ClairCity: Citizen-led air pollution reduction in cities

Deliverable 5.7: City Impact Analysis Report - Sosnowiec

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Document Details

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Version History

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

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

Table of Content

In this document, we elaborate into the methodology and results of the modelling for the Sosnowiec 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/d5-5c-assessment-of-impacts-sosnowiec. Access can be arranged upon request. Furthermore, it was created a ClairCity community on Zenodo.org, where the full dataset was uploaded from the ClairCity Data Portal to Zenodo. The comunity is available on the link: https://zenodo.org/communities/claircity.

1 Methodological particularities

1.1 Transport: activity data

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

- Road network generation
- Production & Attraction for demand generation
- Mode choice
- Assignment
- Post-processing

Road network generation

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

Demand generation

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

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

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

Mode choice

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

Assignment

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

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

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 Sosnowiec: **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, 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.
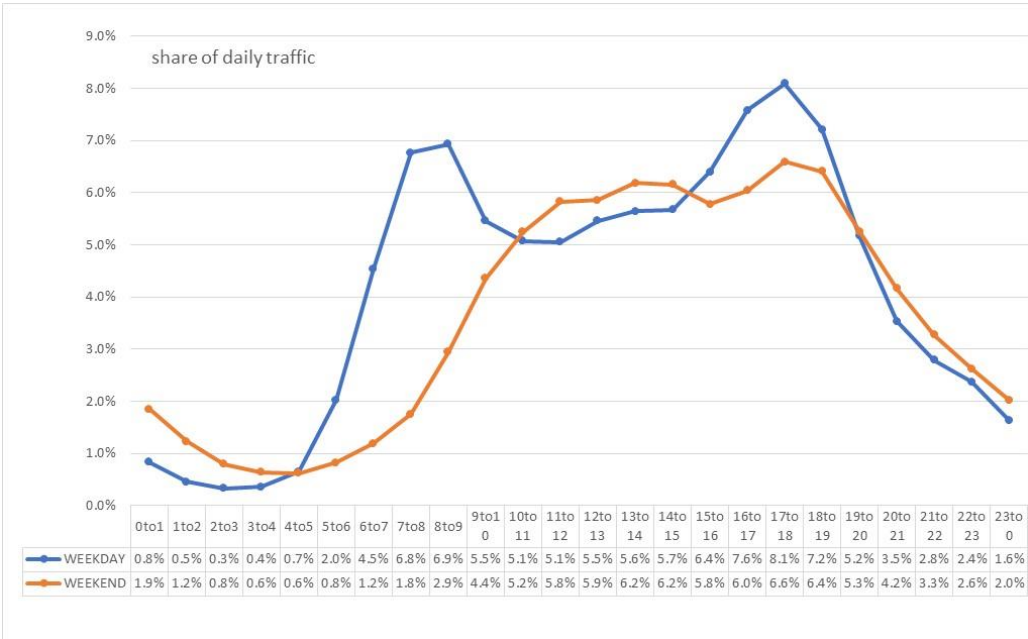

	0to1	1to2	2to3	3to4	4to5	5to6	6to7	7to8	8to9	9to10	10to11	11to12	12to13	13to14	14to15	15to16	16to17	17to18	18to19	19to20	20to21	21to22	22to23	23to0
WEEKDAY	0.8%	0.5%	0.3%	0.4%	0.7%	2.0%	4.5%	6.8%	6.9%	5.5%	5.1%	5.1%	5.5%	5.6%	5.7%	6.4%	7.6%	8.1%	7.2%	5.2%	3.5%	2.8%	2.4%	1.6%
WEEKEND	1.9%	1.2%	0.8%	0.6%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

1.2 Transport: Mode choice model

Since the present time modal split in Sosnowiec and Bristol is very similar (with all modes within a few percent's margin), we used the mode choice model built for Bristol as is for Sosnowiec. 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 16.5 $\mu g.m^{-3}$ and for $PM_{2.5}$ was 15.9 $\mu g.m^{-3}$.

1.3.2 Summary of measuring data

In order to compare and calibrate the modelling results for the year of 2015, for NO_2 and PM10 concentrations the modelling results could be compared with 2 urban background and 1 urban traffic monitoring station. For $PM_{2.5}$, the modelling results could only be compared with 1 urban traffic station.

Figure 1-2 shows the location of the monitoring stations and the annual mean concentration for 2015 for NO_2, PM_{10} and $PM_{2.5}$.
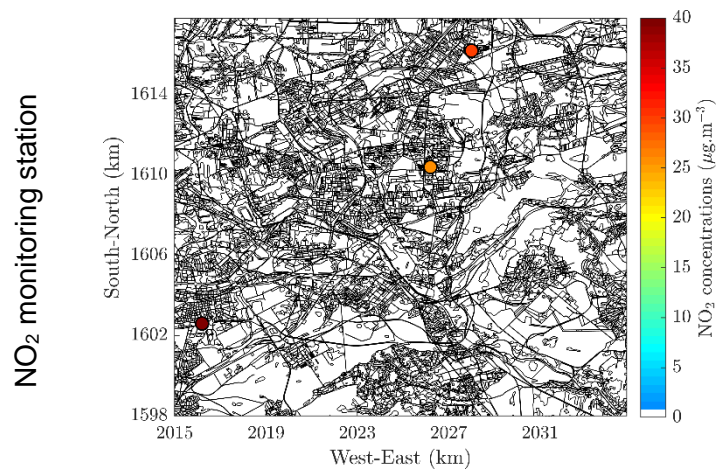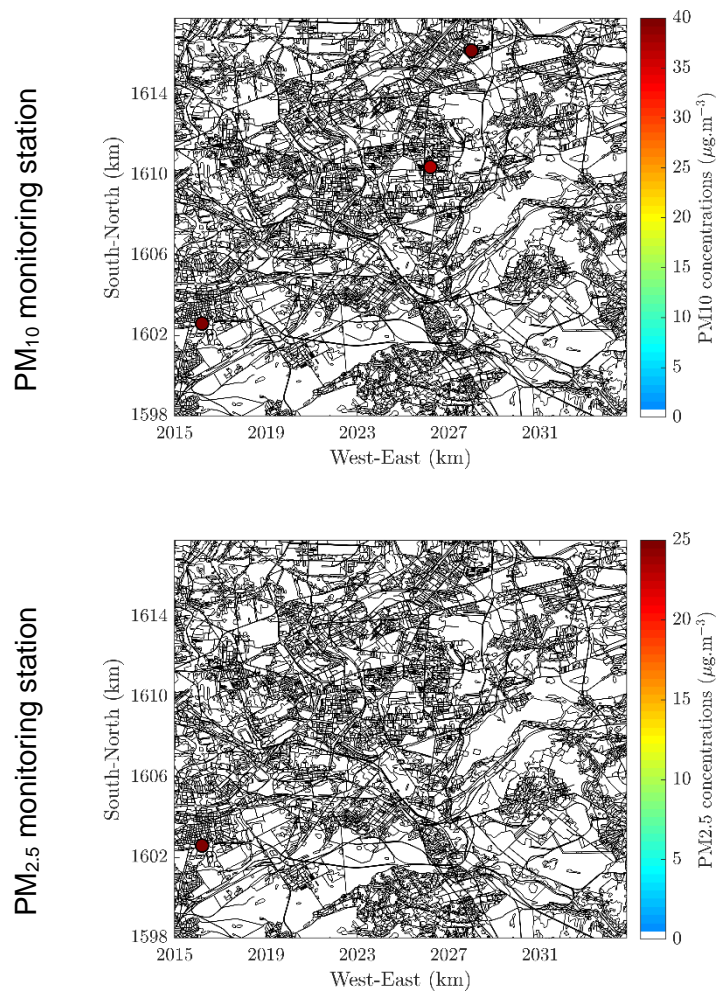
Figure 1-2: Summary data for 2015 with the location of the monitoring stations and respective annual mean concentration for each pollutant in µg.m^{-3}.

The maximum value monitored in 2015 was measured by the urban traffic monitoring station. For NO_2 it measured 58.3 µg.m^{-3} and for PM_{10} it measured 46.4 µg.m^{-3}.

1.3.3 Adjustment procedure

The adjustment procedure is based on the linear regression between the measurements and the simulated concentrations obtained within the cells corresponding to the location of the measurement points. The slope from the linear regression is applied as an adjustment factor over the entire domain. For NO_2 concentrations, the slope obtained from the linear regression is equal to 2.18. For PM_{10} concentrations the resulting slope is equal 1.1 and for $PM_{2.5}$ the slope is 0.86.

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

Sosnowiec (the region of Sosnowiec and Katowice) is special in a sense that some policies only come into effect on days with high air pollution levels. This is easy to understand given the climate, the industry, and the socio-economical background of the population in this corner of Poland. As a consequence, we actually modelled the clean and polluted days separately, and at the end the results were merged to account for a general average.

In a few cases policies (especially the ones targeting modal shift) were overly ambitious (meaning: definitely impossible to reach), so – after consultation with the city correspondents – we proposed and modelled modified policy targets.

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

Table 2-1: overview of the measures in the Sosnowiec SDW and final scenario

Policy	Low Scenario	High Scenario	Final Scenario
Make public transport free/cheaper	Free public transport on days with high level of air pollution by 2020	Free public transport by 2025	Low option
Reduce emissions from public transport	Replace 10% public transport fleet with zero-emission vehicles by 2030	Replace 50% public transport fleet with zero-emission vehicles by 2022	Low option

Improve the public transport service/connectivity	90% public transport journeys on schedule and most areas catered for by 2020	100% public transport journeys on schedule and most areas catered for by 2020	Low option
Create/increase cycle lanes and infrastructure (storage, security)	20 km of new cycle lanes and 15 new cycle parking spaces by 2020	20 km of new cycle lanes and 15 new cycle parking spaces by 2020	High option (High and Low here were the same)
Encourage/incentivise electric vehicles	Replace 10% cars with EVs and 100 EV charging points installed by 2025	Replace 50% cars with EVs and 500 EV charging points installed by 2030	Low option
Restrict (polluting) vehicles	Ban diesel cars from the city centre on days with level of air pollution by 2050 (in model by 2030)	100% ban on fossil fuelled vehicles by 2025 (only diesel in model)	Low option, but ban diesel cars from the city centre on days with level of air pollution in a faster perspective – by 2025
Raise public awareness of health/environmental impacts of air pollution	10% modal shift from private to public transport or active travel by 2030	80% in modal shift from private to public transport or active travel by 2025 (In model 40% by 2030)	High option
Reduce emissions from domestic heating	Ban on domestic coal heating in districts with the highest concentration of air pollution by 2025	100% ban on domestic coal heating by 2020	Low option
Replace old domestic heating systems	Replace 75% heating systems > 10 years old by 2025	Replace 100% heating systems > 10 years old by 2021	High option
Reduce industrial emissions	Reduce industrial emissions by 25% by 2025	Reduce industrial emissions by 50% by 2025	Low option

2.1 Transport

2.1.1 Baseline and BAU

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

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

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

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

$ASC\_1 = ASC\_1-0.4$
$ASC\_2 = ASC\_2+0.1$

ASC_4 = ASC_4+0.24
ASC_5 = ASC_5+0.3

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

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

2.1.2 Proposed SDW scenario's

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

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

The High Scenario is very different, because while in the LOW Scenario people still keep their diesel cars (they simply do not use them on specific days), here we really scrap all diesel vehicles using the usual stepwise approach (similar to the Final Scenario of Bristol). The final ban is implemented by 2025 (with bans of Euro 3-4-5 by 2019-2021-2023). As people are also made aware in time that such a strict ban is coming, we accelerate the uptake of xEV technologies even more by using a technology shift parameter of -10 (which is admittedly very extreme, similar to the observed uptake rate of Norway). Leading up to the ban the sale shares of diesel cars are gradually cut back (according to the actual drop in diesel sales) to model that suddenly less diesels are going to be sold, while the sale shares

of the remaining technologies are boosted to fill the formed gap[2]. This overall means that as diesel is getting phased out, less diesel cars are bought than in the model without scrappage, while the deficit is distributed over the other propulsion types.

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

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

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

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

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

- In Clean model 2025:
    - ASC_2 = ASC_2+0.8

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

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

2.1.3 Final Scenario

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

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

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

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

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

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

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

- Clean 2025:
  - $ASC\_1 = ASC\_1-0.4$
  - $ASC\_2 = ASC\_2+1.45$
  - $ASC\_3 = ASC\_3-0.8$
  - $ASC\_4 = ASC\_4+0.22$
  - $ASC\_5 = ASC\_5+0.18$
- Clean 2035:
  - $ASC\_1 = ASC\_1-0.05$
  - $ASC\_2 = ASC\_2+2$
  - $ASC\_3 = ASC\_3-0.9$
  - $ASC\_4 = ASC\_4+0.6$
  - $ASC\_5 = ASC\_5+0.7$
- Polluted 2025:
  - $ASC\_1 = ASC\_1-0.45$
  - $ASC\_2 = ASC\_2+1.45$
  - $ASC\_3 = ASC\_3-0.7$
  - $ASC\_4 = ASC\_4-0.2$
  - $ASC\_5 = ASC\_5-0.1$
- Polluted 2035:
  - $ASC\_1 = ASC\_1-0.275$
  - $ASC\_2 = ASC\_2+1.9$
  - $ASC\_3 = ASC\_3-0.95$
  - $ASC\_4 = ASC\_4-0.05$
  - $ASC\_5 = ASC\_5+0.1$

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

2.2 Industrial, Residential, Commercial & Institutional (IRCI)

2.2.1 Baseline

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

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);
- Gminy disaggregation variables (Table 2-5).

For heating networks (district heating) we assume the following split between fuels, using national figures excluding waste derived fuels more territorial specific[3]: coal (89%), natural gas (7%), wood (4%).

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[3] Statistics Poland, Energy statistics in 2015 and 2016. Table 8 (13). Public Thermal Plants - Heat Generation

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

Activity	Data availability	Source	Publication	Reference	Disaggregation variable
Industrial sector	Single facility	EIONET	Reporting Obligations Database (ROD), Deliveries for National Emission Ceiling Directive (NECD) - Large point source (LPS) emissions data by source category (GNFR) Poland NECD 2017 Report LPS emissions 2007 2015	http://cdr.eionet.europa.eu/pl/eu/nec_revised/lps/envwql3ba/Annex_VI_LPS_2015_POL__TSP.xls	None (Point sources)

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

Activity	Energy vector	Data availability	Source	Publication	Reference	Note	Disaggregation variable
Residential sector	Natural Gas	Level 3 (Gminy) only for Sosnowiec	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
		Level 2 (Wojewodztwa) for all other Gminy	Główny Urząd Statystyczny	Zużycie paliw i nośników energii w 2015 roku, Tab. 2. Zużycie gazu ziemnego	https://stat.gov.pl/obszary-tematyczne/srodowisko-energia/energia/zuzycie-paliw-i-nosnikow-energii-w-2015-roku,6,10.html		Population

Table 2-3: Methodology and source of data for Sosnowiec fuel consumptions evaluation - Residential and commercial sources (cont.)

Activity	Energy vector	Data availability	Source	Publication	Reference	Note	Disaggregation variable
	Heat[4]	Level 3 (Gminy) only for Sosnowiec	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
		Level 2 (Wojewodztwa) for all other Gminy	Główny Urząd Statystyczny	Zużycie paliw i nośników energii w 2015 roku, Tab. 6. Zużycie ciepła	https://stat.gov.pl/obszary-tematyczne/srodowisko-energia/energia/zuzycie-paliw-i-nosnikow-energii-w-2015-roku,6,10.html		Population
	Wood	Level 3 (Gminy) only for Sosnowiec	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None

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[4] For heating networks (district heating) we assume the following split of fuel, using national figures excluding waste derived fuels more territorial specific: coal (89%), natural gas (7%), wood (4%).

Activity	Energy vector	Data availability	Source	Publication	Reference	Note	Disaggregation variable
		Level 2 (Wojewodztwa) for all other Gminy	Główny Urząd Statystyczny	Zużycie paliw i nośników energii w 2015 roku, Tab. 6. Zużycie ciepła	https://stat.gov.pl/obszary-tematyczne/srodowisko-energia/energia/zuzycie-paliw-i-nosnikow-energii-w-2015-roku,6,10.html	Only data from district heating	Population
	LPG	Level 3 (Gminy) only for Sosnowiec	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
		Level 2 (Wojewodztwa) for all other Gminy	Główny Urząd Statystyczny	Zużycie paliw i nośników energii w 2015 roku, Tabl. 3. Zużycie gazu ciekłego (zużycie stacjonarne, bez pojazdów)	https://stat.gov.pl/obszary-tematyczne/srodowisko-energia/energia/zuzycie-paliw-i-nosnikow-energii-w-2015-roku,6,10.html	Only data from district heating	Population
	Gasoil	Level 3 (Gminy) only for Sosnowiec	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None

Table 2-3: Methodology and source of data for Sosnowiec fuel consumptions evaluation - Residential and commercial sources (cont.)

Table 2-3: Methodology and source of data for Sosnowiec fuel consumptions evaluation - Residential and commercial sources (cont.)
Activity	Energy vector	Data availability	Source	Publication	Reference	Note	Disaggregation variable
		Level 2 (Wojewodztwa) for all other Gminy	Główny Urząd Statystyczny	Zużycie paliw i nośników energii w 2015 roku, Tabl. 4. Zużycie lekkiego oleju opałowego	https://stat.gov.pl/obszary-tematyczne/srodowisko-energia/energia/zuzycie-paliw-i-nosnikow-energii-w-2015-roku,6,10.html	Only data from district heating	Population
	Coal	Level 3 (Gminy) only for Sosnowiec	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
		Level 2 (Wojewodztwa) for all other Gminy	Główny Urząd Statystyczny	Zużycie paliw i nośników energii w 2015 roku, Tab. 1. Zużycie węgla kamiennego	https://stat.gov.pl/obszary-tematyczne/srodowisko-energia/energia/zuzycie-paliw-i-nosnikow-energii-w-2015-roku,6,10.html		Population
Service sector	Natural Gas	Level 3 (Gminy) only for Sosnowiec	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None

Table 2-3: Methodology and source of data for Sosnowiec fuel consumptions evaluation - Residential and commercial sources (cont.)

Activity	Energy vector	Data availability	Source	Publication	Reference	Note	Disaggregation variable
		Level 2 (Wojewodztwa) for all other Gminy	Główny Urząd Statystyczny	Zużycie paliw i nośników energii w 2015 roku, Tab. 2. Zużycie gazu ziemnego	https://stat.gov.pl/obszary-tematyczne/srodowisko-energia/energia/zuzycie-paliw-i-nosnikow-energii-w-2015-roku,6,10.html		Population
	Heat[5]	Level 3 (Gminy) only for Sosnowiec	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
		Level 2 (Wojewodztwa) for all other Gminy	Główny Urząd Statystyczny	Zużycie paliw i nośników energii w 2015 roku, Tab. 6. Zużycie ciepła	https://stat.gov.pl/obszary-tematyczne/srodowisko-energia/energia/zuzycie-paliw-i-nosnikow-energii-w-2015-roku,6,10.html		Population

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[5] For heating networks (district heating) we assume the following split of fuel, using national figures excluding waste derived fuels more territorial specific: coal (89%), natural gas (7%), wood (4%).

Table 2-3: Methodology and source of data for Sosnowiec fuel consumptions evaluation - Residential and commercial sources (cont.)

Activity	Energy vector	Data availability	Source	Publication	Reference	Note	Disaggregation variable
	Wood	Level 3 (Gminy) only for Sosnowiec	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
		Level 2 (Wojewodztwa) for all other Gminy	Główny Urząd Statystyczny	Zużycie paliw i nośników energii w 2015 roku, Tab. 6. Zużycie ciepła	https://stat.gov.pl/obszary-tematyczne/srodowisko-energia/energia/zuzycie-paliw-i-nosnikow-energii-w-2015-roku,6,10.html	Only data from district heating	Population
	LPG	Level 3 (Gminy) only for Sosnowiec	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
		Level 2 (Wojewodztwa) for all other Gminy	Główny Urząd Statystyczny	Zużycie paliw i nośników energii w 2015 roku, Tabl. 3. Zużycie gazu ciekłego (zużycie stacjonarne, bez pojazdów)	https://stat.gov.pl/obszary-tematyczne/srodowisko-energia/energia/zuzycie-paliw-i-nosnikow-energii-w-2015-roku,6,10.html	Only data from district heating	Population

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Table 2-3: Methodology and source of data for Sosnowiec fuel consumptions evaluation - Residential and commercial sources (cont.)

Activity	Energy vector	Data availability	Source	Publication	Reference	Note	Disaggregation variable
	Gasoil	Level 3 (Gminy) only for Sosnowiec	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
		Level 2 (Wojewodztwa) for all other Gminy	Główny Urząd Statystyczny	Zużycie paliw i nośników energii w 2015 roku, Tabl. 4. Zużycie lekkiego oleju opałowego	https://stat.gov.pl/obszary-tematyczne/srodowisko-energia/energia/zuzycie-paliw-i-nosnikow-energii-w-2015-roku,6,10.html	Only data from district heating	Population
	Coal	Level 3 (Gminy) only for Sosnowiec	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
		Level 2 (Wojewodztwa) for all other Gminy	Główny Urząd Statystyczny	Zużycie paliw i nośników energii w 2015 roku, Tab. 1. Zużycie węgla kamiennego	https://stat.gov.pl/obszary-tematyczne/srodowisko-energia/energia/zuzycie-paliw-i-nosnikow-energii-w-2015-roku,6,10.html		Population

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

Variable	Data availability	Sources	Publication	Reference	Note
Technologies split	Level 1 (National)	Central Statistical Office	Energy consumption in households in 2012, 2014	https://stat.gov.pl/download/gfx/portalinformacyjny/en/defaultaktualnosci/3304/2/2/1/energy_consumption_in_households_in_2012.pdf	Central heating boilers, used to produce heat and warm water, were found in 41.3% of households using solid fuels. The single-function boilers were used in 31.9% of households using solid fuels. The most traditional heating devices, such as stoves in rooms (mostly made of tiles), were used in 19.2% of households. 7% of households using solid fuels had fireplaces, usually with closed insert. In the remaining 0.6% of households, solid fuel fired cooking stoves were the only heating devices. We assume boilers for district heating and traditional stoves for the remaining appliances in residential sectors while we assume boilers in overall services appliances

Table 2-5: Methodology and source of data for Sosnowiec fuel consumptions evaluation – Gminy disaggregation variables

Variable	Data availability	Sources	Publication	Reference	Fields
Population	Level 3 (Gminy)	Główny Urząd Statystyczny	Ludność w gminach według stanu w dniu 31.12.2011 r. - bilans opracowany w oparciu o wyniki NSP 2011	http://stat.gov.pl/download/cps/rde/xbcr/gus/LUD_bilans_ludnosci_31-12-2011.xls	Population total by Gminy (Sheet Slaskie column Ogolem)

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 Poland official projections.

The scenario was built in different steps using:

- the projections of greenhouse gas emissions and energy demand from the 7th national communication to UNFCCC[6] using scenario with additional measures (WAM)
- the national measures defined in the 'with measures' (adopted measures) projection in the frame of NECD[7].

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 **Sosnowiec** BAU projections consider:

The Plan for a low-carbon economy was published in 2015 and updated[8] in 2016 and since then has been shaping city policy and strategies around energy and climate.

The plan lists goals for the city which include, by 2020:

- Reducing energy consumption to 3 840 GWh/year (a 5.6% reduction on 2013 consumption);
- Reducing CO_2 emissions to 1 517 ktCO2 (a 5.2% reduction on 2013 levels); and,
- Increasing renewable energy to 104.5 GWh/year (an increase of 12% on 2013 levels).

Two main actions involve building sector:

- Thermal renovations of buildings (with 196 811 MWh/year saving and about 11%);
- Modernization District Heating (with 10 855 MWh/year saving and about 1%).

These reductions have been added to national reductions discussed before.

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

For drivers coming from EU NEC "with measures" data, as it's impossible to derive from available information the split between socio-economic measures, such as for example fuel

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[6] The Republic of Poland, Seventh National Communication and Third Biennial Report Under the United Nations Framework Convention on Climate Change
[7] EEA Eionet, Reporting Obligations Database (ROD), Deliveries for National Emission Ceiling Directive (NECD) - Projected emissions by aggregated NFR sectors
[8] Kompleksowy plan gospodarki niskoemisyjnej dla miasta Sosnowiec, Aktualizacja 2016

consumptions reductions, and technological measures, such as for example advanced combustion technology, all the measures are valuated as technological. The NEC projections for residential & commercial are higher that emissions resulting from application of measures from UNFCCC NC. No more reductions are introduced other than UNFCCC NC ones. For industry the drivers introduced are reported in Table 2-6 from NEC.

