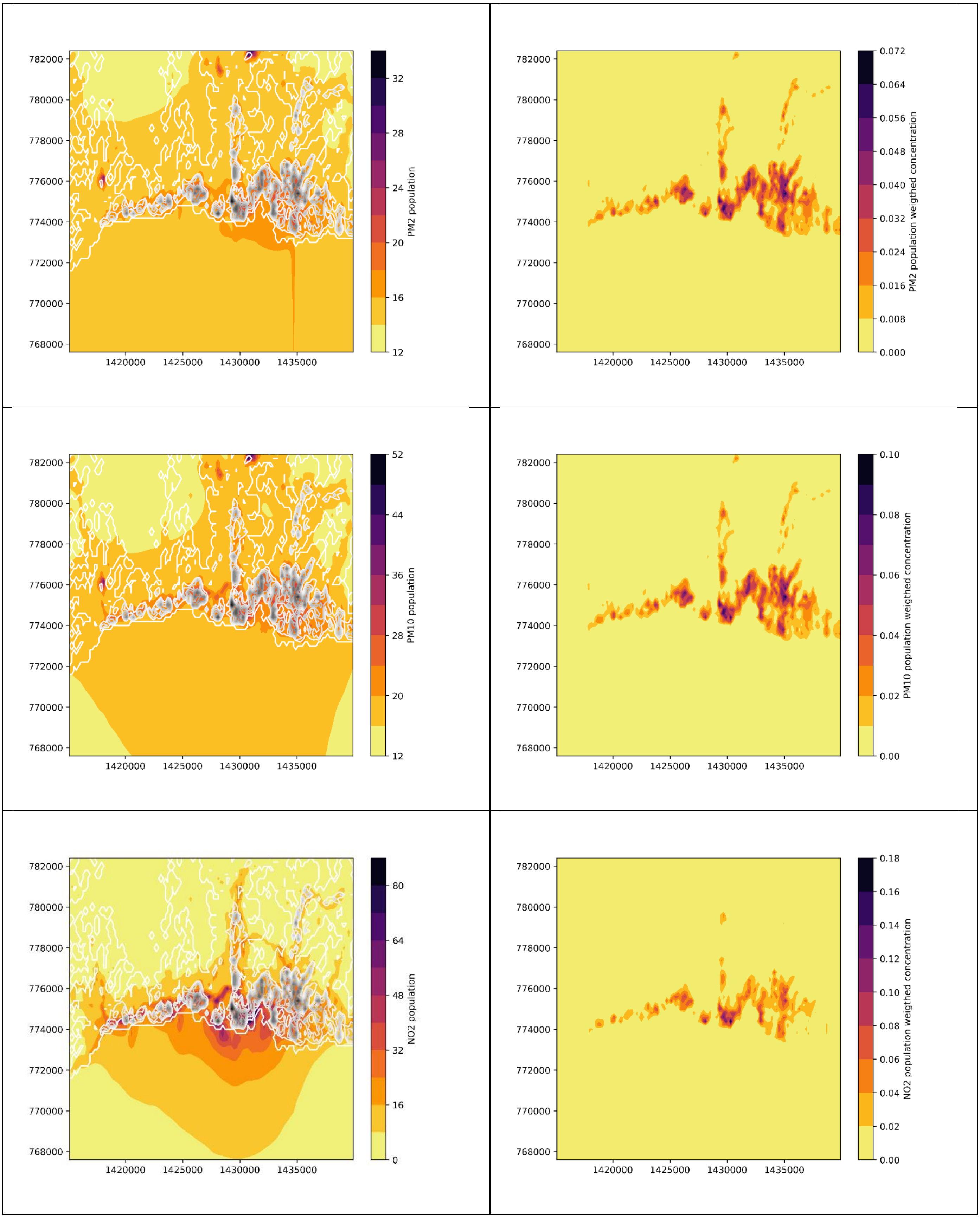
Table 3-22: Summary of results including the annual averages of $PM_{2.5}$ concentrations, together with the number of exceedances to the WHO guideline values (Exc.), as well as the number of exceedances to the WHO guideline values in grid cells with inhabitants allocated to (Exc. Inhabit.), the number 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	13.7	32.5	14.9	9375	2637	566483	100%
FUPS 2025	13.7	27.4	14.7	9375	2637	566483	100%
FUPS 2035	13.7	25.7	14.6	9375	2637	566483	100%
FUPS 2050	13.7	25.7	14.6	9375	2637	566483	100%

3.6 Health impacts

3.6.1 Baseline

The health impacts related to exposure to NO2, PM10, and PM2.5 were calculated based on the baseline emissions scenario. The figures below show maps to illustrate the areas of highest concern regarding human exposure to the individual pollutants. The left panels show the concentration maps overlaid with the population density distribution within the study area. The concentration levels are shown in a colour scale from yellow to dark purple (the same concentrations as presented before) 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 Liguria Region, for individual pollutants. The assessment includes the estimation of premature deaths and year potentially lost due to air pollution exposure.



782000
780000
778000
776000
774000
772000
770000
768000
1420000
1425000
1430000
1435000
PM2 population
12
16
20
24
28
32
PM2 population weigthed concentration
0.000
0.008
0.016
0.024
0.032
0.040
0.048
0.056
0.064
0.072
PM10 population
12
20
28
36
44
52
PM10 population weigthed concentration
0.00
0.02
0.04
0.06
0.08
0.10
NO2 population
0
16
32
48
64
80
NO2 population weigthed concentration
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18

Figure 3-50: Concentration maps overlaid with population density contours (left), population weighted concentration maps (right) for $PM_{2.5}$ (top), PM_{10} (centre), and NO_2 (bottom) based on the baseline emission scenario (2015), for Liguria Region.

3.6.1.1 BAU and UPS

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

Table 3-23: Health impact benefits of implementing emission control measures in Liguria. Region (%).

	PM2.5			PM10			NO2		
	2025	2035	2050	2025	2035	2050	2025	2035	2050
BAU	-5	-6	-6	-8	-11	-10	-59	-73	-79
UPS	-5	-6	-6	-8	-11	-11	-57	-72	-79

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 low, below 12%, with lower reduction for $PM_{2.5}$, 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 3-51 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.

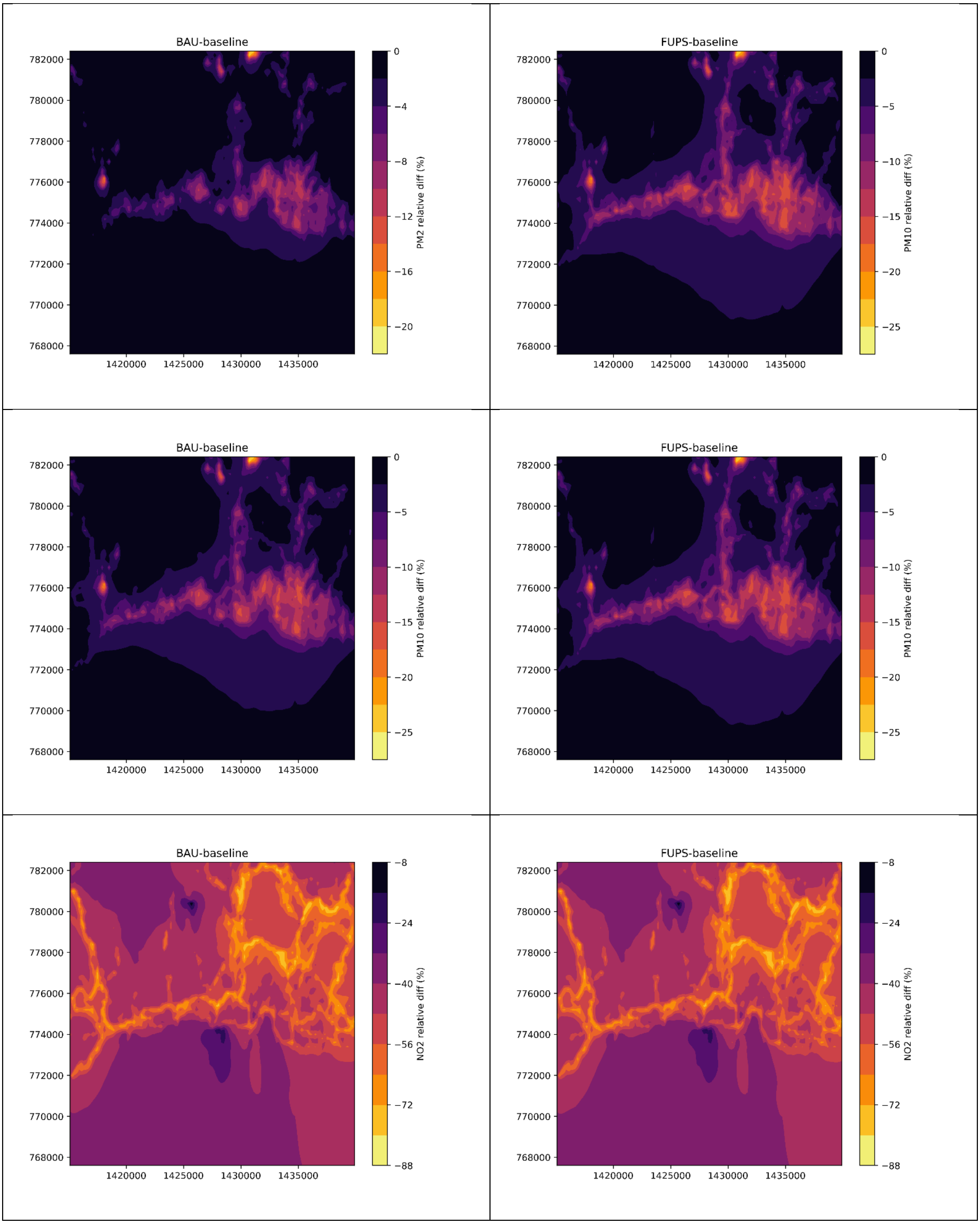

BAU-baseline
782000
780000
778000
776000
774000
772000
770000
768000
1420000
1425000
1430000
1435000
0
−4
−8
−12
−16
−20
PM2 relative diff (%)
FUPS-baseline
0
−5
−10
−15
−20
−25
PM10 relative diff (%)
BAU-baseline
PM10 relative diff (%)
FUPS-baseline
PM10 relative diff (%)
BAU-baseline
−8
−24
−40
−56
−72
−88
NO2 relative diff (%)
FUPS-baseline
NO2 relative diff (%)

Figure 3-51: Air quality impact benefits of implementing emission control measures in 2050 for Liguria Region, BAU vs baseline on the left and UPS vs baseline on the right for $PM_{2.5}$ (top), PM_{10} (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 Liguria Region. The baseline and all the scenarios are quantified as input to the ClairCity Policy Report to be delivered at the end of the process. The ClairCity framework contributes to assess air pollution through the source apportionment of air pollutant emissions and concentrations, as well as, carbon emissions, not only by technology, but by citizens' behaviour.

The impact assessment data illustrating the work undertaken can be found on the ClairCity Data Portal, as follow: https://claircitydata.cbs.nl/dataset/d5-5e-assessment-of-impacts-liguria. 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.