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

Code	Name	Domain
SOS_B_DH_C	Sosnowiec BAU District heating- Hard Coal	all Sosnowiec Gminy
SOS_B_DH_NG	Sosnowiec BAU District heating- Natural gas	all Sosnowiec Gminy
SOS_B_DH_W	Sosnowiec BAU District heating- Solid biomass	all Sosnowiec Gminy
SOS_B_MDH	Sosnowiec BAU Modernisation District Heating.	all Sosnowiec Gminy
SOS_B_RC_C	Sosnowiec BAU Residential & Commercial - Hard Coal	all Sosnowiec Gminy
SOS_B_RC_G	Sosnowiec BAU Residential & Commercial - Gas/Diesel Oil	all Sosnowiec Gminy
SOS_B_RC_L	Sosnowiec BAU Residential & Commercial – LPG	all Sosnowiec Gminy
SOS_B_RC_NG	Sosnowiec BAU Residential & Commercial - Natural gas	all Sosnowiec Gminy
SOS_B_RC_W	Sosnowiec BAU Residential & Commercial - Solid biomass	all Sosnowiec Gminy
SOS_B_TRB	Sosnowiec BAU Thermal renovations of buildings	all Sosnowiec Gminy

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

Code	Name	Domain
SOS_NECI_NOx	Sosnowiec NEC Industry NOx	all Sosnowiec Gminy
SOS_NECI_PM	Sosnowiec NEC Industry PM	all Sosnowiec Gminy

2.2.3 SDW scenarios

Scenarios from the Stakeholder dialog workshop (SWD) includes the measures summarized in table below, relating to the IRCI sector (the codes are defined in this report).

Table 2-8: Sosnowiec: Measures coming from the Stakeholder dialog workshop

Code	Description	Scenario
SOS_CoalB20	Sosnowiec Ban coal on Residential & Commercial from 2020	High
SOS_CoalPB25	Sosnowiec Partial Ban coal on Residential & Commercial	Low
SOS_I-50%25	Sosnowiec Reduce industrial emissions by 50% on 2025	High
SOS_I-25%25	Sosnowiec Reduce industrial emissions by 25% on 2025	Low
SOS_RH75%NOx	Sosnowiec Replace 75% >10 years old by 2025 NOx	Low
SOS_RHallNOx	Sosnowiec Replace all >10 years old by 2025 NOx	High
SOS_RH75%PM	Sosnowiec Replace 75% >10 years old by 2025 PM	Low
SOS_RHallPM	Sosnowiec Replace all >10 years old by 2025 PM	High

We assume that:

- Regarding the measures on Ban coal on Residential & Commercial:
  - we assume that the measures don't apply to heat generated by district heating;
  - for the partial ban, we assume the ban in the areas of Pogoń (2445 households), followed by Zagórze (1446), Niwka (1141), Dańdówka (1105) and Klimontów (1002) and consider 10% of total households.
- Regarding measures to replace 75% or 100% of heating system with more than 10 years old we:
  - apply this measure to wood stoves and fireplaces, where the measure produces a strong reduction of PM emissions (wood stoves and fireplaces);
  - we take into consideration the available data about age of appliances[9] and assume 75% of stoves and 50% of fireplaces have more than 10 years of life;
- Regarding measures to reduce industrial emissions the Scenarios include the only plant into Sosnowiec Wojewodztwa while the emissions from plants on surrounding Wojewodztwa are kept constant.

2.2.4 Unified Policy Scenario

The final Unified Policy Scenario includes the measures summarized in table below, relating to the IRCI sector (the codes are defined in this report).

Table 2-9: Sosnowiec: Measures for the Unified Policy Scenario

Code	Description

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[9] Central Statistical Office, Energy consumption in households in 2012

SOS_CoalPB25	Sosnowiec Partial Ban coal on Residential & Commercial
SOS_I-25%25	Sosnowiec Reduce industrial emissions by 25% on 2025
SOS_RHallNOx	Sosnowiec Replace all >10 years old by 2025 NOx
SOS_RHallPM	Sosnowiec Replace all >10 years old by 2025 PM

2.3 Carbon footprint

2.3.1 Baseline

The following tables document the methodology and data used for:

- Industrial sources (Table 2-10)
- Residential and commercial sources (Table 2-11)

For heating networks (district heating) we assume the following split between fuels, using national figures excluding waste derived fuels more territorial specific[10]: coal (89%), natural gas (7%), wood (4%).

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[10] Statistics Poland, Energy statistics in 2015 and 2016. Table 8 (13). Public Thermal Plants - Heat Generation

Table 2-10: Methodology and source of data for Sosnowiec fuel consumptions evaluation - Industrial sources

Activity	Energy vector	Data availability	Source	Publication	Reference	Field	Disaggregation variable
Industrial sector	Natural Gas	Level 3 (Gminy)	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
	LPG	Level 3 (Gminy)	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
	Gasoil	Level 3 (Gminy)	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
	Coal	Level 3 (Gminy)	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
	Electricity	Level 3 (Gminy)	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None

Table 2-11: Methodology and source of data for Sosnowiec fuel consumptions evaluation - Residential and services sources

Activity	Energy vector	Data availability	Source	Publication	Reference	Field	Disaggregation variable
Residential sector	Natural Gas	Level 3 (Gminy)	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
	Heat[11]	Level 3 (Gminy)	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
	Wood	Level 3 (Gminy)	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None

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[11] For heating networks (district heating) we assume the following split of fuel, using national figures excluding waste derived fuels more territorial specific: coal (89%), natural gas (7%), wood (4%).

Table 2-12: Methodology and source of data for Sosnowiec fuel consumptions evaluation - Residential and services sources (cont.)

Activity	Energy vector	Data availability	Source	Publication	Reference	Field	Disaggregation variable
	LPG	Level 3 (Gminy)	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
	Gasoil	Level 3 (Gminy)	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
	Coal	Level 3 (Gminy)	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
	Electricity	Level 3 (Gminy)	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None

Table 2-12: Methodology and source of data for Sosnowiec fuel consumptions evaluation - Residential and services sources (cont.)

Activity	Energy vector	Data availability	Source	Publication	Reference	Field	Disaggregation variable
Service sector (included in industrial sector statistics)	Natural Gas	Level 3 (Gminy)	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
	Heat[12]	Level 3 (Gminy)	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
	Wood	Level 3 (Gminy)	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None

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[12] For heating networks (district heating) we assume the following split of fuel, using national figures excluding waste derived fuels more territorial specific: coal (89%), natural gas (7%), wood (4%).

Table 2-12: Methodology and source of data for Sosnowiec fuel consumptions evaluation - Residential and services sources (cont.)

Activity	Energy vector	Data availability	Source	Publication	Reference	Field	Disaggregation variable
	LPG	Level 3 (Gminy)	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
	Gasoil	Level 3 (Gminy)	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
	Coal	Level 3 (Gminy)	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None
	Electricity	Level 3 (Gminy)	Urzędu Miasta Sosnowiec	Energoekspert. Kompleksowy Plan Gospodarki Niskoemisyjnej dla Miasta Sosnowiec, Tabela 16-1. Końcowe zużycie energii w roku 2013	http://www.sosnowiec.pl/_upload/PGN%20Sosnowiec%2011.09.2015%20a.pdf	2013 to 2015 with Wojewodztwa data	None

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, data from IRCI and Traffic model results have been assumed for fuel consumptions.

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.

3 Results

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

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

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

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

3.1 Transport

3.1.1 Mode choice changes

We present here the tables containing the relative mileage changes (compared to the Baseline) and the resulting modal split (where applicable[13]) for various reporting years in each scenario. For the Final scenario we also present the calibrated baseline.

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

Figure 3-1: Scenario Low Clean (2025)

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

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

Figure 3-2: Scenario Low Clean (2035-2050)

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

Figure 3-3: Scenario Low Polluted (2025)

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

Figure 3-4: Scenario Low Polluted (2035)

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

Figure 3-5: Scenario Low Polluted (2050)

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

Figure 3-6: Scenario High (2025-2035-2050)

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

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

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

Figure 3-8: Final Clean Scenario (2025)

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

Figure 3-9: Final Clean Scenario (2035-2050)

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

Figure 3-10: Final Polluted Scenario (2025)

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

Figure 3-11: Final Polluted Scenario (2035)

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

Figure 3-12: Final Polluted Scenario (2050)

3.1.2 Fleet and Emissions

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

BAU	VENSIM model in percentage of total fleet per reporting year			
	2016	2025	2035	2050
[LPETROL]	51.13%	42.84%	35.54%	15.77%
[HPETROL]	2.30%	2.22%	2.03%	0.95%
[LDIESEL]	27.07%	34.10%	29.83%	13.30%
[HDIESEL]	5.52%	4.60%	3.50%	1.53%
[ELECTRIC]	0.00%	0.50%	5.75%	20.87%
[FUELCELL]	0.00%	0.10%	2.00%	7.97%
[HYBRID]	0.00%	0.75%	6.10%	25.63%
[HYBDIS]	0.00%	0.43%	1.77%	2.18%
[CNG]	0.01%	0.43%	0.54%	0.27%
[LPG]	13.96%	14.00%	12.93%	11.52%
[E85]	0.01%	0.00%	0.00%	0.00%

LOW CLEAN	VENSIM model in percentage of total fleet per reporting year			
	2016	2025	2035	2050
[LPETROL]	51.13%	38.50%	25.20%	5.95%
[HPETROL]	2.30%	1.96%	1.40%	0.36%
[LDIESEL]	27.07%	30.41%	21.09%	5.02%
[HDIESEL]	5.52%	4.19%	2.50%	0.58%
[ELECTRIC]	0.00%	4.54%	13.89%	30.32%
[FUELCELL]	0.00%	0.77%	4.39%	11.51%
[HYBRID]	0.00%	3.30%	13.68%	31.31%
[HYBDIS]	0.00%	1.92%	4.51%	3.34%
[CNG]	0.01%	0.36%	0.37%	0.10%
[LPG]	13.96%	14.06%	12.97%	11.51%
[E85]	0.01%	0.00%	0.00%	0.00%

LOW POLL.	VENSIM model in percentage of total fleet per reporting year			
	2016	2025	2035	2050
[LPETROL]	51.13%	38.50%	25.20%	5.95%
[HPETROL]	2.30%	1.96%	1.40%	0.36%
[LDIESEL]	27.07%	30.41%	0.00%	0.00%
[HDIESEL]	5.52%	4.19%	0.00%	0.00%
[ELECTRIC]	0.00%	4.54%	13.89%	30.32%
[FUELCELL]	0.00%	0.77%	4.39%	11.51%
[HYBRID]	0.00%	3.30%	13.68%	31.31%
[HYBDIS]	0.00%	1.92%	4.51%	3.34%
[CNG]	0.01%	0.36%	0.37%	0.10%
[LPG]	13.96%	14.06%	12.97%	11.51%
[E85]	0.01%	0.00%	0.00%	0.00%

HIGH	VENSIM model in percentage of total fleet per reporting year			
	2016	2025	2035	2050
[LPETROL]	51.13%	41.73%	19.76%	2.29%
[HPETROL]	2.30%	2.14%	1.07%	0.14%
[LDIESEL]	27.07%	0.00%	0.00%	0.00%
[HDIESEL]	5.52%	0.00%	0.00%	0.00%
[ELECTRIC]	0.00%	16.44%	24.94%	38.56%
[FUELCELL]	0.00%	2.33%	7.03%	14.51%
[HYBRID]	0.00%	11.63%	22.41%	28.61%
[HYBDIS]	0.00%	7.14%	8.49%	3.95%
[CNG]	0.01%	0.40%	0.27%	0.04%
[LPG]	13.96%	18.19%	16.02%	11.90%
[E85]	0.01%	0.01%	0.00%	0.00%

Figure 3-13: Passenger car fleet composition in the BAU and in the (Clean and Polluted, also Final) and High Scenario. Since the fleet component of the Final Scenario is the same as the one of the Low Scenario, the central two rows (Low Clean and Low Polluted) also corresponds to the Final Scenarios (Clean and Polluted).

Table 3-1: relative emissions in the BAU and SDW scenario (top) and the final scenario (bottom)

MIDZWVR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	67.38%	42.47%	12.96%
Scenario 1		67.38%	42.47%	12.96%
Scenario 2		67.38%	42.47%	12.96%

PM

Year	2015	2025	2035	2050
BAU	100.00%	43.82%	21.25%	14.00%
Scenario 1		43.82%	21.25%	14.00%
Scenario 2		43.82%	21.25%	14.00%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	111.01%	123.23%	144.14%
Scenario 1		111.01%	123.23%	144.14%
Scenario 2		111.01%	123.23%	144.14%

MOTO

Nox

Year	2015	2025	2035	2050
BAU	100.00%	105.97%	74.70%	22.62%
Scenario 1		105.97%	74.70%	22.62%
Scenario 2		105.97%	74.70%	22.62%

PM

Year	2015	2025	2035	2050
BAU	100.00%	69.88%	35.66%	23.67%
Scenario 1		69.88%	35.66%	23.67%
Scenario 2		69.88%	35.66%	23.67%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	110.46%	122.02%	141.66%
Scenario 1		110.46%	122.02%	141.66%
Scenario 2		110.46%	122.02%	141.66%

ZWVR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	52.74%	22.72%	6.83%
Scenario 1		52.74%	22.72%	6.83%
Scenario 2		52.74%	22.72%	6.83%

PM

Year	2015	2025	2035	2050
BAU	100.00%	59.25%	27.05%	17.82%
Scenario 1		59.25%	27.05%	17.82%
Scenario 2		59.25%	27.05%	17.82%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	109.92%	120.82%	139.23%
Scenario 1		109.92%	120.82%	139.23%
Scenario 2		109.92%	120.82%	139.23%

CAR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	75.19%	38.91%	6.64%
Scenario 1_badAQ		52.20%	4.50%	1.18%
Scenario 1_goodAQ		68.67%	28.58%	3.12%
scenario 2		10.87%	5.66%	0.94%

PM

Year	2015	2025	2035	2050
BAU	100.00%	55.61%	17.59%	9.68%
Scenario 1_badAQ		39.40%	4.84%	4.77%
Scenario 1_goodAQ		51.83%	13.93%	6.87%
scenario 2		7.48%	4.68%	3.14%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	120.17%	137.12%	154.84%
Scenario 1_badAQ		89.99%	74.75%	105.63%
Scenario 1_goodAQ		118.38%	125.26%	141.45%
scenario 2		65.14%	74.32%	83.93%

BUS

Nox

Year	2015	2025	2035	2050
BAU	100.00%	105.51%	75.00%	22.71%
Scenario 1_badAQ		255.29%	190.04%	47.95%
Scenario 1_goodAQ		96.74%	97.34%	24.56%
scenario 2		180.80%	64.25%	0.00%

PM

Year	2015	2025	2035	2050
BAU	100.00%	59.07%	30.93%	20.53%
Scenario 1_badAQ		142.92%	78.37%	43.35%
Scenario 1_goodAQ		54.16%	40.14%	22.21%
scenario 2		101.22%	26.50%	0.00%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	110.46%	122.02%	141.66%
Scenario 1_badAQ		281.33%	343.55%	398.85%
Scenario 1_goodAQ		106.60%	175.97%	204.30%
scenario 2		378.56%	418.17%	485.48%

VAN

Nox

Year	2015	2025	2035	2050
BAU	100.00%	71.29%	40.69%	9.80%
Scenario 1_badAQ		59.79%	23.49%	7.07%
Scenario 1_goodAQ		68.03%	35.52%	8.04%
scenario 2		5.43%	2.83%	0.47%

PM

Year	2015	2025	2035	2050
BAU	100.00%	49.72%	19.42%	11.84%
Scenario 1_badAQ		41.61%	13.05%	9.39%
Scenario 1_goodAQ		47.83%	17.59%	10.44%
scenario 2		3.74%	2.34%	1.57%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	115.59%	130.18%	149.49%
Scenario 1_badAQ		100.50%	98.99%	124.88%
Scenario 1_goodAQ		114.70%	124.25%	142.79%
scenario 2		32.57%	37.16%	41.96%

MIDZWVR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	67.38%	42.47%	12.96%
UPS-good AQ		67.38%	42.47%	12.96%
UPS-bad AQ		67.38%	42.47%	12.96%

PM

Year	2015	2025	2035	2050
BAU	100.00%	43.82%	21.25%	14.00%
UPS-good AQ		43.82%	21.25%	14.00%
UPS-bad AQ		43.82%	21.25%	14.00%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	111.01%	123.23%	144.14%
UPS-good AQ		111.01%	123.23%	144.14%
UPS-bad AQ		111.01%	123.23%	144.14%

MOTO

Nox

Year	2015	2025	2035	2050
BAU	100.00%	105.97%	74.70%	22.62%
UPS-good AQ		105.97%	74.70%	22.62%
UPS-bad AQ		105.97%	74.70%	22.62%

PM

Year	2015	2025	2035	2050
BAU	100.00%	69.88%	35.66%	23.67%
UPS-good AQ		69.88%	35.66%	23.67%
UPS-bad AQ		69.88%	35.66%	23.67%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	110.46%	122.02%	141.66%
UPS-good AQ		110.46%	122.02%	141.66%
UPS-bad AQ		110.46%	122.02%	141.66%

ZWVR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	52.74%	22.72%	6.83%
UPS-good AQ		52.74%	22.72%	6.83%
UPS-bad AQ		52.74%	22.72%	6.83%

PM

Year	2015	2025	2035	2050
BAU	100.00%	59.25%	27.05%	17.82%
UPS-good AQ		59.25%	27.05%	17.82%
UPS-bad AQ		59.25%	27.05%	17.82%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	109.92%	120.82%	139.23%
UPS-good AQ		109.92%	120.82%	139.23%
UPS-bad AQ		109.92%	120.82%	139.23%

CAR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	75.19%	38.91%	6.64%
UPS-good AQ		58.01%	22.58%	2.47%
UPS-bad AQ		4.35%	2.62%	0.85%

PM

Year	2015	2025	2035	2050
BAU	100.00%	55.61%	17.59%	9.68%
UPS-good AQ		43.79%	11.00%	5.43%
UPS-bad AQ		2.84%	2.81%	3.43%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	120.17%	137.12%	154.84%
UPS-good AQ		100.01%	98.98%	111.76%
UPS-bad AQ		30.14%	43.49%	75.90%

BUS

Nox

Year	2015	2025	2035	2050
BAU	100.00%	105.51%	75.00%	22.71%
UPS-good AQ		124.71%	97.15%	24.51%
UPS-bad AQ		245.93%	183.98%	46.43%

PM

Year	2015	2025	2035	2050
BAU	100.00%	59.07%	30.93%	20.53%
UPS-good AQ		69.82%	40.06%	22.16%
UPS-bad AQ		137.69%	75.87%	41.97%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	110.46%	122.02%	141.66%
UPS-good AQ		137.43%	175.62%	203.89%
UPS-bad AQ		271.01%	332.59%	386.13%

VAN

Nox

Year	2015	2025	2035	2050
BAU	100.00%	71.29%	40.69%	9.80%
UPS-good AQ		62.70%	32.53%	7.71%
UPS-bad AQ		35.87%	22.55%	6.90%

PM

Year	2015	2025	2035	2050
BAU	100.00%	49.72%	19.42%	11.84%
UPS-good AQ		43.80%	16.13%	9.72%
UPS-bad AQ		23.33%	12.03%	8.72%

PM_NE

Year	2015	2025	2035	2050
BAU	100.00%	115.59%	130.18%	149.49%
UPS-good AQ		105.51%	111.10%	127.95%
UPS-bad AQ		70.58%	83.36%	110.02%

3.2 Spatial-temporal

▪ Data pre-processing

In this case the temperature dataset was retrieved from a commercial weather service company. We selected the dataset from a station near Sosnowiec: Krakow/Balice Poland, with coordinates 50.08N, 19.80E, 237m. The raw data are available in 365 files with csv ("comma-separated values") as the file extensions: that is, each day represents one .csv file. This means that we have to integrate the 365 files into a single dataset. Each file consists of more than 40 records, representing the half-hourly temperature records. However, not all files have the maximum of 48 observations, that is, the records have missing values. Each file consists of 29 variables, of which we only need two: "datetime" and "temp". Hence, a

reduction technique is required here to remove the 27 non-relevant variables. The "datetime" is in yyyymmddhhhh format, the "temp" unit in Celsius. The first technique we applied is reduction, given that we want to keep only two variables: "datetime" and "temp". Moreover, some solutions for how to merge .csv files into a single worksheet are available online [44]. In this case, the daily 365 .csv files needed to be integrated into a single dataset. Accordingly we applied the solution via Command Prompt (cmd), which copies all the records from the 365 files into a single.txt file, which we then imported into Microsoft Excel. In this case, we applied the transformation technique. To overcome the issue of the missing values in the cleaning task, we interpolated the data. Interpolation is the process of finding and constructing unknown values based on known values [34]. As a result, we have arranged the temperature datasets into hourly (8760 records) and daily average (365 records) resolutions to be used in modelling the load profiles.

Table 3-2: resulting intra-day profiles

Typical days (TD)	Pattern (%)		
	Commercial	Residential	
	NOX and PM10	NOX	PM10
11-02-2015	0,319743007	0,319747738	0,319853728
15-02-2015	0,328261241	0,328266097	0,328374911
12-08-2015	0,237476461	0,237473498	0,237407094
16-08-2015	0,240598803	0,2405958	0,240528524

3.3 IRCI

3.3.1 Baseline

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

- Sosnowiec Gminy Residential, Commercial & Institutional NO_x emissions for all sectors and fuels (Figure 3-14)
- Sosnowiec Gminy Residential, Commercial & Institutional PM_{10} emissions for all sectors and fuels (Figure 3-15),
- Sosnowiec Gminy Residential, Commercial & Institutional NO_x emissions from solid biomass (Figure 3-16),
- Sosnowiec Gminy Residential, Commercial & Institutional PM_{10} emissions from solid biomass (Figure 3-17),
- Sosnowiec Gminy Residential, Commercial & Institutional NO_x emissions from hard coal (Figure 3-18),
- Sosnowiec Gminy Residential, Commercial & Institutional PM_{10} emissions from hard coal Sosnowiec (Figure 3-19),
- Industry NO_x point emissions (Figure 3-20),
- Sosnowiec Industry PM_{10} point emissions (Figure 3-21).
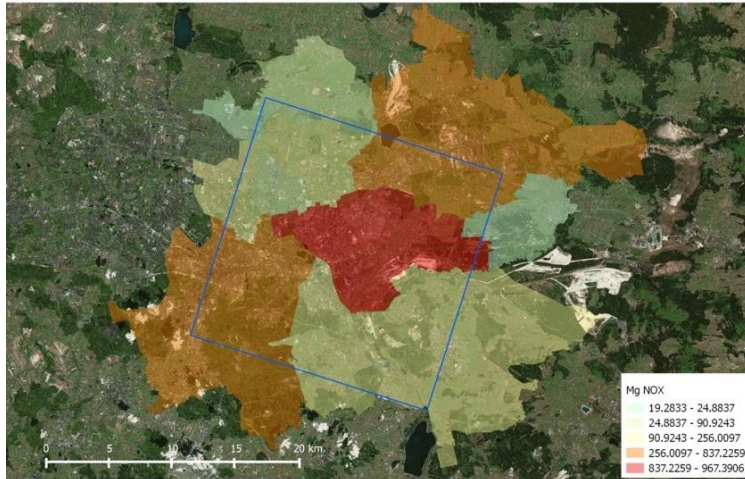
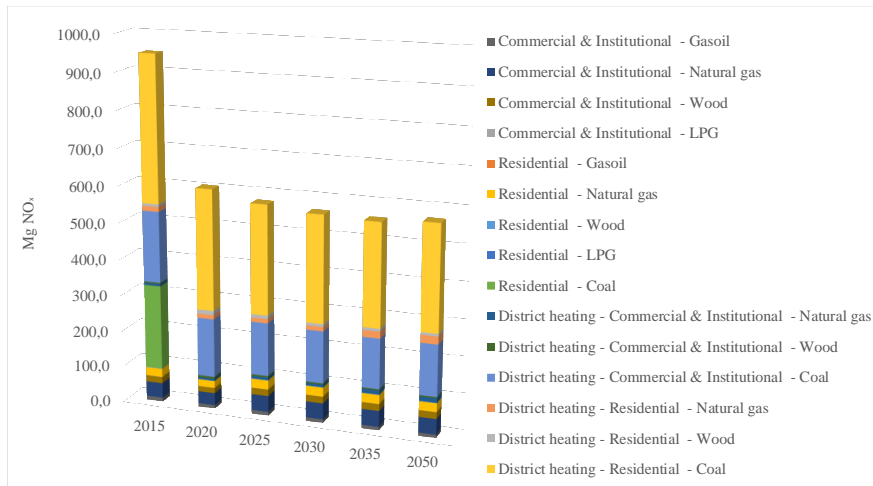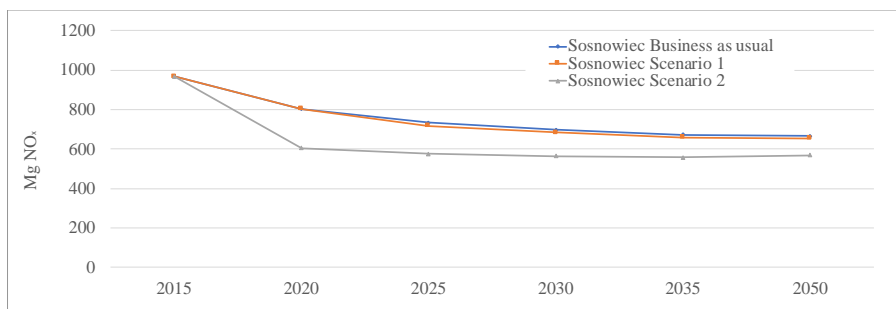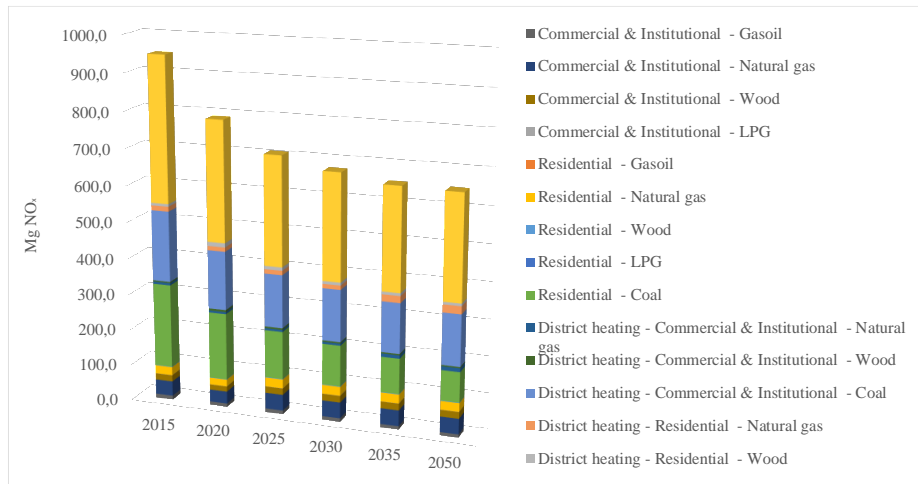**Figure 3-14: Sosnowiec Gminy Residential, Commercial & Institutional NOx emissions – all sectors and fuels**
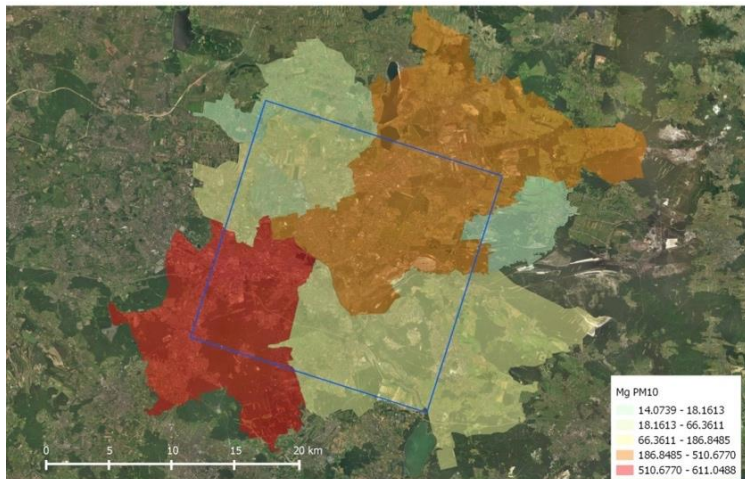
Figure 3-15: Sosnowiec Gminy Residential, Commercial & Institutional PM10 emissions – all sectors and fuels
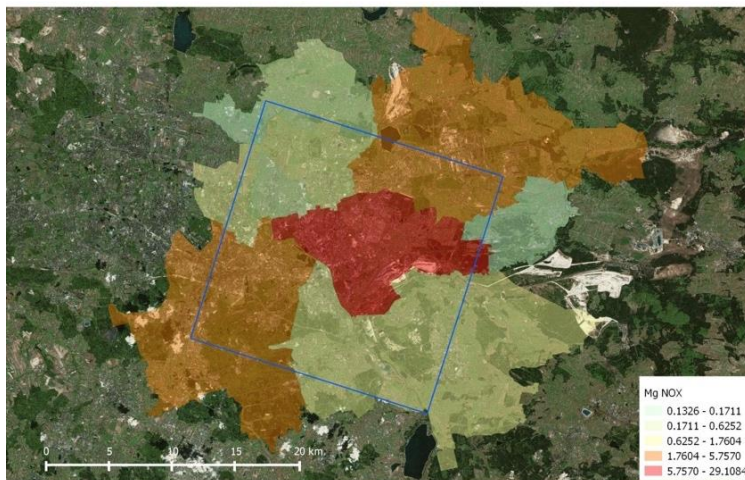
Figure 3-16: Sosnowiec Gminy Residential, Commercial & Institutional NOx emissions – solid biomass
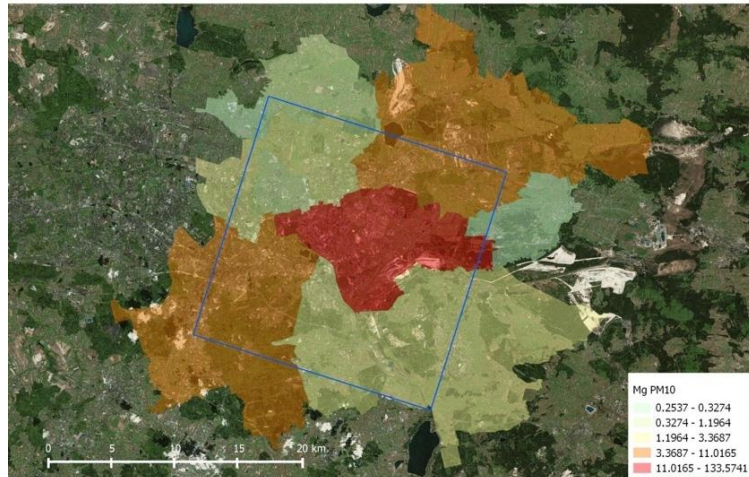
**Figure 3-17: Sosnowiec Gminy Residential, Commercial & Institutional PM10 emissions –
solid biomass**
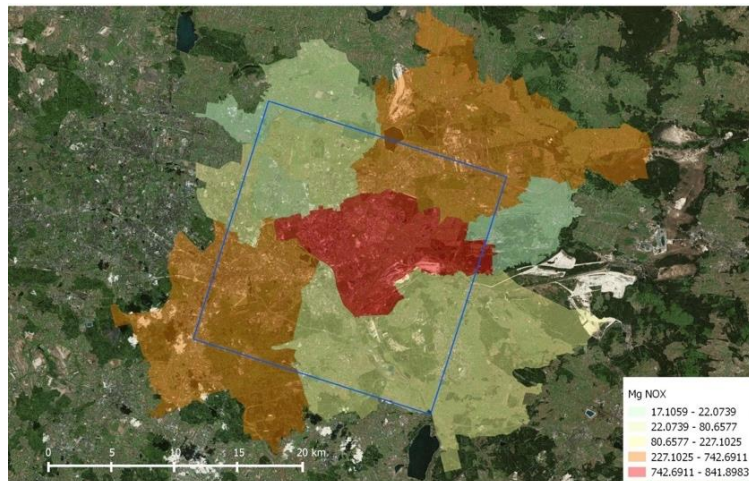
**Figure 3-18: Sosnowiec Gminy Residential, Commercial & Institutional NOx emissions –
hard coal**
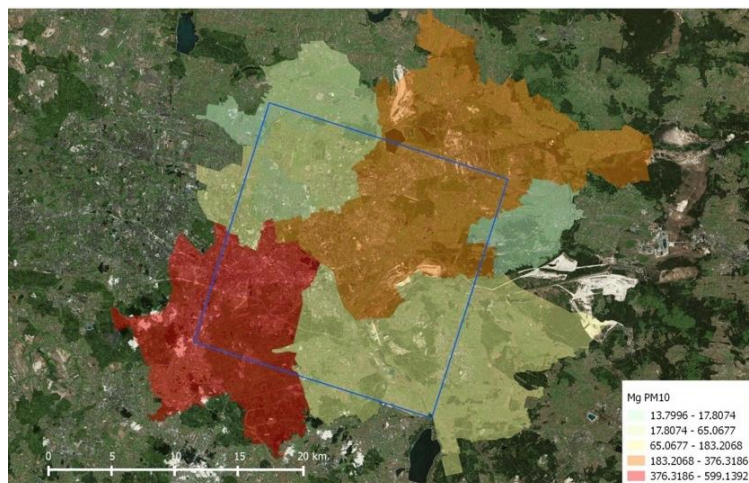
**Figure 3-19: Sosnowiec Gminy Residential, Commercial & Institutional PM10 emissions –
hard coal**

Figure 3-20: Sosnowiec IRC Industry NOx point emissions

Figure 3-21: Sosnowiec IRC Industry PM10 point emissions

Finally, in the following Figure 3-22 and Figure 3-23 the emissions for the different activities & fuels in the only *Sosnowiec Wojewodztwa* are reported.
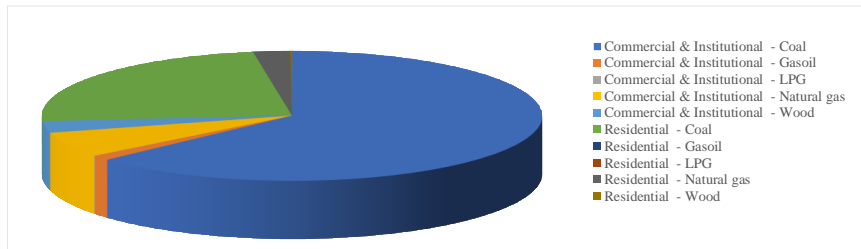
Figure 3-22: Sosnowiec Wojewodztwa Residential, Commercial & Institutional NOx emissions
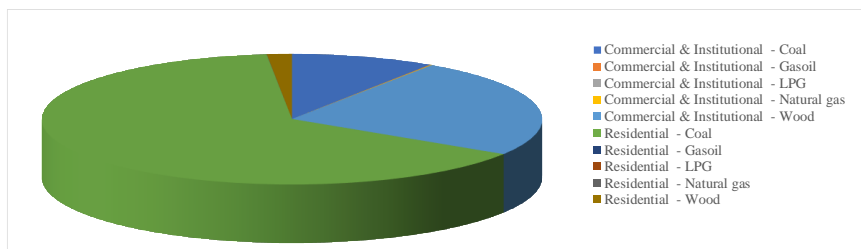
Figure 3-23: Sosnowiec Wojewodztwa Residential, Commercial & Institutional PM10 emissions

3.3.2 BAU

The evolutions of industrial area emissions are reported in Figure 3-24 for nitrogen oxides (NO_x) and in Figure 3-25 for suspended particles with diameter less than 10μ (PM_{10}). The variation is evaluated as the average variation of industrial emissions in national projection.
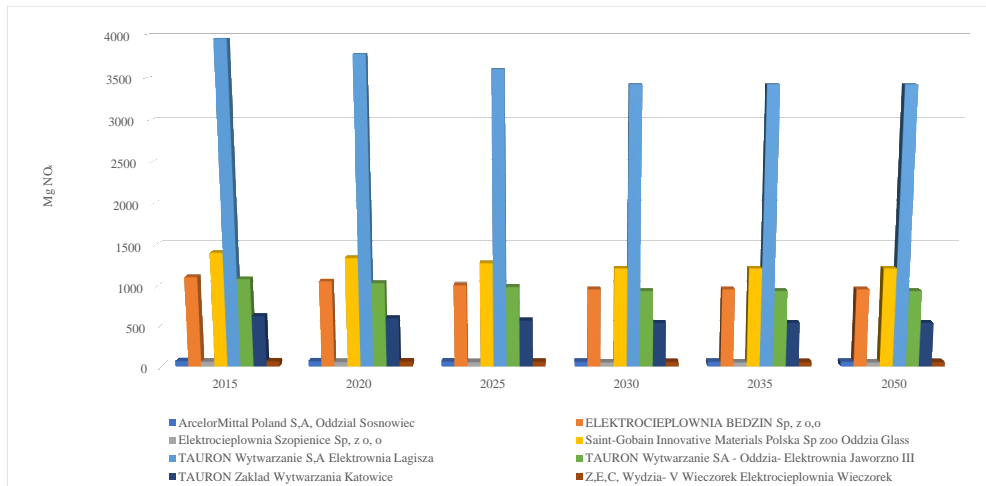
Figure 3-24: Sosnowiec BAU Industrial main point sources NOx emissions
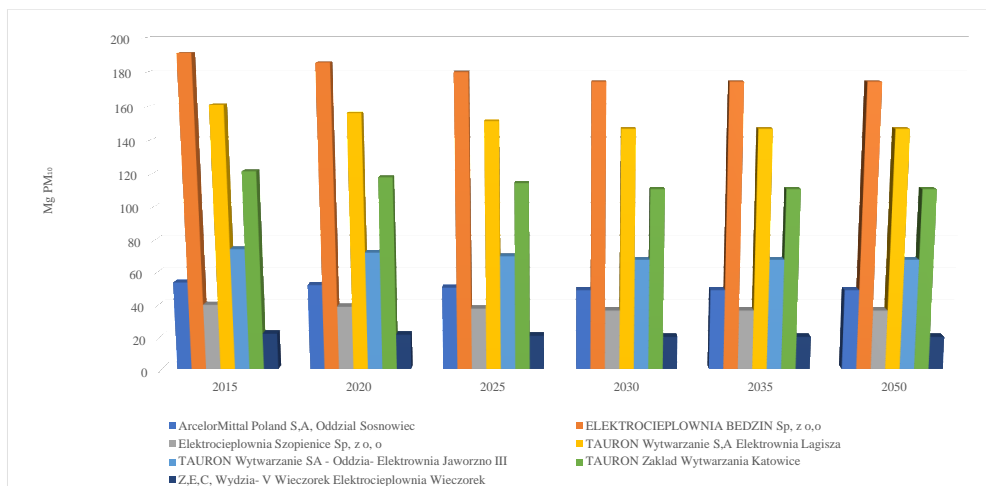
Figure 3-25: Sosnowiec BAU Industrial main point sources PM10 emissions

In Figure 3-26 for nitrogen oxides (NO_x) and in Figure 3-27 for suspended particles with diameter less than 10μ (PM_{10}) the evolutions of emissions are reported for residential, commercial and institutional emissions.
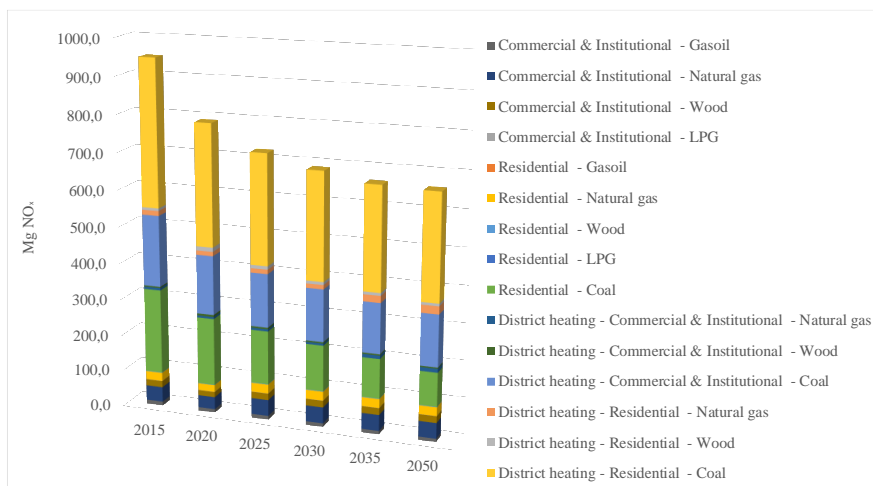
Figure 3-26: Sosnowiec BAU total Residential, Commercial & Institutional NOx emissions
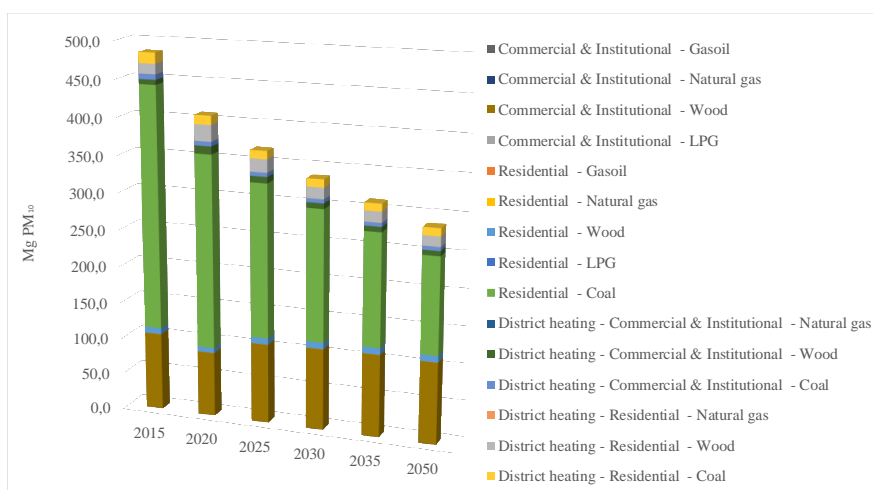
Figure 3-27: Sosnowiec BAU Residential, Commercial & Institutional PM10 emissions

3.3.3 Stakeholder dialog workshop Scenarios

In Figure 3-29 for nitrogen oxides (NO$_x$) and Figure 3-30 for suspended particles with diameter less than 10μ (PM$_{10}$) the trends of emissions are reported for scenario 1 ("low"); in Figure 3-31 for nitrogen oxides (NO$_x$) and Figure 3-32 for suspended particles with diameter less than 10μ (PM$_{10}$) the trends of emissions are reported for scenario 2 ("high"). The Scenario include only the Sosnowiec Wojewodztwa while the emissions from surrounding Wojewodztwa are kept constant.

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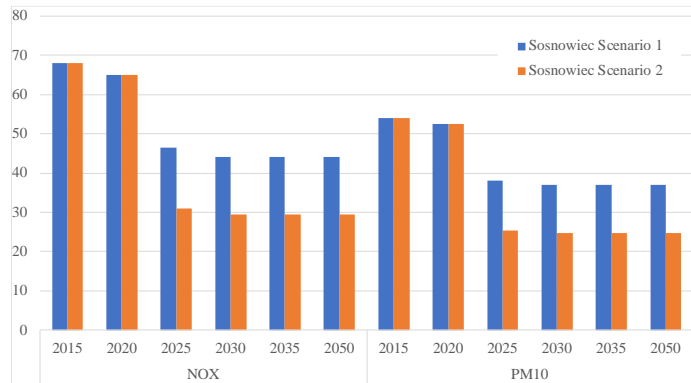
Figure 3-28: Sosnowiec Scenario 1 (low) & 2 (high): Industrial point sources NOx and PM10 emissions inside the municipality
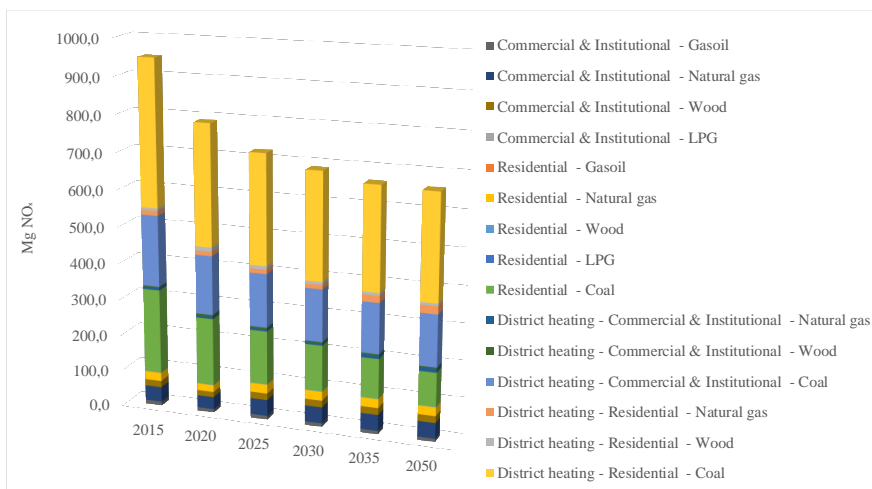
Figure 3-29: Sosnowiec Scenario 1 (low): Residential, Commercial & Institutional NOx emissions – all sectors and fuels
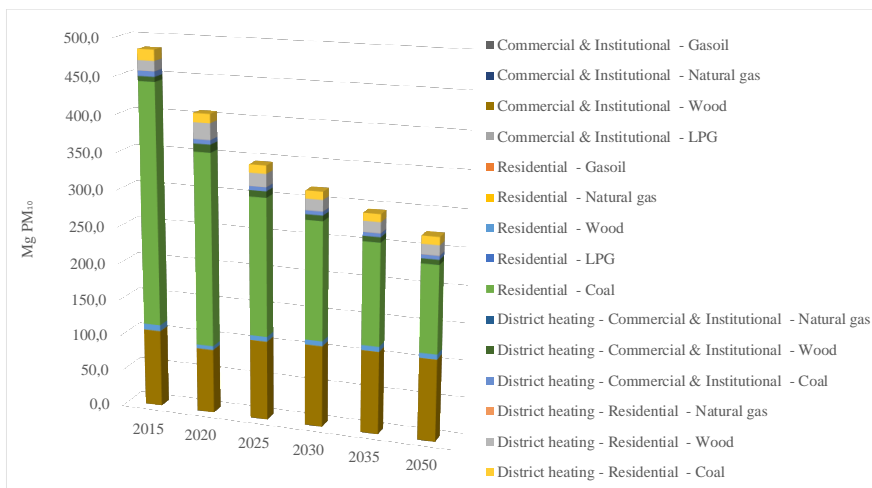
Figure 3-30: Sosnowiec Scenario 1 (low): (renewables & efficiency): Residential, Commercial & Institutional PM10 emissions – all sectors and fuels

Figure 3-31: Sosnowiec Scenario 2 (high): Residential, Commercial & Institutional NOx emissions – all sectors and fuels
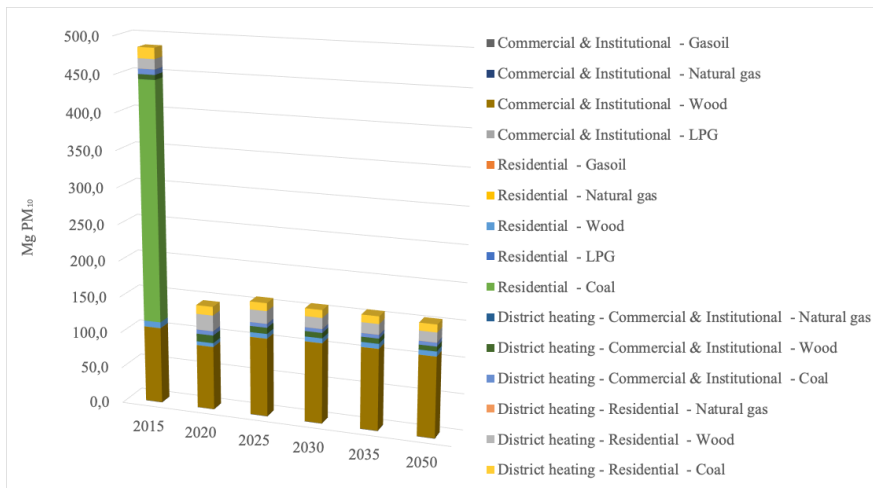
Figure 3-32: Sosnowiec Scenario 2 (high): (renewables & efficiency): Residential, Commercial & Institutional PM10 emissions – all sectors and fuels

In Figure 3-33 for nitrogen oxides (NO$_x$) and Figure 3-34 for suspended particles with diameter less than 10μ (PM$_{10}$) the trends of emissions in the different scenarios are reported for industrial sources.
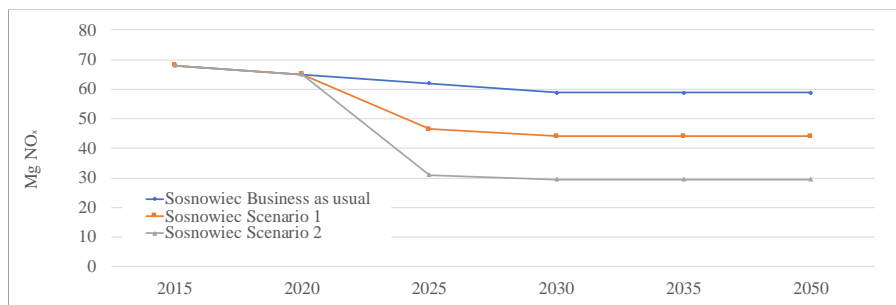
Figure 3-33: Sosnowiec Scenarios: Industrial sources NOx emissions
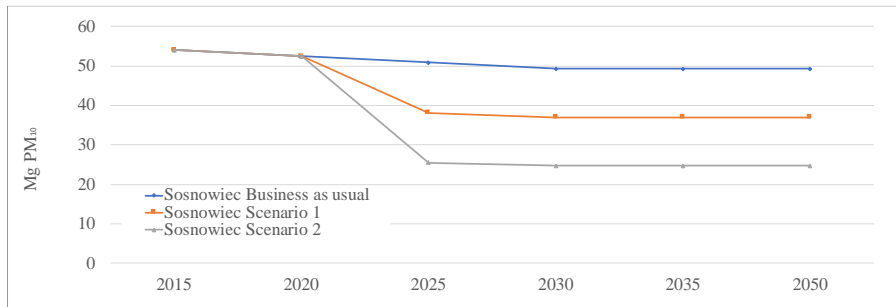
Figure 3-34: Sosnowiec Scenarios: Industrial sources PM10 emissions

In Figure 3-35 for nitrogen oxides (NO_x) and in Figure 3-36 for suspended particles with diameter less than 10μ (PM_{10}) the comparison of the trends of emissions are reported for Residential, Commercial, Institutional emissions.

Figure 3-35: Sosnowiec BAU & Scenarios comparison: Residential, Commercial, Institutional NOx emissions – all sectors and fuels
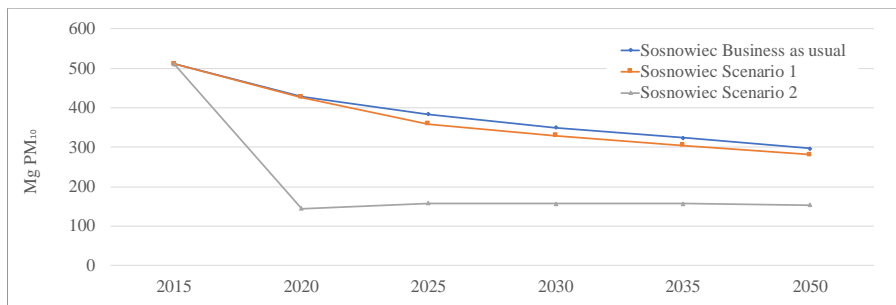
Figure 3-36: Sosnowiec BAU & Scenarios comparison: Residential, Commercial & Institutional PM10 emissions – all sectors and fuels

3.3.4 Unified Policy Scenario

In Figure 3-37 for nitrogen oxides (NO_x) and Figure 3-38 for suspended particles with diameter less than 10μ (PM_{10}) the trends of emissions are reported for Unified Policy Scenario.

Figure 3-37: Sosnowiec Unified Policy Scenario: Residential, Commercial & Institutional NOx emissions – all sectors and fuels
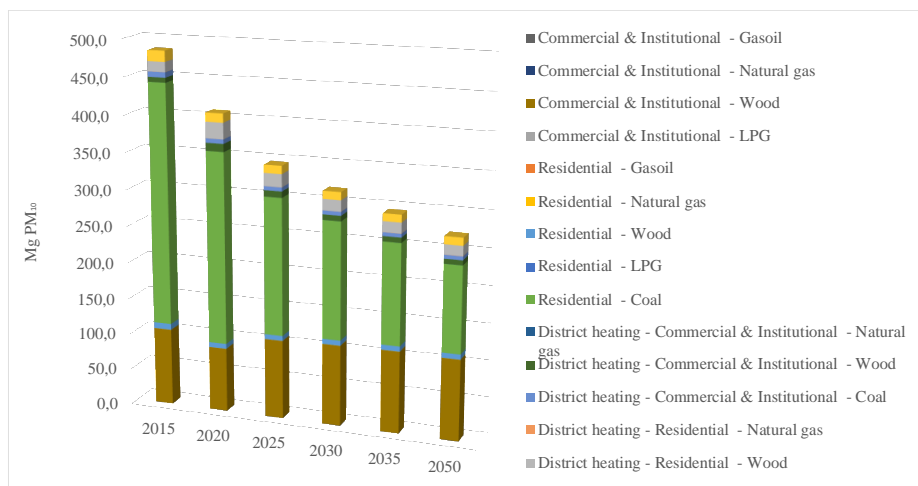
Figure 3-38: Sosnowiec Unified Policy Scenario: Residential, Commercial & Institutional PM10 emissions – all sectors and fuels

In Figure 3-39 for nitrogen oxides (NO$_x$) and Figure 3-40 for suspended particles with diameter less than 10μ (PM$_{10}$) the trends of industrial emissions in the different scenarios are reported.
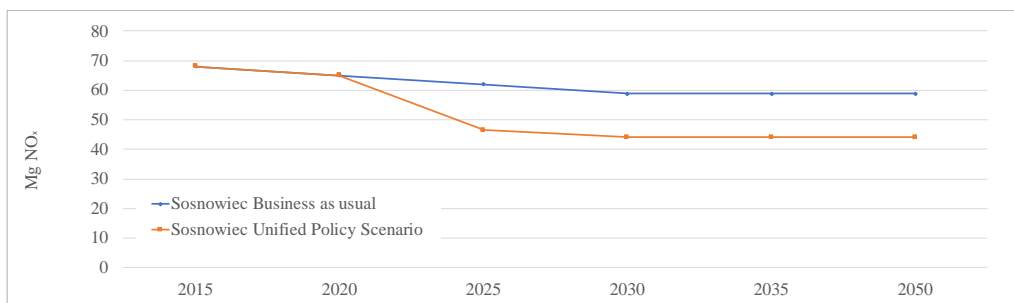
Figure 3-39: Sosnowiec BAU & Unified Policy Scenario comparison: Industrial sources NOx emissions
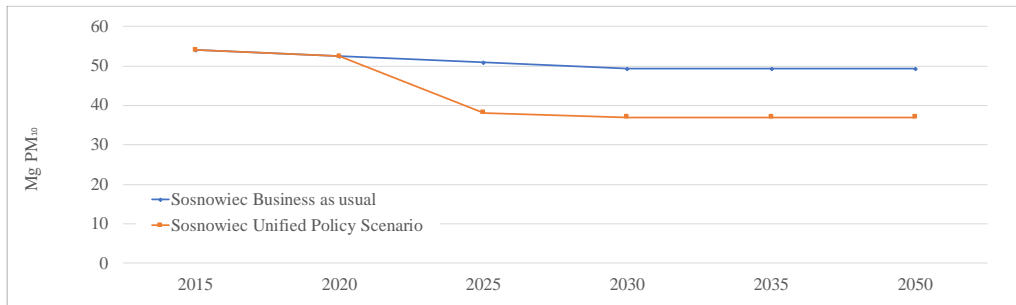
Figure 3-40: Sosnowiec BAU & Unified Policy Scenario comparison: Industrial sources PM10 emissions

In Figure 3-41 for nitrogen oxides (NO$_x$) and in Figure 3-42 for suspended particles with diameter less than 10μ (PM$_{10}$) the comparison of the trends of Residential, Commercial & Institutional emissions are reported for Business As Usual (BAU) and Unified Policy (UPS) scenarios.
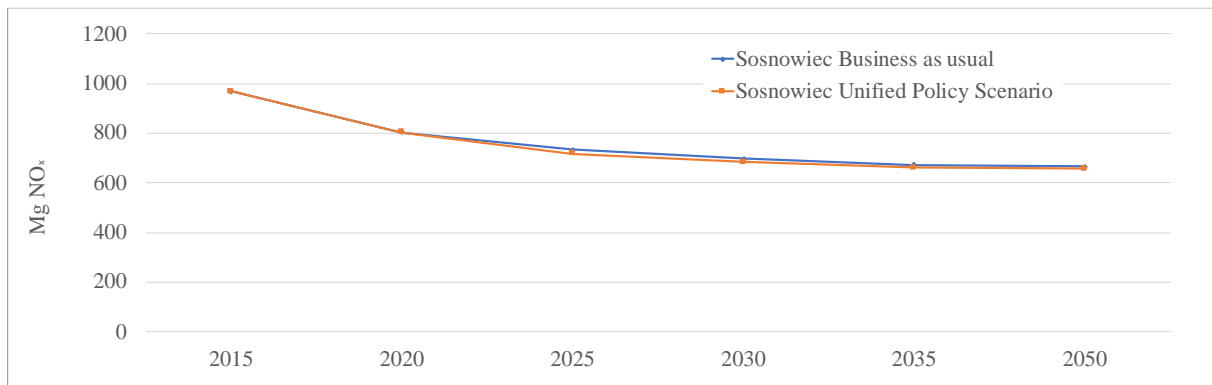
Figure 3-41: Sosnowiec BAU & Unified Policy Scenario comparison: Residential, Commercial & Institutional NOx emissions – all sectors and fuels
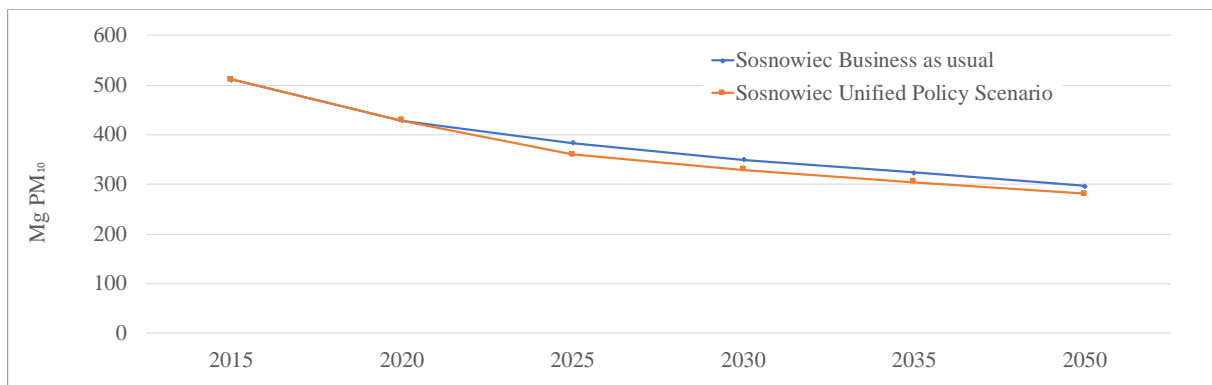
Figure 3-42: Sosnowiec BAU & Unified Policy Scenario comparison: Residential, Commercial & Institutional PM10 emissions – all sectors and fuel

3.4 Carbon footprint

3.4.1 Baseline

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

Table 3-3: Sosnowiec Carbon Footprint by Fuel (Mg)

Energy Vector	CO_2	CO_{2eq}	$CO_{2eq,LCA}$
Biomass	-	477	193
Gasoil/diesel	74.085	84.868	74.285
Gasoline	30.010	37.816	30.097
LPG	772	956	772
Natural gas	103.449	122.996	103.449
Coal	424.056	444.796	426.704
Electricity	832.889	896.229	836.145
Total	**1.465.262**	**1.588.137**	**1.471.644**

In figure below, the Carbon Footprint expressed as CO_2 equivalent on Life Cycle is reported by fuel and sector. The data source used reports aggregate values for industry and services fuel consumptions; in consequence also in carbon footprint the data are reported together.
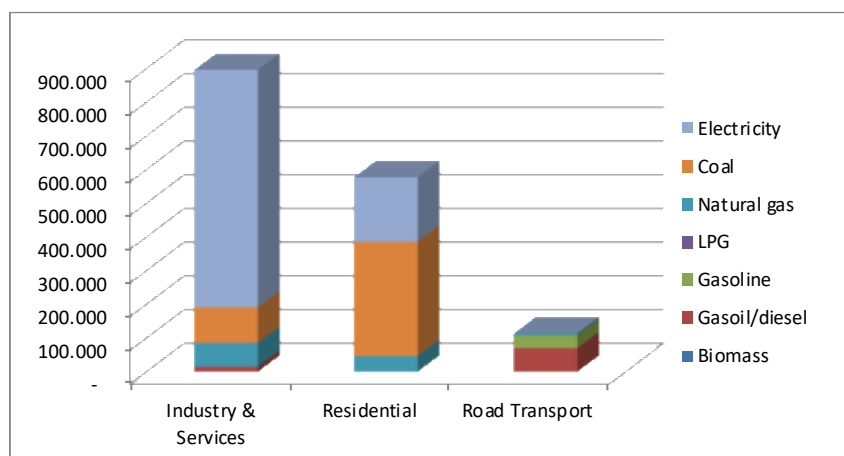
Figure 3-43: Sosnowiec Carbon Footprint (Mg CO₂ equivalent on Life Cycle)

3.4.2 BAU

In Table 3-4 Carbon Footprint by sector is reported for Sosnowiec BAU expressed as CO_2, CO_2 equivalent and CO_2 equivalent on Life Cycle. In Table 3-5 CO_2 equivalent on Life Cycle reductions on 2015 are reported.

Table 3-4: Sosnowiec BAU Carbon Footprint by Sector (Gg)

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide (CO₂)						
Residential	540,3	487,5	477,9	485,6	491,6	497,1
Services & Industry	828,4	861,8	901,5	971,0	1.016,0	1.037,5
Transport	96,5	97,0	96,9	93,2	88,8	62,4
Total	*1.465,3*	*1.446,3*	*1.476,3*	*1.549,8*	*1.596,5*	*1.597,0*
Carbon dioxide equivalent (CO₂eq)						
Residential	543,2	490,2	480,4	488,0	494,1	499,5
Services & Industry	831,6	865,2	904,9	974,7	1.019,9	1.041,5
Transport	96,8	97,2	97,2	93,5	89,1	62,5
Total	*1.471,6*	*1.452,5*	*1.482,5*	*1.556,3*	*1.603,0*	*1.603,6*
Carbon dioxide equivalent on life cycle (CO₂eq)						
Residential	577,5	522,6	512,9	521,4	528,7	534,8

Services	896,4	932,7	975,8	1.050,7	1.099,4	1.122,6
Transport	114,2	114,7	114,7	110,2	105,0	73,4
Total	*1.588,1*	*1.570,0*	*1.603,3*	*1.682,3*	*1.733,1*	*1.730,9*

Table 3-5: Sosnowiec 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	89	90	92	93
Services	100	104	109	117	123	125
Transport	100	100	100	97	92	64
Total	*100*	*99*	*101*	*106*	*109*	*109*

Carbon Footprint, expressed as CO$_2$ equivalent on Life Cycle, is reported in Figure 3-44 by sector and in Figure 3-45 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.
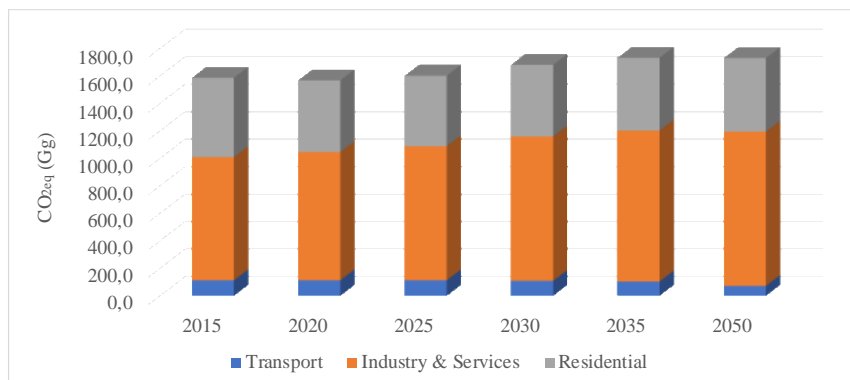
Figure 3-44: Sosnowiec BAU Carbon Footprint by sector (Gg CO$_2$ equivalent on Life Cycle)
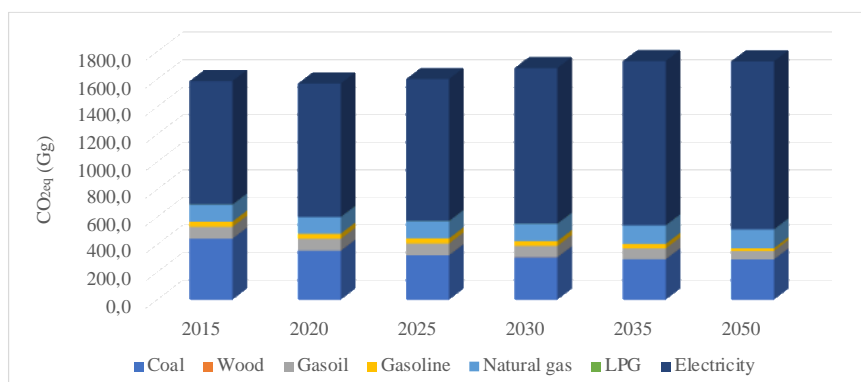
Figure 3-45: Sosnowiec BAU Carbon Footprint by fuel (Gg CO_2 equivalent on Life Cycle)

3.4.3 Stakeholder dialog workshop 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.

In Table 3-6 Carbon Footprint by sector is reported for Sosnowiec Scenario *low* expressed as CO_2, CO_2 equivalent and CO_2 equivalent on Life Cycle. In Table 3-7 CO_2 equivalent on Life Cycle reductions on 2015 are reported.

Table 3-6: Sosnowiec Scenario low Carbon Footprint by Sector (Gg)

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide (CO_2)						
Residential	540,3	487,5	468,2	476,7	483,4	489,3
Services & Industry	828,4	861,8	900,7	970,3	1.015,4	1.036,9
Transport	96,5	95,1	93,3	87,0	80,3	57,5
Total	*1.465,3*	*1.444,4*	*1.462,1*	*1.534,1*	*1.579,1*	*1.583,8*
Carbon dioxide equivalent (CO_{2eq})						
Residential	543,2	490,2	470,6	479,1	485,8	491,7
Services & Industry	831,6	865,2	904,2	974,0	1.019,2	1.040,9
Transport	96,8	95,3	93,5	87,2	80,6	57,6
Total	*1.471,6*	*1.450,6*	*1.468,3*	*1.540,4*	*1.585,6*	*1.590,3*

Carbon dioxide equivalent on life cycle (CO_{2eq})

Residential	577,5	522,6	502,7	512,1	520,1	526,7
Services & Industry	896,4	932,7	975,0	1.049,9	1.098,7	1.122,0
Transport	114,2	112,5	110,2	102,8	94,8	67,5
Total	*1.588,1*	*1.567,7*	*1.587,9*	*1.664,8*	*1.713,6*	*1.716,2*

Table 3-7: Sosnowiec Scenario low Carbon Footprint by Sector: index (2015=100)

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide equivalent on life cycle (CO_{2eq})						
Residential	100	90	87	89	90	91
Services	100	104	109	117	123	125
Transport	100	98	97	90	83	59
Total	*100*	*99*	*100*	*105*	*108*	*108*

For the Scenario 1, Carbon Footprint, expressed as CO_2 equivalent on Life Cycle, is reported in Figure 3-46 by sector and in Figure 3-47 by fuel.
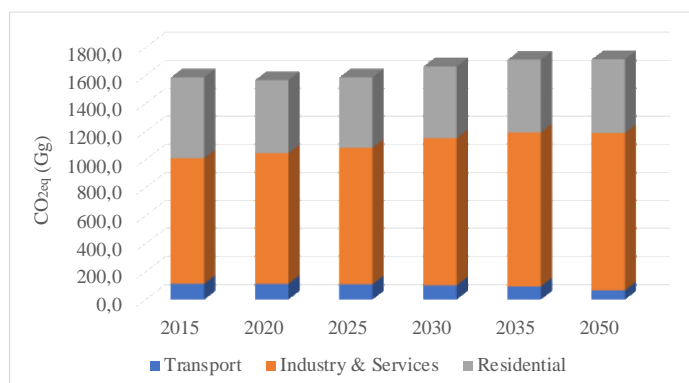
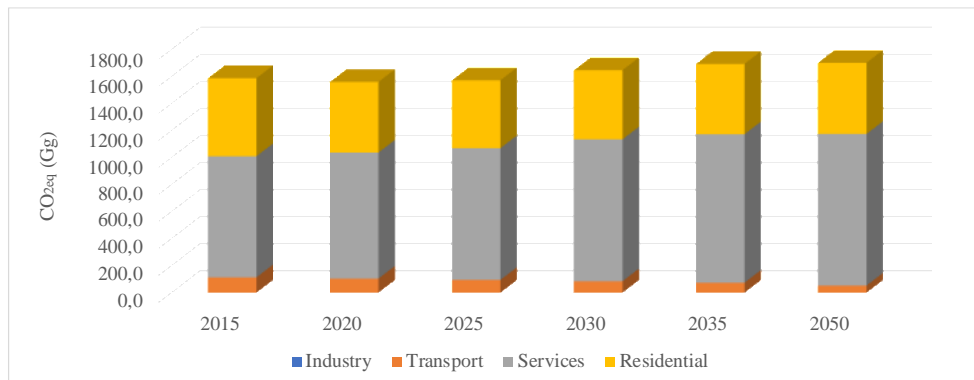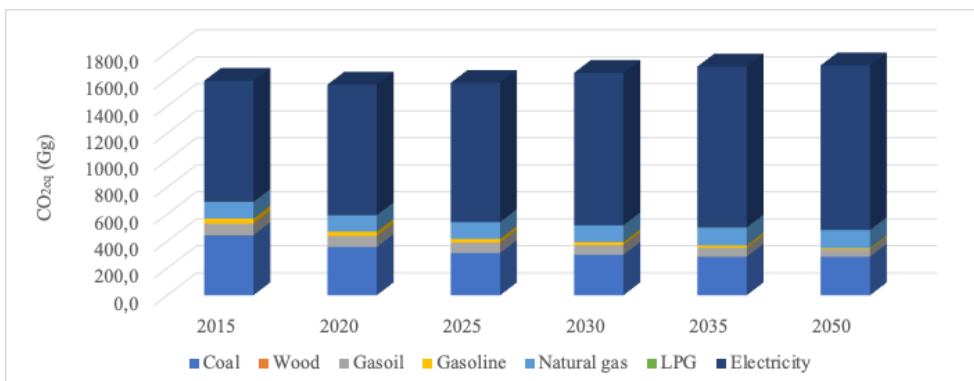**Figure 3-46: Sosnowiec Scenario *low* Carbon Footprint by sector (Gg CO₂ equivalent on Life Cycle)**
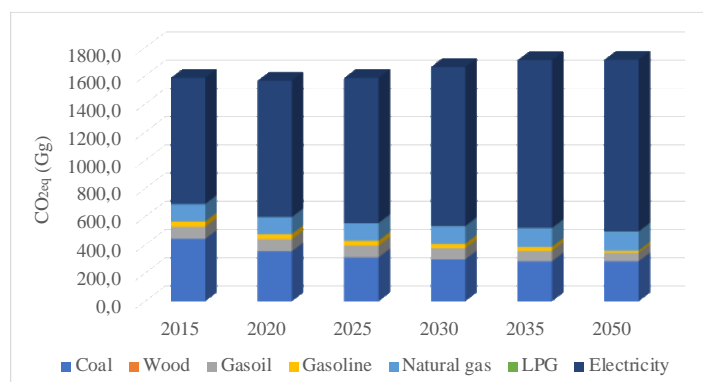
Figure 3-47: Sosnowiec Scenario *low* Carbon Footprint by fuel (Gg CO$_2$ equivalent on Life Cycle)

In Table 3-8 Carbon Footprint by sector is reported for Sosnowiec Scenario high expressed as CO$_2$, CO$_2$ equivalent and CO$_2$ equivalent on Life Cycle. In Table 3-9 CO$_2$ equivalent on Life Cycle reductions on 2015 are reported.

Table 3-8: Sosnowiec Scenario high Carbon Footprint by Sector (Gg)

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide (CO$_2$)						
Residential	540,3	381,3	380,5	396,9	409,2	419,6
Services & Industry	828,4	853,5	893,8	964,0	1.009,5	1.031,4
Transport	96,5	80,0	63,3	60,4	57,3	44,7
Total	*1.465,3*	*1.314,8*	*1.337,6*	*1.421,3*	*1.476,0*	*1.495,8*
Carbon dioxide equivalent (CO$_{2eq}$)						
Residential	543,2	383,3	382,4	398,8	411,1	421,6
Services & Industry	831,6	856,7	897,2	967,7	1.013,4	1.035,4
Transport	96,8	80,2	63,5	60,5	57,5	44,8
Total	*1.471,6*	*1.320,3*	*1.343,1*	*1.427,1*	*1.481,9*	*1.501,8*
Carbon dioxide equivalent on life cycle (CO$_{2eq}$)						
Residential	577,5	411,2	410,7	428,4	442,3	453,6
Services & Industry	896,4	923,9	967,8	1.043,4	1.092,6	1.116,2
Transport	114,2	94,2	74,2	70,6	67,1	52,1
Total	*1.588,1*	*1.429,4*	*1.452,6*	*1.542,4*	*1.601,9*	*1.621,9*

Table 3-9: Sosnowiec Scenario high Carbon Footprint by Sector: index (2015=100)

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide equivalent on life cycle (CO_{2eq})						
Residential	100	71	71	74	77	79
Services & Industry	100	103	108	116	122	125
Transport	100	82	65	62	59	46
Total	*100*	*90*	*91*	*97*	*101*	*102*

For the Scenario high, Carbon Footprint, expressed as CO_2 equivalent on Life Cycle, is reported in Figure 3-48 by sector and in Figure 3-49 by fuel.
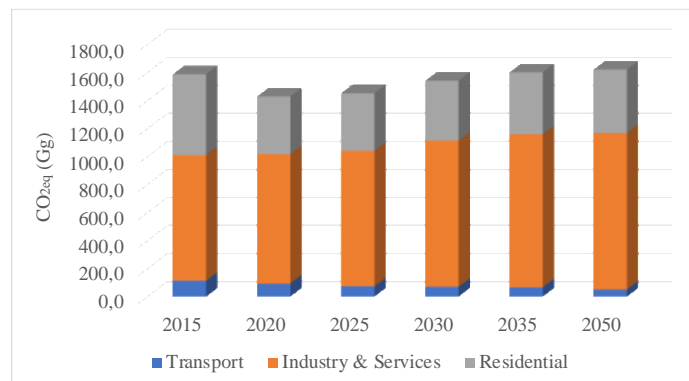
Figure 3-48: Sosnowiec Scenario *high* Carbon Footprint by sector (Gg CO₂ equivalent on Life Cycle)
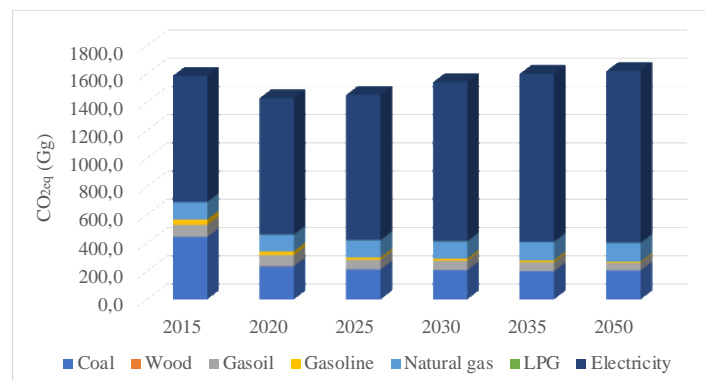
Figure 3-49: Sosnowiec Scenario *high* Carbon Footprint by fuel (Gg CO₂ equivalent on Life Cycle)

3.4.4 Unified Policy Scenario

In Table 3-10 Carbon Footprint by sector is reported for Sosnowiec Unified Policy Scenario expressed as CO_2, CO_2 equivalent and CO_2 equivalent on Life Cycle. In Table 3-11 CO_2 equivalent on Life Cycle reductions on 2015 are reported.

Table 3-10: Sosnowiec Unified Policy Scenario Carbon Footprint by Sector (Gg)

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide (CO$_2$)						
Residential	540,3	487,5	468,2	476,7	483,4	489,3
Services & Industry	828,4	861,8	900,7	970,3	1.015,4	1.036,9
Transport	96,5	89,0	81,0	72,6	63,8	45,9
Total	*1.465,3*	*1.438,3*	*1.449,9*	*1.519,7*	*1.562,6*	*1.572,1*
Carbon dioxide equivalent (CO$_{2eq}$)						
Residential	543,2	490,2	470,6	479,1	485,8	491,7
Services & Industry	831,6	865,2	904,2	974,0	1.019,2	1.040,9
Transport	96,8	89,2	81,2	72,8	64,0	46,0
Total	*1.471,6*	*1.444,5*	*1.456,0*	*1.526,0*	*1.569,0*	*1.578,6*
Carbon dioxide equivalent on life cycle (CO$_{2eq}$)						
Residential	577,5	522,6	502,7	512,1	520,1	526,7
Services & Industry	896,4	932,7	975,0	1.049,9	1.098,7	1.122,0
Transport	114,2	105,1	95,5	85,5	74,9	53,5
Total	*1.588,1*	*1.560,4*	*1.573,2*	*1.647,5*	*1.693,7*	*1.702,2*

Table 3-11: Sosnowiec Unified Policy Scenario Carbon Footprint by Sector: index (2015=100)

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide equivalent on life cycle (CO$_{2eq}$)						
Residential	100	90	87	89	90	91
Services & Industry	100	104	109	117	123	125
Transport	100	92	84	75	66	47
Industry	100	98	99	104	107	107
Total	*100*	*90*	*87*	*89*	*90*	*91*

For the Unified Policy Scenario, Carbon Footprint, expressed as CO$_2$ equivalent on Life Cycle, is reported in Figure 3-50 by sector and in Figure 3-51 by fuel.

Figure 3-50: Sosnowiec Unified Policy Scenario Carbon Footprint by sector (Gg CO$_2$ equivalent on Life Cycle)

Figure 3-51: Sosnowiec Unified Policy Scenario Carbon Footprint by fuel (Gg CO$_2$ equivalent on Life Cycle)

Total Carbon Footprint in the business as usual (BAU) and unified policy scenario (UPS) is compared in Figure 3-52 expressed as CO_2 equivalent on Life Cycle. Finally, in Figure 3-55 Sosnowiec Carbon Footprint on life cycle generated by citizens' activities is reported in BAU and UPS scenario.
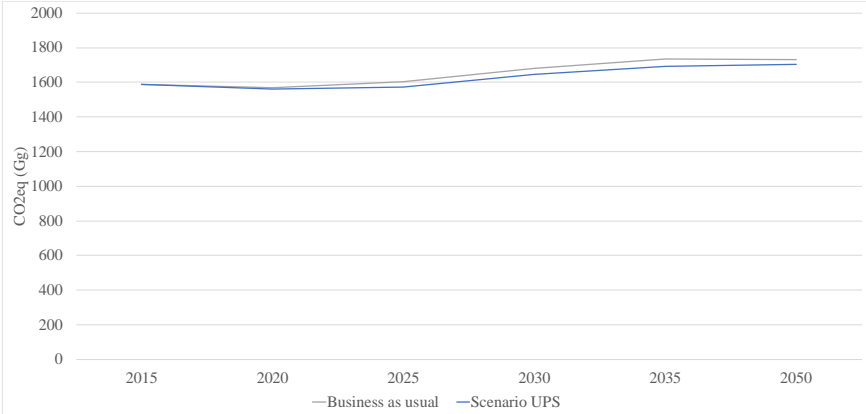
Figure 3-52: Sosnowiec Carbon Footprint (Mg CO$_2$ equivalent on Life Cycle) by BAU scenario and final unified scenario

In Figure 3-53 results are reported by sector and in Figure 3-54 by sector and fuel. Finally, in Figure 3-55 Carbon Footprint on life cycle generated by citizens' activities is reported in BAU and UPS scenario.
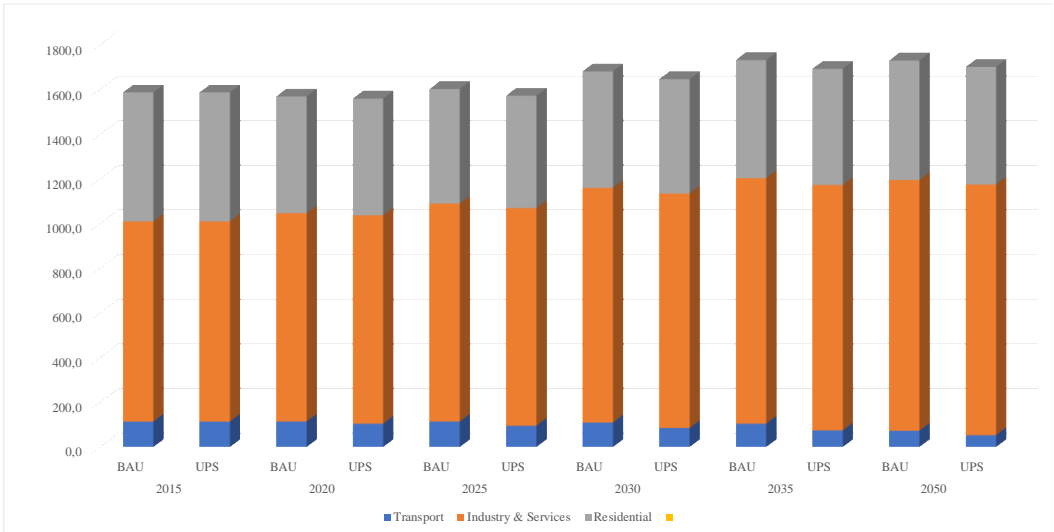
Figure 3-53: Sosnowiec Carbon Footprint BAU and UPS comparison by sector (Mg CO$_2$ equivalent on Life Cycle)
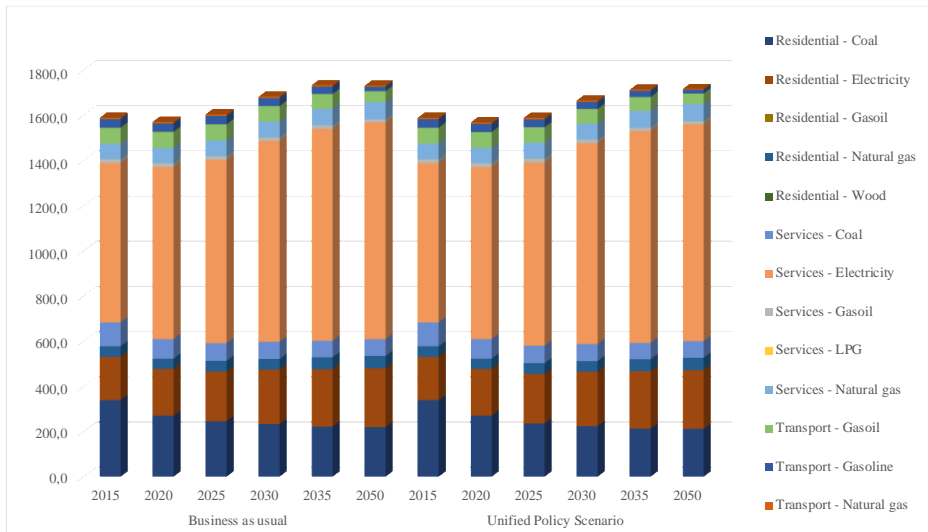
Figure 3-54: Sosnowiec Carbon Footprint BAU and UPS comparison by sector and fuel (Mg CO₂ equivalent on Life Cycle)
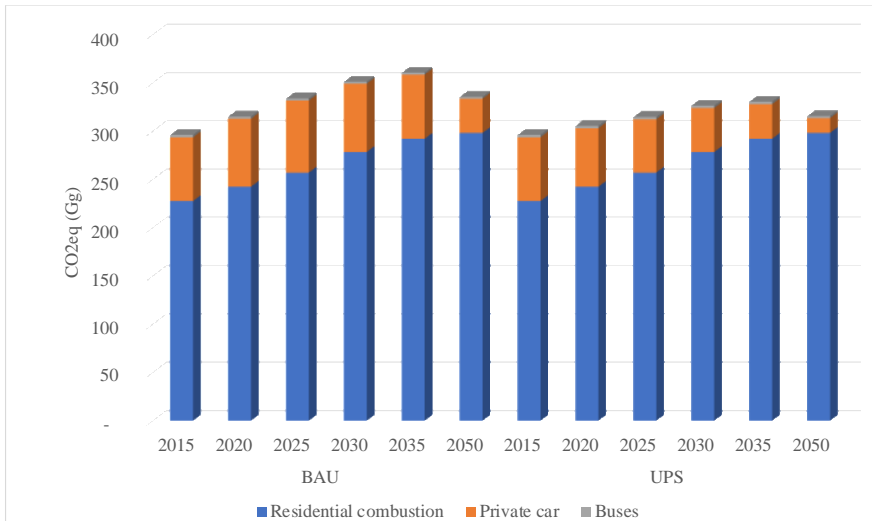
Figure 3-55: Sosnowiec Carbon Footprint generated by citizens' activities in BAU and UPS scenario (Mg CO2 equivalent on Life Cycle)

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 3-56 shows the emission values for NO_x and PM in Mg.year^{-1} for each sector.

	NOx	PM
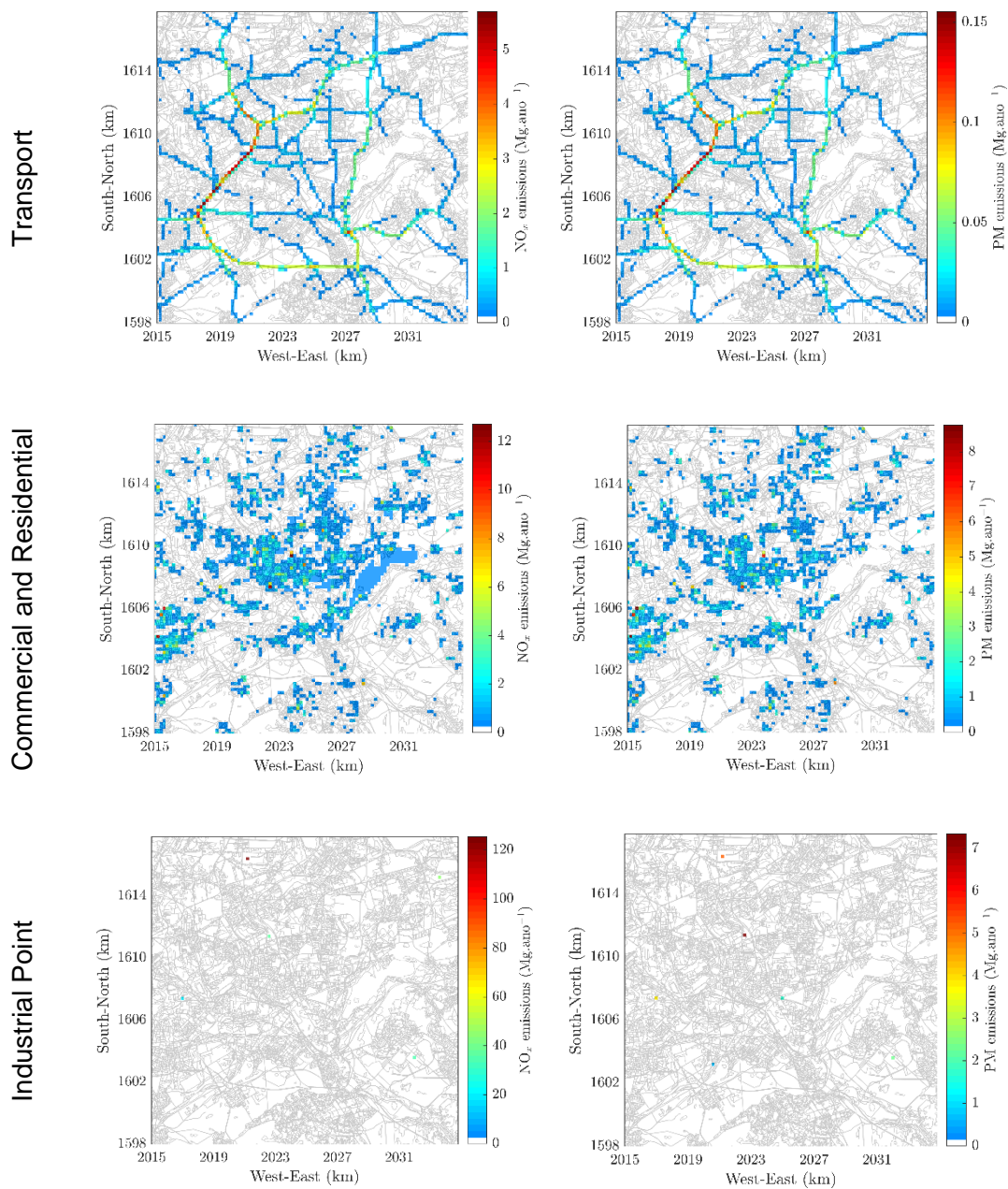
Figure 3-56: Emission values for NOx and PM by sector, in Mg.year-1

3.5.2   Assessment of air quality at mesoscale: baseline year

The meteorological characterization in Sosnowiec, at mesoscale, was based on the analysis of the spatial average of the following variables: temperature, precipitation and wind speed and direction. The mean air temperatures and accumulated temperature, for each month, are presented in Figure 3-57.
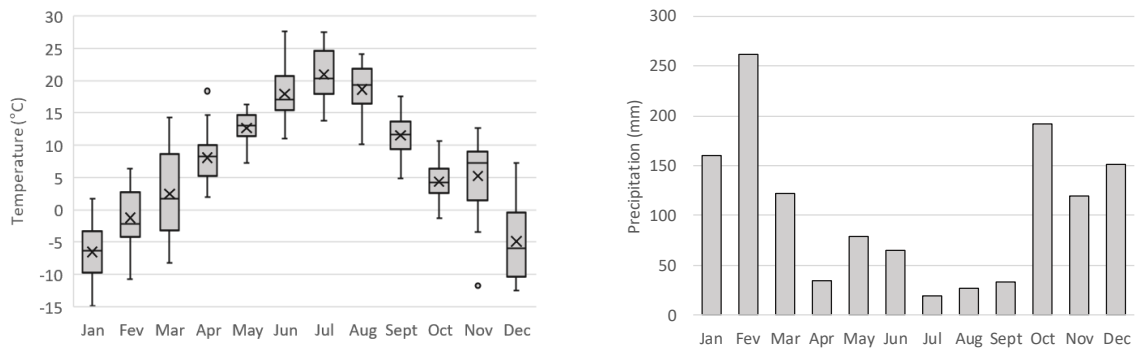
Figure 3-57: (Left) Box and whisker plot of temperature by month; boxes indicate the lower and upper quartile; horizontal line in each box represents the median temperature; the mean temperature for each month is indicated by a x; vertical lines extending from each

According to Figure 3-57, in Sosnowiec, the minimum mean temperatures are obtained in January, December and February, with -6.5°C, -4.9°C and -1.2°C, respectively. The month where the highest mean temperature is recorded is July, with 18.3°C, followed by August, with 15.8°C. Regarding precipitation, the months with the highest accumulated precipitation go from October to March (with values from 120 to 260 mm), while the driest month is July with 20 mm. During almost the whole year, the prevailing winds from the 3rd quadrant (SW), with a wind speed between 2 and 10 m.s^{-1}.

The air quality characterization in Sosnowiec, at mesoscale, was based on concentrations fields 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 3-58).

NO_2 (µg.m^{-3})   PM10 (µg.m^{-3})   PM2.5 (µg.m^{-3})
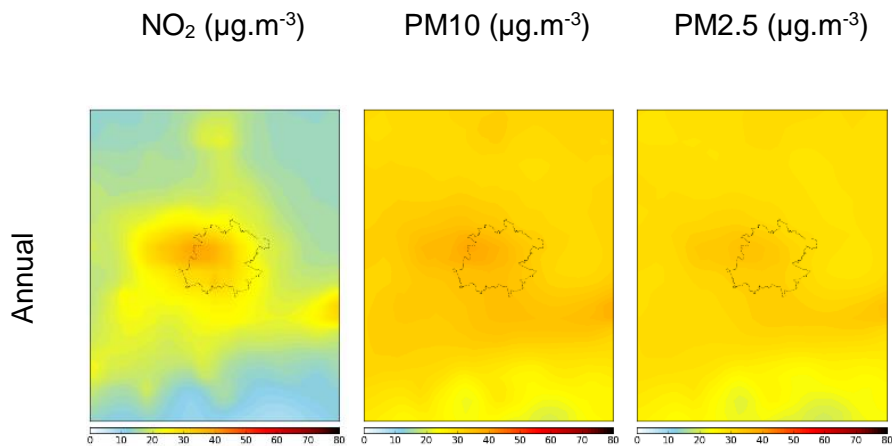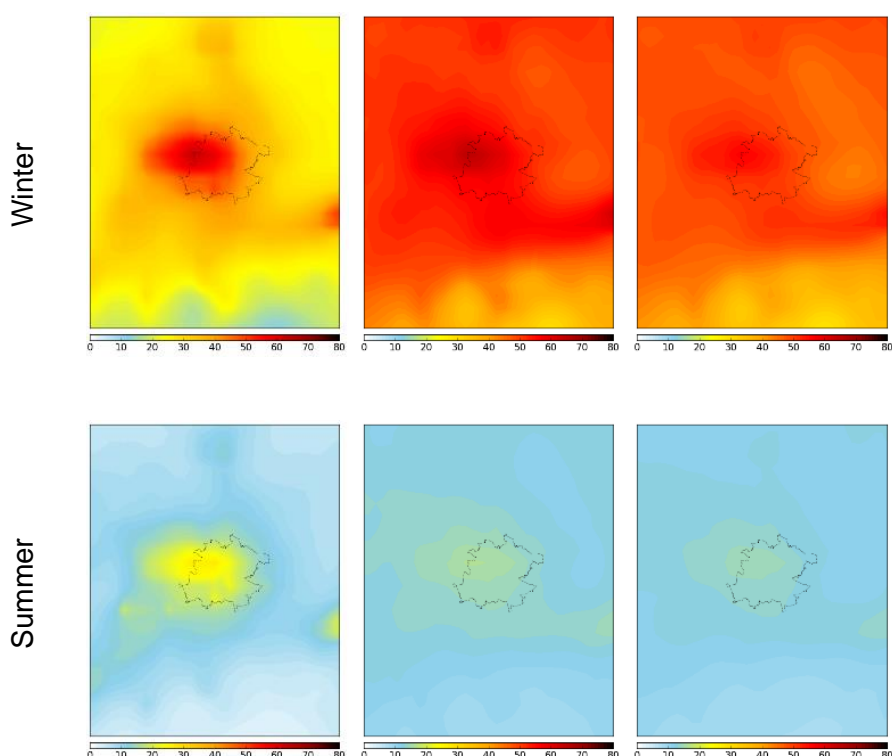
Figure 3-58: Spatial distribution of NO2, PM10 and PM2.5 concentrations, for the different periods analysed (annual, winter and summer) in Sosnowiec.

For each pollutant, NO_2, PM10 and PM2.5, results presented in Figure 3-58 show similar spatial patterns for the different periods and pollutants analysed. For all pollutants, the highest concentration values are found northwest of Sosnowiec and the lowest values in the southern region of the domain.

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 40 $\mu g.m^{-3}$, 63 $\mu g.m^{-3}$ and 28 $\mu g.m^{-3}$, respectively. For PM10, the maximum concentration values are close to 46 $\mu g.m^{-3}$, for the annual average, 71 $\mu g.m^{-3}$ in winter and 26 $\mu g.m^{-3}$ in summer. For PM2.5, the highest concentration values are 35 $\mu g.m^{-3}$, 56 $\mu g.m^{-3}$ and 15 $\mu g.m^{-3}$ 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 Sosnowiec, 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 Sosnowiec for the three periods previously defined, are analysed in Figure 3-59.
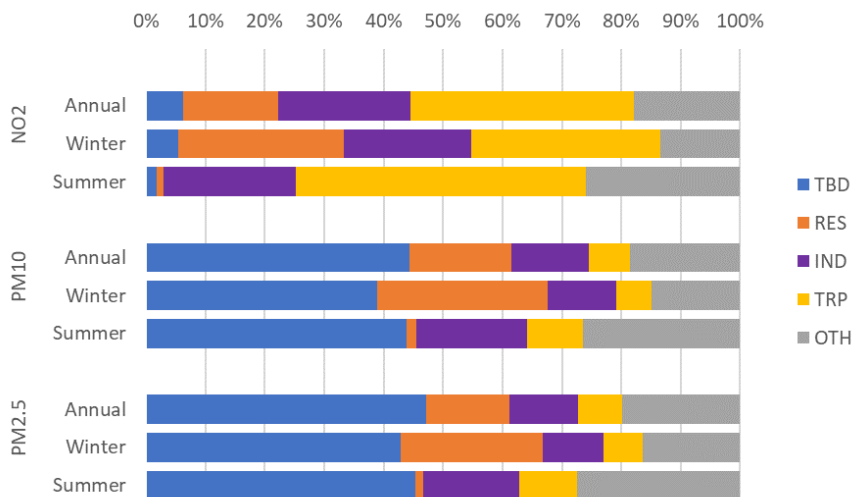
Figure 3-59: Annual, winter and summer averages contribution for each source group for NO2, PM10 and PM2.5 concentrations, for Sosnowiec urban area; (TBD- transboundary transport, RES - residential and commercial combustion, IND - industrial combustion and processes, TRP - road transport and OTH - all the remaining sources).

The average annual contributions of each source group reveal that, for NO_2, the largest contribution is from TRP, followed by IND and RES. While RES presents higher values in the winter, TRP and IND remains almost unchanged in the three analysed periods.

For PM10, the annual average contributions of each source group reveal that one of the major contributions is from TBD (44%), highlighting the importance of transboundary transport for the PM10 pollution in the study region. Source contribution results also point to a great influence of the contribution of different human activities, such as residential and commercial combustion and industrial combustion and processes, to the PM10 levels, with the residential commercial combustion being higher in the winter period and the industrial combustion and processes in the summer period. 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 3-60 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 colour scheme are presented, a) the standard ClairCity color scheme and b) a customized color scheme based on the EC assessment thresholds, which the EC directive EU/50/2008 establishes for each pollutant an upper and a lower assessment threshold. For NO_2 the lower assessment threshold (LAT) is 26 and the upper assessment threshold (UAT) is 32. For PM_{10} the LAT value is 20 and the UAT value is 28, and for $PM_{2.5}$ the LAT value is 12 and the UAT value is 17.

a) Standard colour scheme   b) EC assessment thresholds

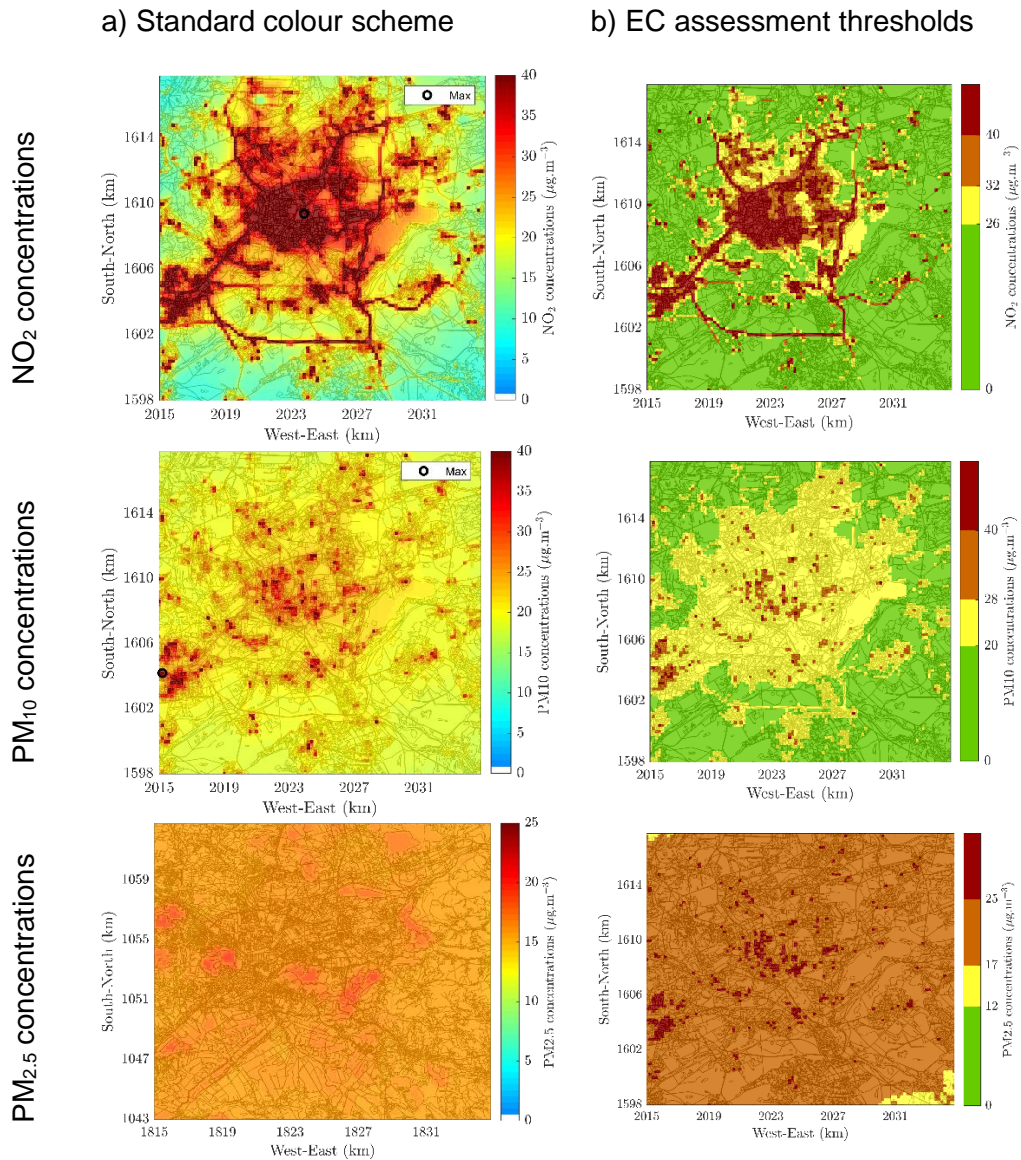NO₂ concentrations — PM₁₀ concentrations — PM₂.₅ concentrations

Figure 3-60: Annual average of the NO₂, PM10 and PM2.5 concentrations, including the background concentrations and the adjustment factor. a) using a standard colour scheme, and b) using a customized colour scheme based on the EC assessment thresholds

The maximum value of the annual NO₂ concentrations in 2015 is equal to 207.7 µg.m⁻³ and is located within the urban area (as indicated on the map). The main sector contributing to that maximum value is the residential and commercial, with a contribution of 85.8, followed by the industrial sector with a contribution of 11.4%, and the road transport sector with a contribution of 2.8 %. These contributions are obtained from the source apportionment analysis. The average value of the NO₂ concentrations over the entire domain is equal to 24.3 and the source apportionment analysis indicates that transport is contributing with 22.5%, industrial sector with 24.8% and the residential and commercial sector with 52.7% to the simulated concentrations.

The maximum value of the annual PM$_{2.5}$ concentrations in 2015 is equal to 62.1 µg.m^{-3} and is located within the urban area (indicated on the map). A source apportionment analysis to the cell where the maximum annual value is simulated presents a contribution of 0.1% from transport sector, 0.2% from the industrial and 99.7% from the residential and commercial sector. The average value over the entire domain is equal to 19.3 µg.m^{-3}. For PM$_{2.5}$ concentrations average over all the domain a source apportionment analysis allowed to determine the contribution of each sector, which indicates transport is contributing with 2.2%, industrial sector with 4.1% and the residential and commercial sector with 93.7%.

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 3-61 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.
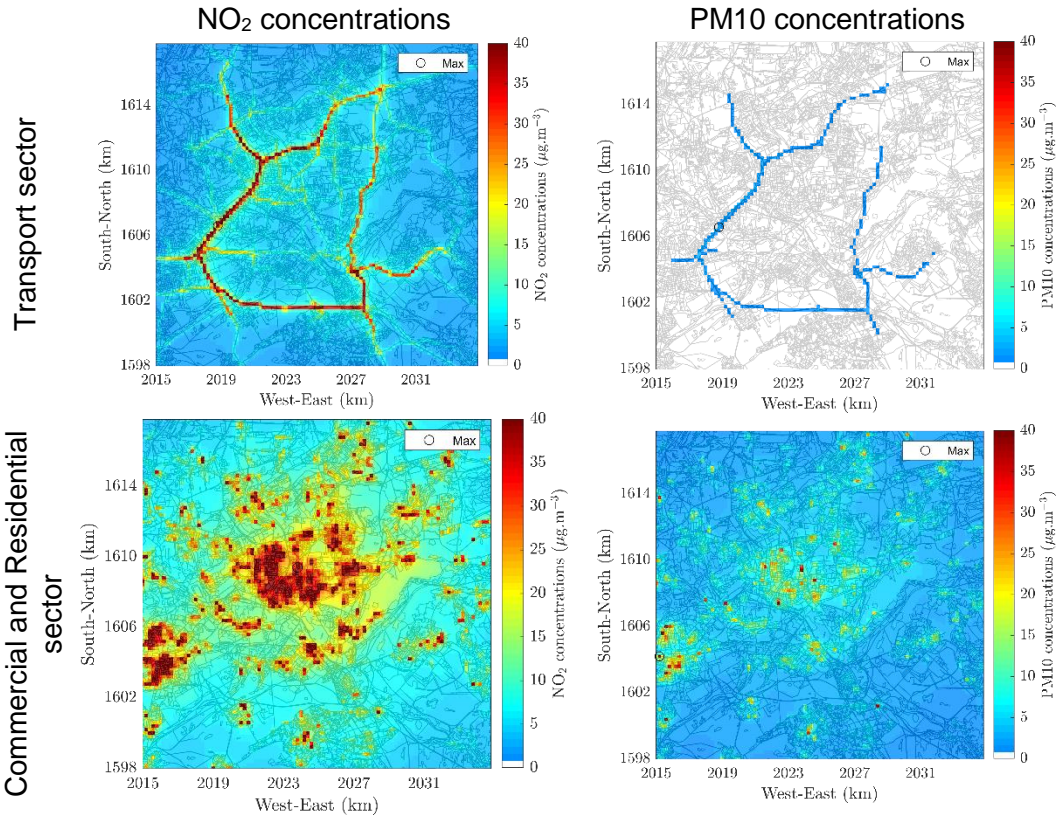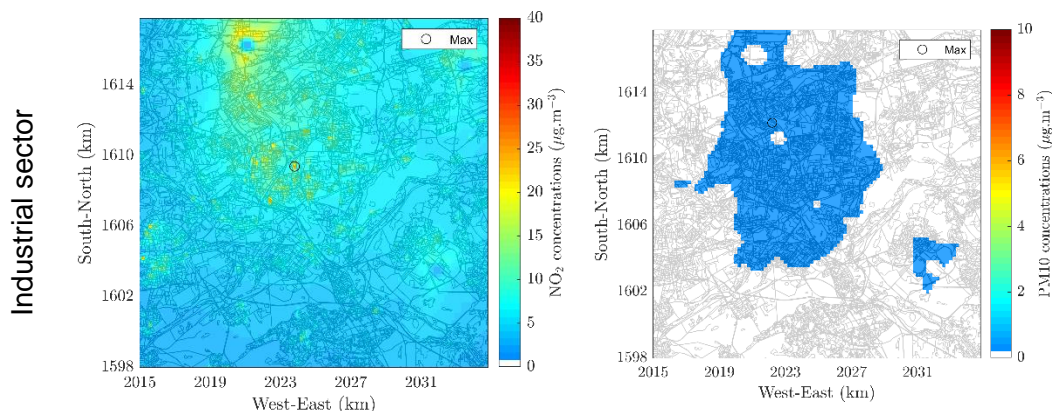
Figure 3-61: Air quality maps for NO2 and PM adjusted concentrations by sector without the added background.

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 is different due to different $PM_{10}/PM_{2.5}$ contribution from exhaust and non-exhaust emissions, as explained before at the transport methodology. In terms of concentrations, for the transport sector the spatial distribution is roughly the same although smaller concentration of $PM_{2.5}$ are simulated. For transport, the maximum value simulated for PM_{10} is 3.0 µg.m^{-3} and for $PM_{2.5}$ is 1.2 µg.m^{-3}.

The final air quality results are then compared with the measuring data. Table 3-12presents the comparison between the measurements and the simulated NO_2 concentrations (with the background concentrations and the adjustment factor) and the sector contribution for all the monitoring sites.

Table 3-12: Comparison between the measurements and the simulated NO_2 concentrations (with the background concentrations and the adjustment factor) and contribution of each sector to the simulated values.

Station		NO_2 concentrations		Contribution by sector for the corresponding cell (%)		
ID	Station type	Measurement	Simulated	Transport sector	Industrial sector	Com. and Res. Sector
PL0237A	Urban Background	30.0	27.3	13.0	26.6	60.4
PL0529A	Urban Background	25.8	45.2	12.5	18.3	69.2
PL0567A	Urban Traffic	58.3	27.1	40.1	14.4	45.5

For NO_2, the major contribution for these locations comes from the commercial and residential sector. Although, as expected for the urban traffic station, the transport sector has a significant contribution.

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Table 3-13 presents the comparison between the measurements and the simulated PM_{10} concentrations (with the background concentrations and the adjustment factor) and the sector contribution for all the monitoring locations.

Table 3-13: Comparison between the measurements and the simulated PM_{10} concentrations (with the background concentrations and the adjustment factor) and contribution of each sector to the simulated values.

Station		PM_{10} concentrations		Contribution by sector for the corresponding cell (%)		
ID	Station type	Measurement	Simulated	Transport sector	Industrial sector	Com. and Res. Sector
PL0237A	Urban Background	41.21	22.62	1.9	2.9	95.2
PL0529A	Urban Background	36.96	25.58	2.1	2.5	95.4
PL0567A	Urban Traffic	46.37	21.33	8.1	2.7	89.2

For PM_{10} all the locations show a major contribution from commercial and residential sector. For $PM_{2.5}$, for the year of 2015, only measured data from the traffic background monitoring station was available. The sector with the biggest contribution for $PM_{2.5}$ is the commercial and residential sector (92.9%).

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 3-62 shows the population exposure to NO_2, PM_{10} and $PM_{2.5}$ baseline concentration values.
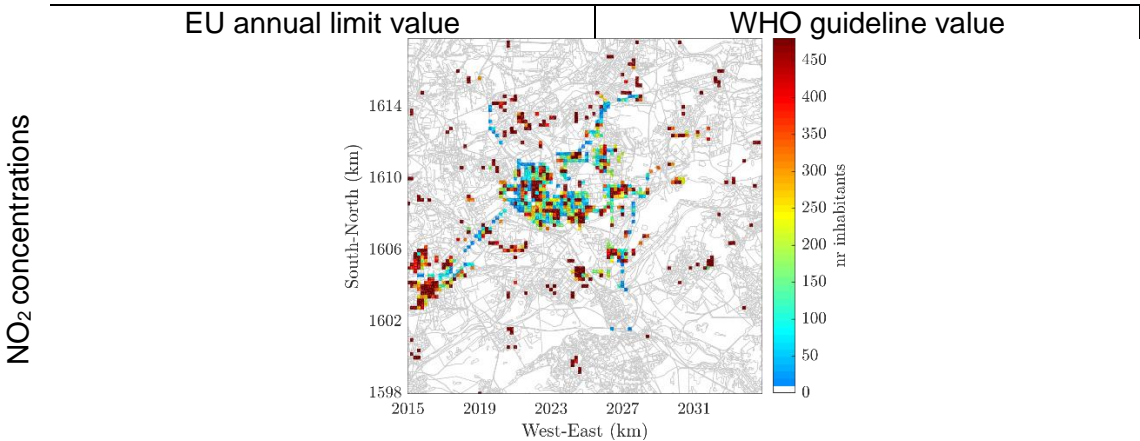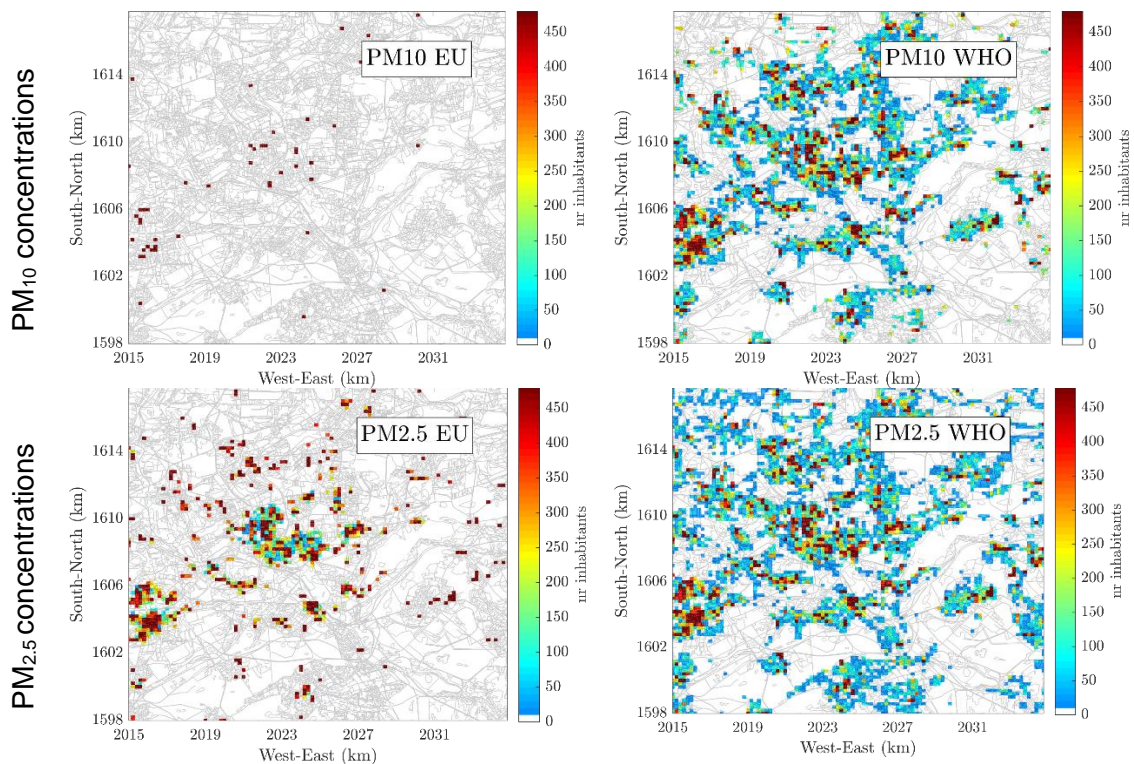
Figure 3-62: Population potentially exposed to values above the EU limits and WHO guideline values for NO_2, PM10 and PM2.5 baseline concentrations.

For NO_2 the limits established by the EU and the WHO are equivalent, being 40 $\mu g.m^{-3}$ for the annual mean. In Sosnowiec, the NO_2 annual limits are exceeded in 1043 cells corresponding to 59% 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 $\mu g.m^{-3}$ and under WHO guidelines are 20 $\mu g.m^{-3}$, for $PM_{2.5}$ the EU established for the annual mean limit value of 25 $\mu g.m^{-3}$ and for the WHO limits it is established at 10 $\mu g.m^{-3}$. The EU annual legal limit value for PM_{10} concentrations is exceeded in 46 cells, which represents 12.7% of the population within the urban area potentially exposed to those concentrations. For $PM_{2.5}$, the EU annual legal limit value is exceeded in 372 cells, corresponding to 45.7% of the population potentially exposed. In the urban area of Sosnowiec 95% and 100% of the total population are potentially exposed to PM_{10} and $PM_{2.5}$ concentrations, respectively, exceeding the WHO recommendations

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 3-63 presents the NO_2 annual averaged concentrations considering the impacts of BAU scenario in 2025 and 2050. The maximum annual averaged NO_2

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concentrations will be equal to 168.2 µg.m^{-3} in 2025 and to 143.3 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 26.7% and 79.9%, when compared to the baseline.
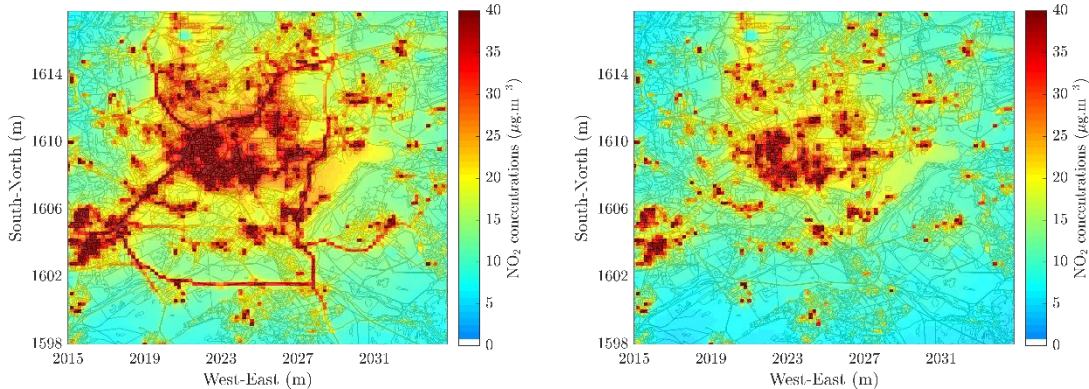

Figure 3-63: NO$_2$ annual average concentrations in the BAU scenario (left) in 2025 and (right) 2050.

Figure 3-64 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$_2$ $_{baseline\ year}$ – NO$_2$ $_{scenarios}$ in µg.m^{-3}. The BAU scenario will lead to a maximum reduction of 39.4 µg.m^{-3} of the NO$_2$ concentrations in 2025, corresponding to a reduction of 26.7%, while the spatial average over the entire the domain will reduce 4.7 µg.m^{-3} of NO$_2$ concentrations, which corresponds to a reduction of 18.7%. In 2050 the BAU scenario will lead to a maximum reduction of the NO$_2$ concentrations of 73.8 µg.m^{-3} which corresponds to a reduction of 79.9%, while the average over the entire domain will reduce 9.8 µg.m^{-3} (39.5%).
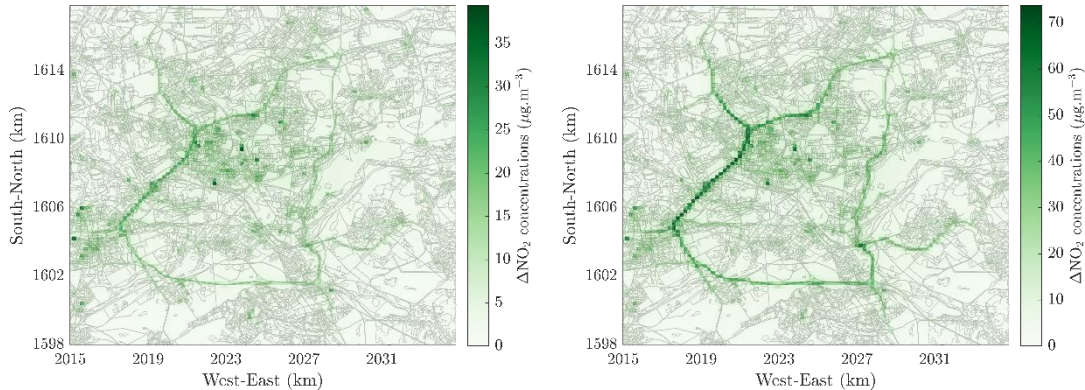

Figure 3-64: Differences of the NO$_2$ annual averaged concentrations in the BAU scenario (left) in 2025 and (right) 2050.

Table 3-14 summarizes the overall impacts of BAU scenarios on air quality and population exposure. The population within the urban area of Sosnowiec potentially exposed to NO$_2$ concentrations will diminish from 59.2% in the baseline year to 28.3% of inhabitants in risk of exposure with the implementation of the BAU scenario in 2050. Therefore, the simulation results indicate no compliance with the EU limits with the BAU scenario even in 2050 within 180 computational cells with inhabitants allocated.

Table 3-14: Summary of results including the annual averages of NO$_2$ concentrations, together with the number of exceedances to the EU legal limit value (Exc.), as well as the number of exceedances to the EU 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	7.7	207.7	24.3	1027	915	369524	59.2%
BAU 2025	6.4	168.2	19.7	519	493	280109	44.9%
BAU 2035	5.4	148.3	16.3	256	252	210907	33.8%
BAU 2050	4.9	143.3	14.5	180	180	176914	28.3%

BAU scenarios: PM$_{10}$ concentrations

The reductions of PM emissions in the BAU scenario will also lead to reductions of the PM concentrations. Figure 3-65 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 59.6 µg.m^{-3} in 2025 and to 45.7 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 20.8% and 39.3%, when compared to the baseline.
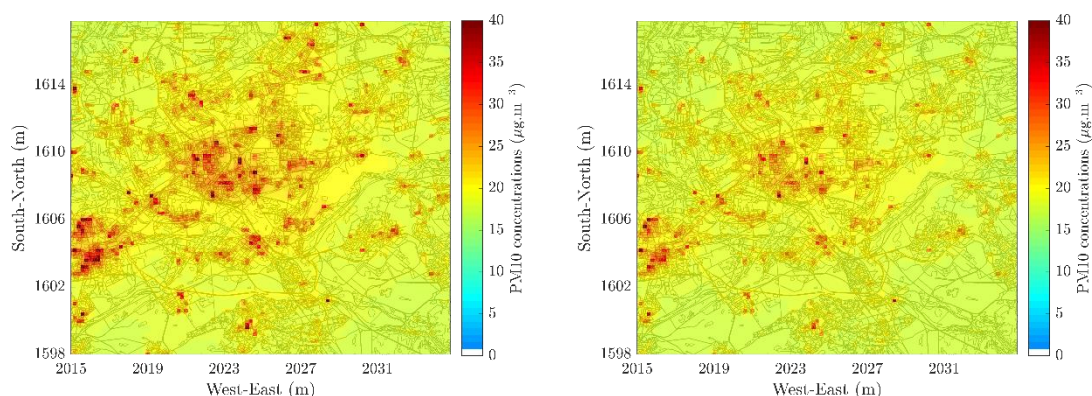

Figure 3-65: PM10 annual average concentrations in the BAU scenario (left) in 2025 and (right) 2050.

Figure 3-66 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 15.7 µg.m^{-3} of the PM$_{10}$ concentrations in 2025, corresponding to a reduction of

20.8%, while the spatial average over the entire the domain will reduce 1.1 µg.m^{-3} of PM$_{10}$ concentrations, which corresponds to a reduction of 5.0%. In 2050 the BAU scenario will lead to a maximum reduction of the PM10 concentrations of 29.6 µg.m^{-3} which corresponds to a reduction of 39.3%, while the average over the entire domain will reduce 2.1 µg.m^{-3} (9.2%).
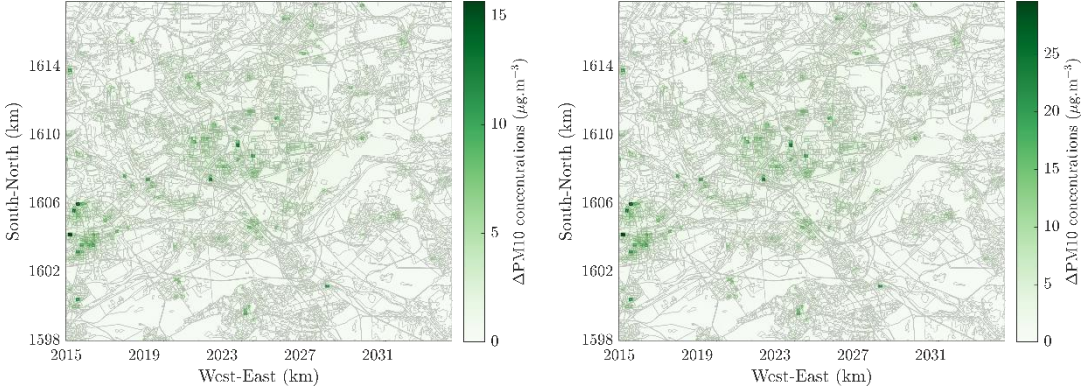

Figure 3-66: Differences of the PM10 annual averaged concentrations in the BAU scenario (left) in 2025 and (right) 2050.

Table 3-15 and 3-16 summarize the overall impacts of BAU scenarios on PM$_{10}$ concentrations and population exposure to those concentrations. The population within the urban area of Sosnowiec potentially exposed to PM$_{10}$ concentrations above the EU legal limit value will diminish from 12.7% in 2015 to 2.0% in 2050 with the implementation of the BAU scenario. While, when considering the WHO guideline values, the population potentially exposed to PM$_{10}$ concentrations will diminish from 95.1% in 2015 to 74.9% in 2050 with the implementation of the BAU scenario. The simulation results indicate no compliance with the EU limits in the BAU scenario even in 2050 within 4 computational cells with inhabitants allocated to, and no compliance with the stricter WHO guideline values within 1385 grid cells with inhabitants.

Table 3-15: Summary of results including the annual averages of PM$_{10}$ concentrations, together with the number of exceedances to the EU legal limit value (Exc.), as well as the number of exceedances to the EU 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	17.7	75.3	21.0	46	46	79005	12.7%
BAU 2025	17.4	59.6	19.8	16	16	37015	5.9%
BAU 2035	17.2	49.7	19.1	5	5	15732	2.5%

	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
BAU 2050	17.1	45.7	18.9	4	4	12576	2.0%

Table 3-16: Summary of results including the annual averages of PM$_{10}$ concentrations, together with the number of exceedances to the WHO guideline values (Exc.), as well as the number of exceedances to the WHO guideline values in grid cells with inhabitants allocated to (Exc. Inhabit.), the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit (Inhabit.), and the corresponding % of population (Pop.).

	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	17.7	75.3	21.0	4899	3800	593613	95.1%
BAU 2025	17.4	59.6	19.8	3105	2670	555275	88.9%
BAU 2035	17.2	49.7	19.1	1848	1740	499245	79.9%
BAU 2050	17.1	45.7	18.9	1443	1385	467926	74.9%

BAU scenarios: PM$_{2.5}$ concentrations

Figure 3-67 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 49.8 µg.m^{-3} in 2025 and to 38.8 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 19.8% and 37.5%, when compared to the baseline.
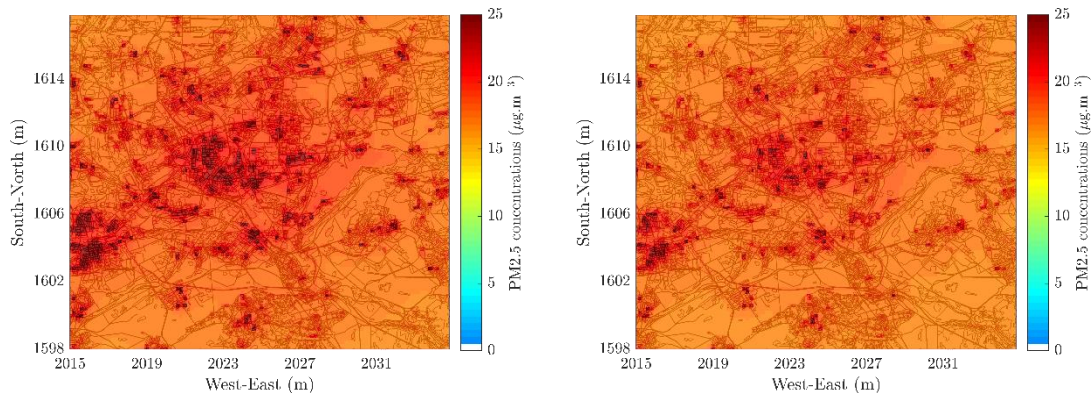
Figure 3-67: PM2.5 annual average concentrations in the BAU scenario (left) in 2025 and (right) 2050.

Figure 3-68 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 12.3 µg.m^{-3} of the PM$_{2.5}$ concentrations in 2025, corresponding to a reduction of 19.8%, while the spatial average over the entire the domain will reduce 0.9 µg.m^{-3} of PM$_{2.5}$ concentrations, which corresponds to a reduction of 4.1%. In 2050 the BAU scenario will lead to a maximum reduction of the PM$_{2.5}$ concentrations of 23.3 µg.m^{-3} which corresponds to a reduction of 37.5%, while the average over the entire domain will reduce 1.6 µg.m^{-3} (7.8%).
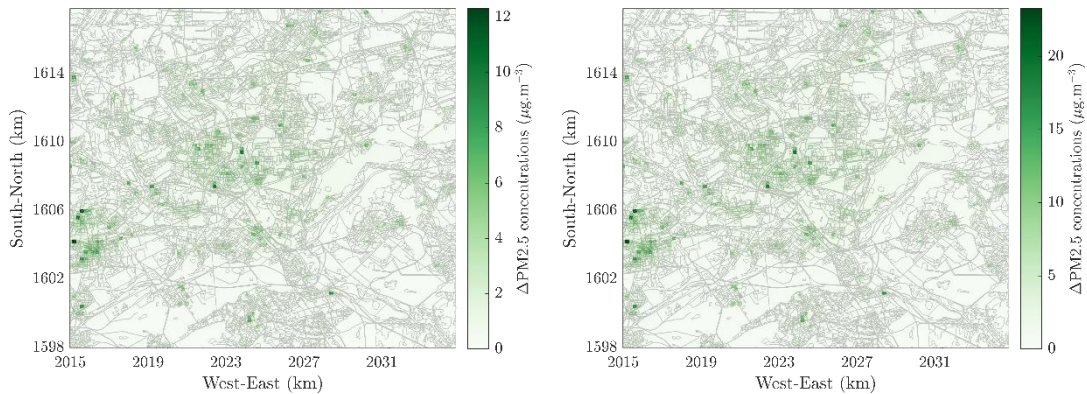

Figure 3-68: Differences of the PM2.5 annual averaged concentrations in the BAU scenario (left) in 2025 and (right) 2050.

Table 3-17 and 3-18 summarize the overall impacts of BAU scenarios on PM$_{10}$ concentrations and population exposure to those concentrations. The population within the urban area of Sosnowiec potentially exposed to PM$_{10}$ concentrations above the EU legal limit value will diminish from 12.7% in 2015 to 2.0% in 2050 with the implementation of the BAU scenario. While, when considering the WHO guideline values, the population potentially exposed to PM$_{10}$ concentrations will diminish from 95.1% in 2015 to 74.9% in 2050 with the implementation of the BAU scenario. The simulation results indicate no compliance with the EU limits in the BAU scenario even in 2050 within 4 computational cells with inhabitants allocated to, and no compliance with the stricter WHO guideline values within 1385 grid cells with inhabitants.

Table 3-17: Summary of results including the annual averages of PM2.5 concentrations, together with the number of exceedances to the EU legal limit value (Exc.), as well as the number of exceedances to the EU 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	16.8	62.1	19.3	372	372	285593	45.7
BAU 2025	16.6	49.8	18.5	170	170	183547	29.4
BAU 2035	16.4	42.0	17.9	69	69	102317	16.4
BAU 2050	16.4	38.8	17.7	47	47	80141	12.8

Table 3-18: 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	16.8	62.1	19.3	10000	5755	624542	100%
BAU 2025	16.6	49.8	18.5	10000	5755	624542	100%
BAU 2035	16.4	42.0	17.9	10000	5755	624542	100%
BAU 2050	16.4	38.8	17.7	10000	5755	624542	100%

SDW scenarios: NO$_2$ concentrations

The two proposed scenarios from the SDW – low and high ambition scenarios – will distinctly impact the air quality over the urban area of Sosnowiec. Figure 3-69 shows the differences of the NO$_2$ annual concentrations with the implementation of the SDW scenarios compared to the baseline year. The maximum NO$_2$ concentrations will range from 166.3 µg.m^{-3} to 141.7 µg.m^{-3} between 2025 and 2050 with the implementation of the low ambition scenario, while with the implementation of the high ambition scenario the maximum NO$_2$ concentrations will range from 156.6 µg.m^{-3} to 136.7 µg.m^{-3}. Figure 3-69 also points out that the maximum reductions of the NO$_2$ concentrations are simulated over the city centre and over the main

roads and motorways, denoting a relevant link between the reduction of NO_x emissions in the transport sector and the reductions of NO_2 concentrations achieved with the implementation of those scenarios. The low ambition scenario will led to an overall reduction of the NO_2 concentrations of 20.3% over the entire computational domain in 2025, and of 40.4% in 2050. While the high ambition scenario will lead to an averaged reduction over the entire area of the NO_2 concentrations of 31.6% in 2025, and of 42.3% in 2050.
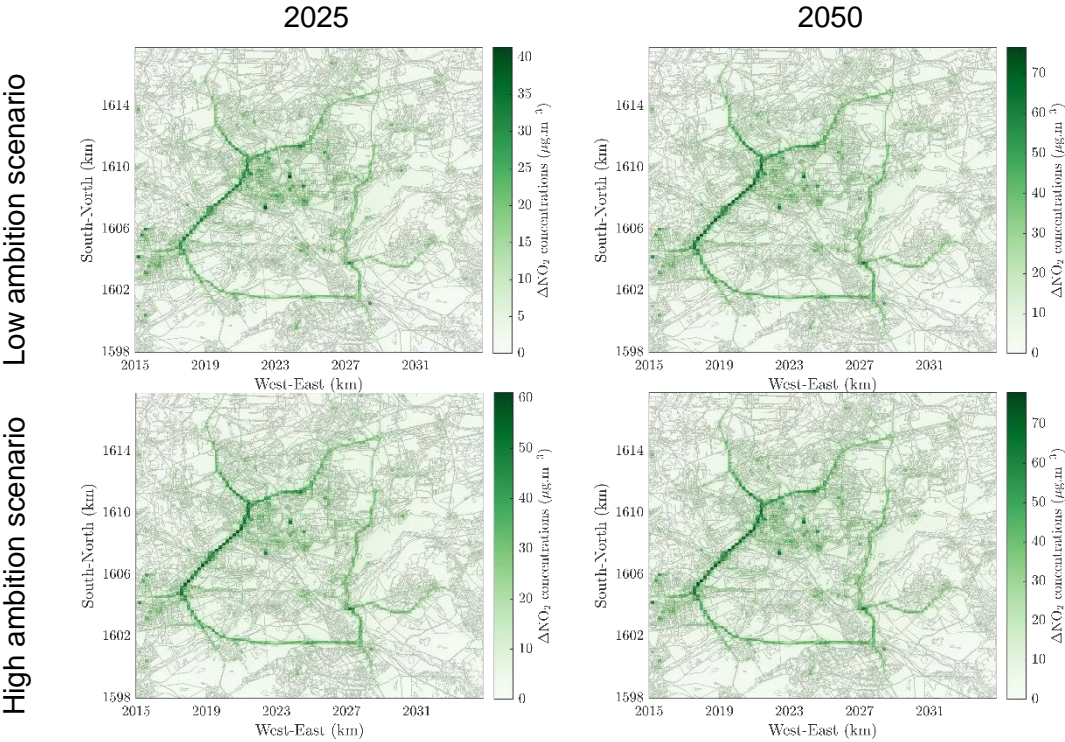
Figure 3-69: Differences of the NO₂ annual averaged concentrations in the SDW scenarios in 2025 and 2050.

Table 3-19 presents an overview of the overall impact of the SDW scenarios on the NO_2 concentrations, indicating that independently on the level of ambition of the scenarios all of them will lead to high risk of population exposure to those concentrations even in 2050. The high ambition scenario in 2050 will still led to 25.3% of the population within Sosnowiec computational domain potentially exposed to NO_2 concentrations above the EU annual legal limit value.

Table 3-19: Summary of the SDW impacts including the annual averages of NO₂ concentrations, together with the number of exceedances to the EU legal limit value, the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit, and the corresponding % of population.

	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.

2015	7.7	207.7	24.3	1027	915	369524	59.2%
Low 2025	6.3	166.3	19.2	457	442	271239	43.4%
Low 2035	5.3	146.3	15.6	201	201	191170	30.6%
Low 2050	4.9	141.7	14.2	170	170	171277	27.4%
High 2025	5.5	156.6	16.4	275	275	227578	36.4%
High 2035	4.9	140.3	14.4	170	170	170321	27.3%
High 2050	4.7	136.7	13.8	148	148	157999	25.3%

SDW scenarios: PM$_{10}$ concentrations

The overall measures impacting the PM$_{10}$ emissions will also promote reductions of PM$_{10}$ concentrations over the urban area of Sosnowiec as indicated in Figure 3-70. The differences contour maps of the annual PM$_{10}$ concentrations point out a maximum concentration ranging from 58.9 µg.m^{-3} to 45.2 µg.m^{-3} between 2025 and 2050 with the implementation of the low ambition scenario, while the high ambition scenario will lead to a maximum concentration of PM10 concentrations from 41.7 µg.m^{-3} in 2050.
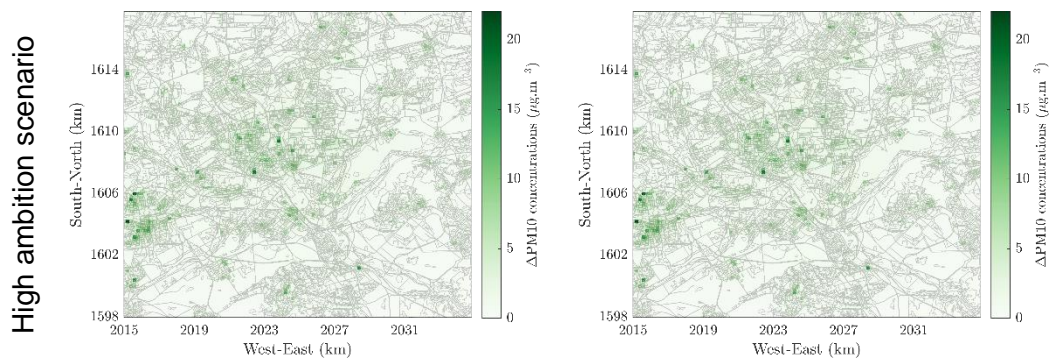
High ambition scenario
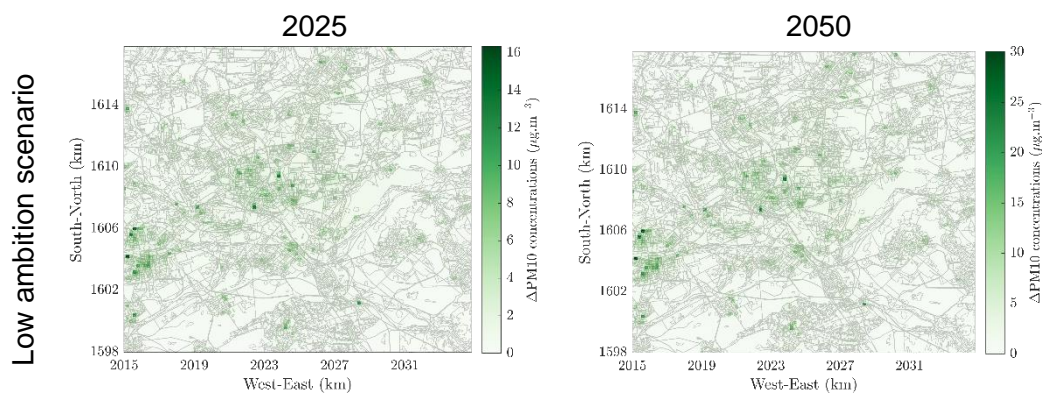
Figure 3-70: Differences of the PM10 annual averaged concentrations in the SDW scenario in 2025 and 2050.

Table 3-20 and 3-21 present an overview of the overall impact of the SDW scenarios on the PM_{10} concentrations. The low ambition scenario will lead to an overall reduction of 5.3% over the entire computational domain in 2025, and of 9.6% in 2050. While the high ambition scenario will lead to a reduction of 7.3% in 2025, and of 10.8% in 2050.

The population within the urban area of Sosnowiec potentially exposed to PM_{10} concentrations above the EU legal limit value will diminish from 12.7% in 2015 to 2.0% in 2050 with the implementation of the low ambition scenario, and to 1.1% in 2050 with the high ambition scenario. However, the population of Sosnowiec potentially exposed to PM_{10} concentrations above the stricter, but still voluntary, WHO guideline values will diminish from 95.1% in 2015 to 73.7% in 2050 with the implementation of the low ambition scenario, and to 67.2% in 2050 with the high ambition scenario. The simulation results indicate no compliance with the EU limits in the low ambition scenario even in 2050 within 4 computational cells with inhabitants allocated to, and no compliance with the stricter WHO guideline values within 1288 grid cells with inhabitants. The results also indicate no compliance with the EU limits in the high ambition scenario even in 2050 within only 2 computational cells with inhabitants allocated to, and no compliance with the stricter WHO guideline values within 962 grid cells with inhabitants.

Table 3-20: Summary of results including the annual averages of PM_{10} concentrations, together with the number of exceedances to the EU legal limit value (Exc.), as well as the number of exceedances to the EU 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	17.7	75.3	21.0	46	46	79005	12.7%
Low 2025	17.4	58.9	19.8	14	14	33033	5.3%

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Low 2035	17.2	48.0	19.0	5	5	15732	2.5%
Low 2050	17.1	45.2	18.8	4	4	12576	2.0%
High 2025	17.3	53.2	19.3	7	7	19782	3.2%
High 2035	17.1	45.0	18.7	3	3	10032	1.6%
High 2050	17.0	41.7	18.5	2	2	6597	1.1%

Table 3-21: Summary of results including the annual averages of PM$_{10}$ concentrations, together with the number of exceedances to the WHO guideline values (Exc.), as well as the number of exceedances to the WHO guideline values in grid cells with inhabitants allocated to (Exc. Inhabit.), the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit (Inhabit.), and the corresponding % of population (Pop.).

	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	17.7	75.3	21.0	46	46	79005	12.7%
Low 2025	17.4	58.9	19.8	2964	2589	552146	88.4%
Low 2035	17.2	48.0	19.0	1545	1486	481387	77.1%
Low 2050	17.1	45.2	18.8	1333	1288	460383	73.7%
High 2025	17.3	53.2	19.3	2138	1989	520448	83.3%
High 2035	17.1	45.0	18.7	1243	1213	454126	72.7%
High 2050	17.0	41.7	18.5	976	962	419534	67.2%

SDW scenarios: PM$_{2.5}$ concentrations

Figure 3-71 shows the contour maps with the differences between the proposed scenarios and the baseline of the annual PM$_{2.5}$ concentrations. These contour maps point out a

maximum concentration ranging from 49.3 µg.m^{-3} to 38.5 µg.m^{-3} between 2025 and 2050 with the implementation of the low ambition scenario, and ranging from 44.8 µg.m^{-3} to 35.7 µg.m^{-3} between 2025 and 2050 with the implementation of the high ambition scenario.
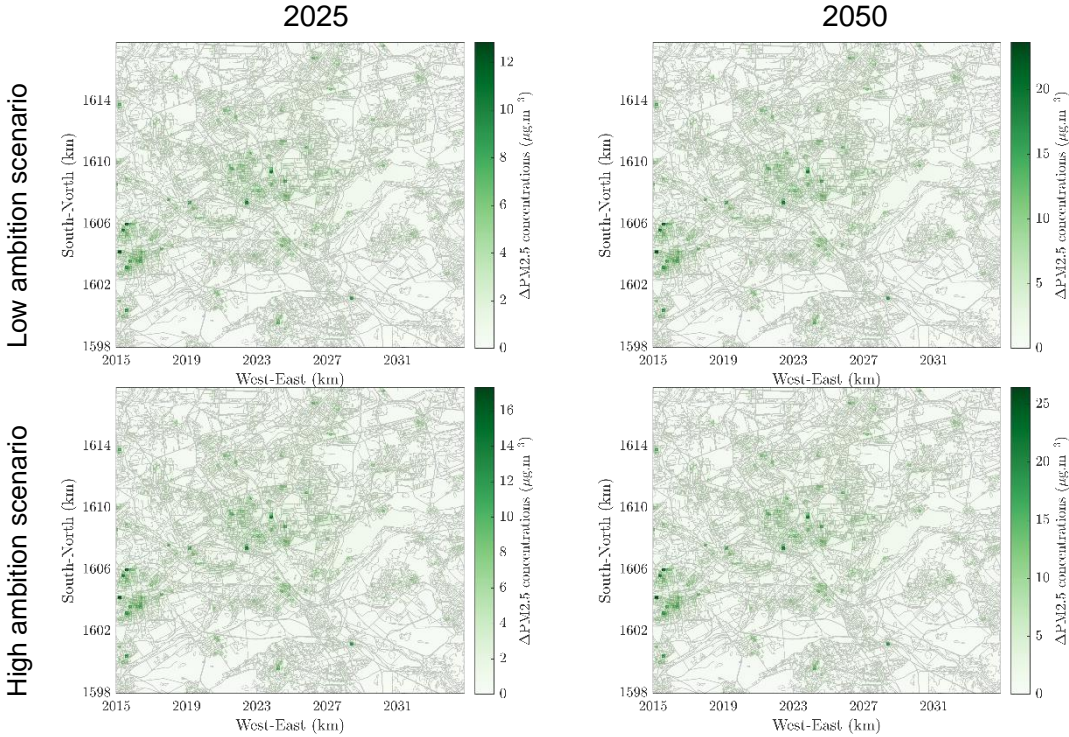

Figure 3-71: Differences of the PM2.5 annual averaged concentrations in the FUPS scenario in 2025 and 2050.

Table 3-22 and 3-23 present an overview of the overall impact of the SDW scenarios on the PM$_{2.5}$ concentrations. The low ambition scenario will lead to an overall reduction of 4.4% of the PM$_{2.5}$ concentrations over the entire computational domain in 2025, and of 8.1% in 2050. While the high ambition scenario will lead to a reduction of 6.0% of the PM$_{2.5}$ concentrations in 2025, and of 9.1% in 2050. The population within the urban area of Sosnowiec potentially exposed to PM$_{2.5}$ concentrations above the EU legal limit value will diminish from 45.7% in 2015 to 12.5% in 2050 with the implementation of the low ambition scenario, and to 8.5% in 2050 with the high ambition scenario. However, all the population of the urban area of Sosnowiec 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 high ambition scenario. The simulation results indicate no compliance with the EU limits in the low ambition scenario even in 2050 within 45 computational cells with inhabitants allocated to, and no compliance with the stricter WHO guideline values within 5755 grid cells with inhabitants. The results also indicate no compliance with the EU limits in the high ambition scenario even in 2050 within 27 computational cells with inhabitants allocated to, and no compliance with the stricter WHO guideline values within 5755 grid cells with inhabitants.

Table 3-22: Summary of results including the annual averages of PM$_{2.5}$ concentrations, together with the number of exceedances to the EU legal limit value (Exc.), as well as the number of exceedances to the EU legal limit value in grid cells with inhabitants allocated

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to (Exc. Inhabit.), the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit (Inhabit.), and the corresponding % of population (Pop.).

	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	16.8	62.1	19.3	372	372	285593	45.7%
Low 2025	16.6	49.3	18.4	158	158	175691	28.1%
Low 2035	16.4	40.7	17.8	57	57	91665	14.7%
Low 2050	16.4	38.5	17.7	45	45	78059	12.5%
High 2025	16.5	44.8	18.1	97	97	127487	20.4
High 2035	16.4	38.3	17.6	44	44	76555	12.3%
High 2050	16.3	35.7	17.4	27	27	52955	8.5%

Table 3-23: 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	16.8	62.1	19.3	10000	5755	624542	100%
Low 2025	16.6	49.3	18.4	10000	5755	624542	100%
Low 2035	16.4	40.7	17.8	10000	5755	624542	100%
Low 2050	16.4	38.5	17.7	10000	5755	624542	100%

High 2025	16.5	44.8	18.1	10000	5755	624542	100%
High 2035	16.4	38.3	17.6	10000	5755	624542	100%
High 2050	16.3	35.7	17.4	10000	5755	624542	100%

FUPS scenarios

The UPS scenario for the measures focusing on the transport sector stablishes two levels of emission reduction, one to be applied for *bad air quality conditions*, and another one to be applied for *good air quality conditions*. The ClairCity quantification framework was adapted to consider these criteria. Therefore, the emission reduction targets from the bad air quality scenario were applied to the grid cells where the annual concentrations exceeded the EU limit value for NO_2, PM_{10} and $PM_{2.5}$ concentrations, while the good air quality scenario was applied to the grid cells below the legal limit.

FUPS scenarios: NO_2 concentrations

There are important reductions of NO_x emissions in the FUPS scenario, which will lead to significant reductions of the NO_2 concentrations. Figure 3-72 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 166.8 $\mu g.m^{-3}$ in 2025 and to 141.7 $\mu g.m^{-3}$ in 2050, corresponding to an overall reduction of the maximum concentration of 61.9% and 82.1%, when compared to the baseline.
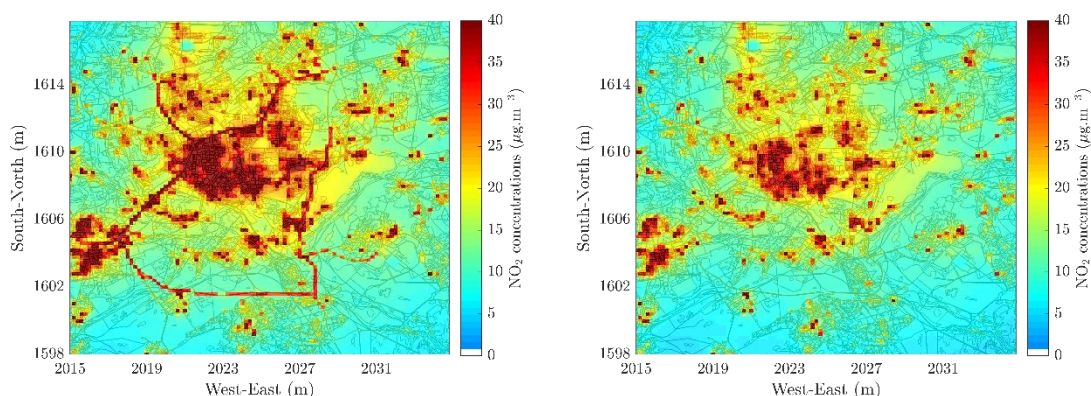

Figure 3-72: NO_2 annual average concentrations in the FUPS scenario (left) in 2025 and (right) 2050.

Figure 3-73 shows the differences of the NO_2 annual concentrations with the implementation of the FUPS scenarios compared to the baseline year. Figure 3-73 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 28.8% over the entire computational domain in 2025, and of 40.7% in 2050.
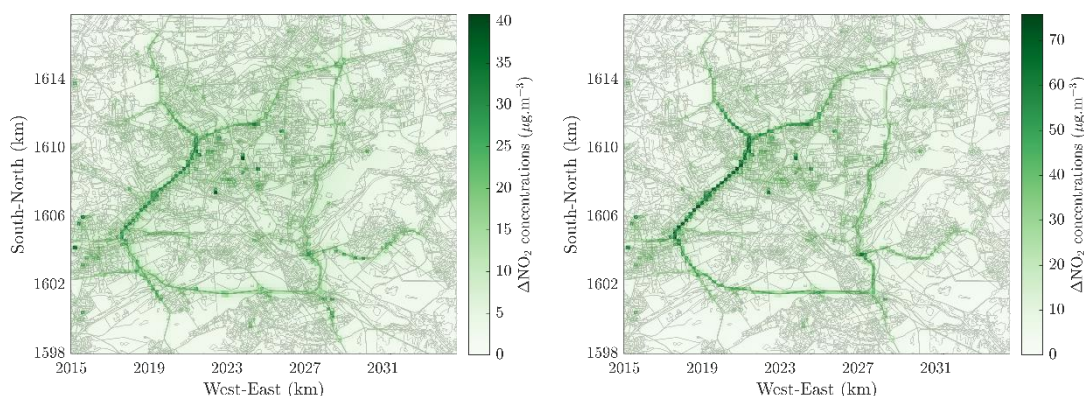

Figure 3-73: Differences of the NO₂ annual averaged concentrations in the FUPS scenario (left) in 2025 and (right) 2050.

Table 3-24 shows the summary of the overall impact of the FUPS scenario on the NO_2 concentrations, indicating an high risk of population exposure to those concentrations even in 2050. The FUPS scenario in 2050 will still led to 27.5% of the population within Sosnowiec computational domain potentially exposed to NO_2 concentrations above the EU annual legal limit value.

Table 3-24: Summary of the FUPS impacts including the annual averages of NO₂ concentrations, together with the number of exceedances to the EU legal limit value, the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit, and the corresponding % of population.

	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	7.7	207.7	24.3	1027	915	369524	59.2%
FUPS 2025	5.6	166.8	17.5	475	459	274271	43.9%
FUPS 2035	5.0	144.8	14.9	214	214	196083	31.4%
FUPS 2050	4.8	141.7	14.2	171	171	171631	27.5%

Figure 3-74 and Figure 3-75 present the impact of the FUPS scenario on PM$_{10}$ concentrations. The contour maps with the differences of the annual PM$_{10}$ concentrations (Figure 3-75) point out a maximum concentration ranging from 58.9 µg.m^{-3} to 45.2 µg.m^{-3} between 2025 and 2050 with the implementation of the FUPS scenario.
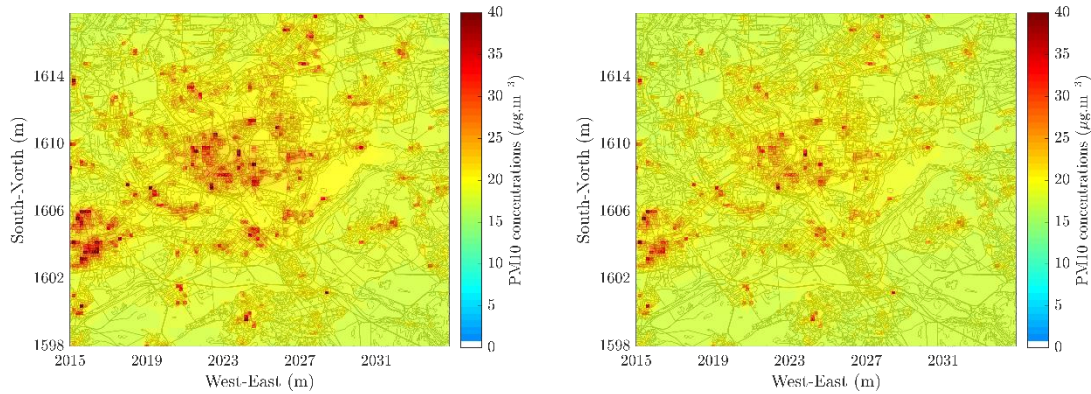
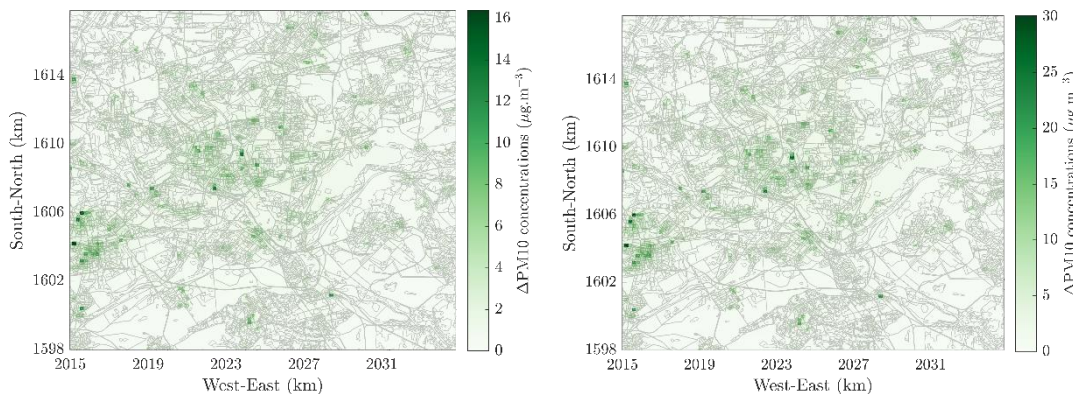**Figure 3-74: PM10 annual average concentrations in the FUPS scenario (left) in 2025 and (right) 2050.**

Figure 3-75: Differences of the PM10 annual averaged concentrations in the FUPS scenario (left) in 2025 and (right) 2050.

Table 3-25 and 3-26 summarize the overall impact of the FUPS scenario on the PM$_{10}$ concentrations. This scenario will lead to an overall reduction of 5.6% over the entire computational domain in 2025, and of 9.7% in 2050. The population within the urban area of Sosnowiec potentially exposed to PM$_{10}$ concentrations above the EU legal limit value will diminish from 12.7% in 2015 to 1.6% in 2050 with the implementation of the FUPS scenario. However, the population of Sosnowiec potentially exposed to PM$_{10}$ concentrations above the stricter, but still voluntary, WHO guideline values will diminish from 95.1% in 2015 to 73.2% in 2050 with the implementation of the FUPS scenario. The simulation results indicate no compliance with the EU limits even in 2050 within 3 computational cells with inhabitants allocated to, and no compliance with the stricter WHO guideline values within 1245 grid cells with inhabitants.

Table 3-25 - Summary of results including the annual averages of PM$_{10}$ concentrations, together with the number of exceedances to the EU legal limit value (Exc.), as well as the number of exceedances to the EU 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	17.7	75.3	21.0	46	46	79005	12.7%
FUPS 2025	17.4	58.9	19.7	14	14	33033	5.3%
FUPS 2035	17.2	49.1	19.0	5	5	15732	2.5%
FUPS 2050	17.1	45.2	18.8	3	3	10032	1.6%

Table 3-26: Summary of results including the annual averages of PM$_{10}$ concentrations, together with the number of exceedances to the WHO guideline values (Exc.), as well as the number of exceedances to the WHO guideline values in grid cells with inhabitants allocated to (Exc. Inhabit.), the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit (Inhabit.), and the corresponding % of population (Pop.).

	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	17.7	75.3	21.0	4899	3800	593613	95.1%
FUPS 2025	17.4	58.9	19.7	2830	2505	550033	88.1%
FUPS 2035	17.2	49.1	19.0	1613	1547	487795	78.1%
FUPS 2050	17.1	45.2	18.8	1279	1245	457115	73.2%

FUPS scenarios: PM$_{2.5}$ concentrations

Figure 3-76 and Figure 3-77 present the impact of the FUPS scenario on PM$_{10}$ concentrations. Figure 3-76 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 49.2 µg.m^{-3} in 2025 and to 38.4 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 20.7% and 38.1%, when compared to the baseline.
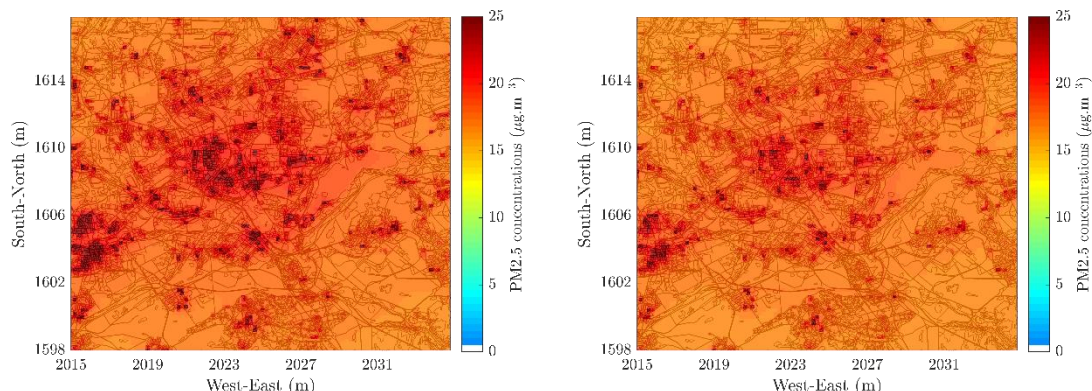

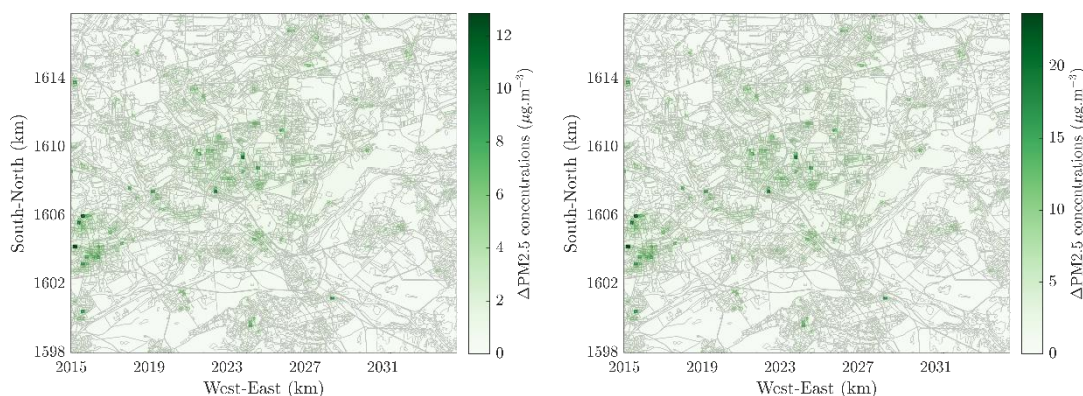**Figure 3-76: PM2.5 annual average concentrations in the FUPS scenario (left) in 2025 and (right) 2050.**

Figure 3-77: Differences of the PM2.5 annual averaged concentrations in the FUPS scenario (left) in 2025 and (right) 2050.

Table 3-27 and 3-28 presents the overall impact of the FUPS scenario on the PM$_{2.5}$ concentrations. The FUPS scenario will lead to an overall reduction of 4.6% over the entire computational domain in 2025, and of 8.1% in 2050.

The population within the urban area of Sosnowiec potentially exposed to PM$_{2.5}$ concentrations above the EU legal limit value will diminish from 45.7% in 2015 to 12.5% in 2050 with the implementation of the FUPS scenario. However, all the population of the urban area of Sosnowiec 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 high ambition scenario. The simulation results indicate no compliance with the EU limits in the FUPS scenario even in 2050 within 45 computational cells with inhabitants allocated to, and no compliance with the stricter WHO guideline values within 5755 grid cells with inhabitants.

Table 3-27: Summary of results including the annual averages of PM$_{2.5}$ concentrations, together with the number of exceedances to the EU legal limit value (Exc.), as well as the number of exceedances to the EU 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	16.8	62.1	19.3	372	372	285593	45.7%
FUPS 2025	16.5	49.2	18.4	155	155	172968	27.7%
FUPS 2035	16.4	41.5	17.8	65	65	98915	15.8%
FUPS 2050	16.4	38.4	17.6	45	45	78059	12.5%

Table 3-28: Summary of results including the annual averages of PM$_{2.5}$ concentrations, together with the number of exceedances to the WHO guideline values (Exc.), as well as the number of exceedances to the WHO guideline values in grid cells with inhabitants allocated to (Exc. Inhabit.), the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit (Inhabit.), and the corresponding % of population (Pop.).

	Min.	Max.	Aver.	Exc.	Exc. Inhabit.	Inhabit.	Pop.
2015	16.8	62.1	19.3	10000	5755	624542	100%
FUPS 2025	16.5	49.2	18.4	10000	5755	624542	100%
FUPS 2035	16.4	41.5	17.8	10000	5755	624542	100%
FUPS 2050	16.4	38.4	17.6	10000	5755	624542	100%

3.6 Health impacts

3.6.1 Baseline

The health impacts related to exposure to NO_2, PM_{10}, and $PM_{2.5}$ were calculated based on the baseline emissions scenario. The figures below show maps to illustrate the areas of highest concern regarding human exposure to the individual pollutants. The left panels show the concentration maps overlaid with the population density distribution within the study area. The concentration levels are shown in a colour scale from yellow to dark purple (the same concentrations as presented in section 3.3.6) and population density with contours from light to dark grey (no colour bar), the darker the grey, the denser the population is. On the right panels, the concentration weighted population maps indicating where the population is mostly affected by the air concentration levels in Sosnowiec, for individual pollutants. The population weighted concentration maps indicate that exposure is the highest closer to the city centre of Sosnowiec and neighbouring town Katowice (south-west of the domain).

The assessment includes the estimation of premature deaths and year potentially lost due to air pollution exposure. The results for the baseline scenario indicate there has been 879, 664, and 1194 premature deaths, and 12552, 9479, and 17039 years of life potentially lost attributed to $PM_{2.5}$, PM_{10}, and NO_2 pollution levels in Sosnowiec in 2015, respectively.
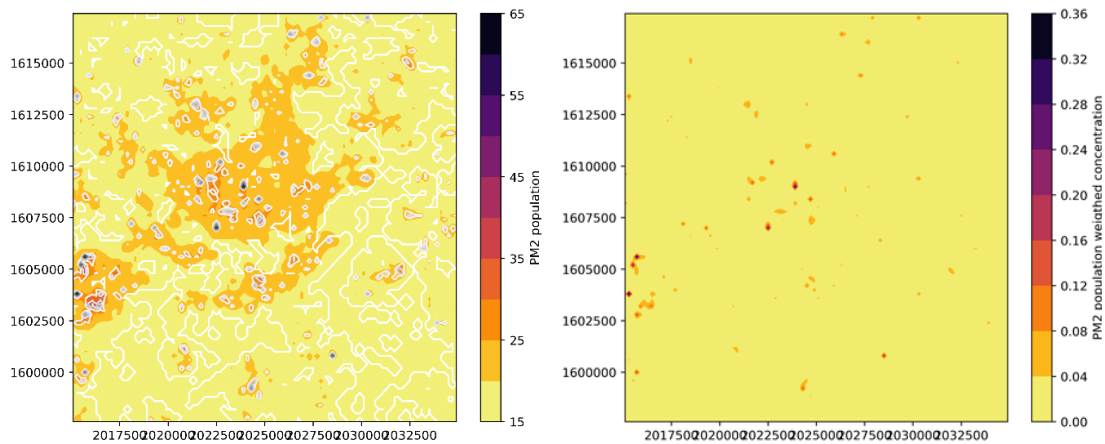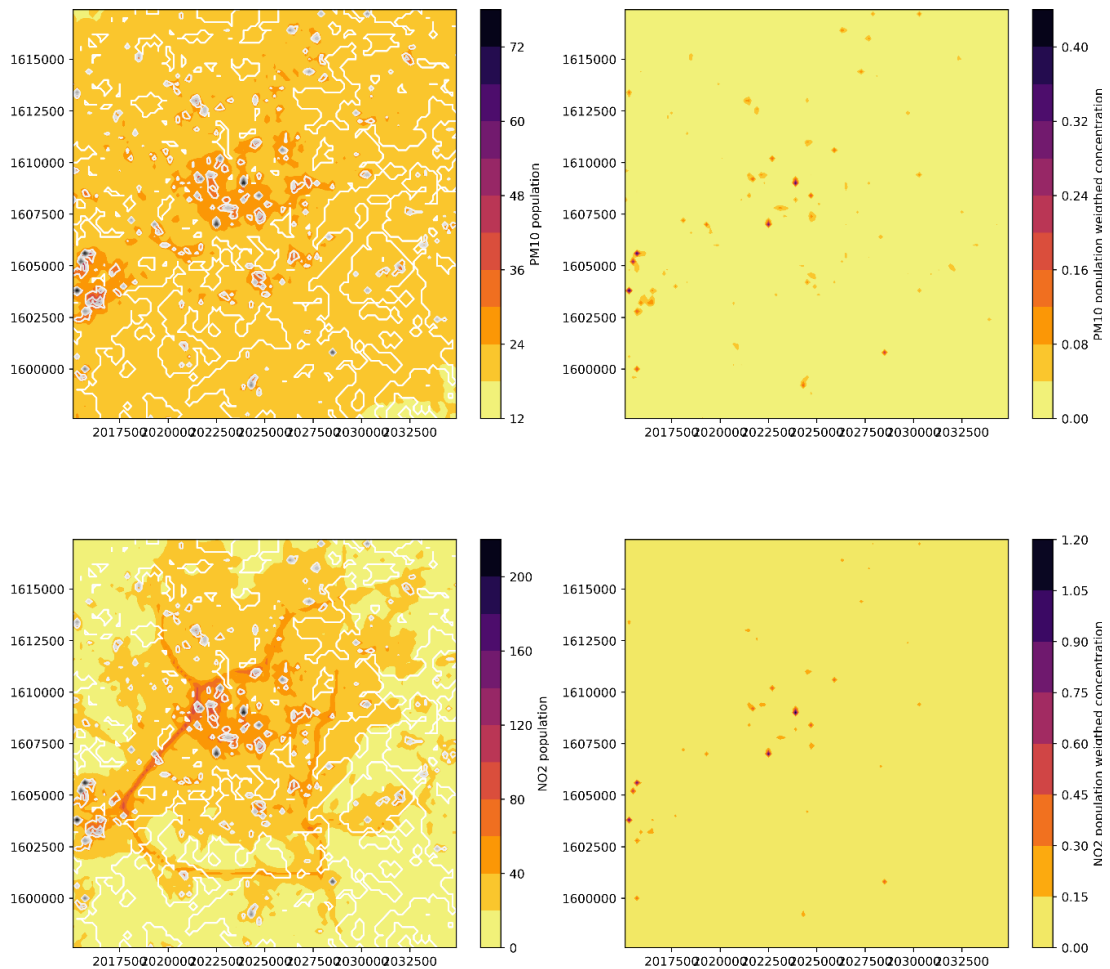
Figure 3-78: Concentration maps overlaid with population density contours (left), population weighted concentration maps (right) for PM2.5 (top), PM10 (centre), and NO₂ (bottom) based on the baseline emission scenario (2015), for Sosnowiec.

3.6.1.1 BAU and UPS

The analysis of the health impact benefits of implementing emission control measures can be quantified by benchmarking the health indicators estimated based on the BAU and UPS emission scenarios. The results in relative terms (%) are described in the table below. Note that independently of the indicators, the impact is the same since the indicators are related (see Equation [2.7.6]).
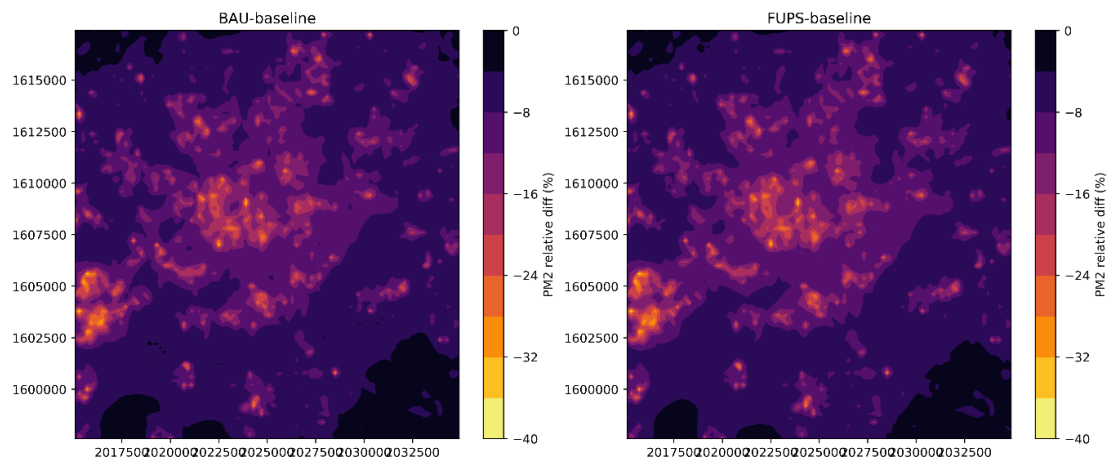
Table 3-29: Health impact benefits of implementing emission control measures in Sosnowiec (%).

PM2.5			PM10			NO2		
2025	2035	2050	2025	2035	2050	2025	2035	2050

BAU	-9	-16	-18	-11	-18	-21	-21	-34	-40
UPS	-10	-16	-19	-12	-19	-21	-24	-37	-41

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. However, there is no substantial difference between implementing BAU or UPS emission scenarios in terms of human help impact reduction. According to these results, both future scenarios will be more efficient on reducing the impact of NO_2 on human health and less on $PM_{2.5}$; the reduction on the impact will be larger at later years.

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 with the comparison between future and current emission scenario for the year 2050 are shown in Figure 3-79. Note that the maps have different scales and they show the reduction, thus the higher the negative values, the larger the reduction is. NO_2 concentration levels have a larger reduction across the city, reducing the impact of NO2 on human health of the people living in Sosnowiec area. NO_2 reduction scenarios seem to be more successful to target areas where people live than the scenarios for particulate matter. There is an expected increase on the health impact benefit across the years due to the implementation of the emissions control measures for both emissions scenarios.
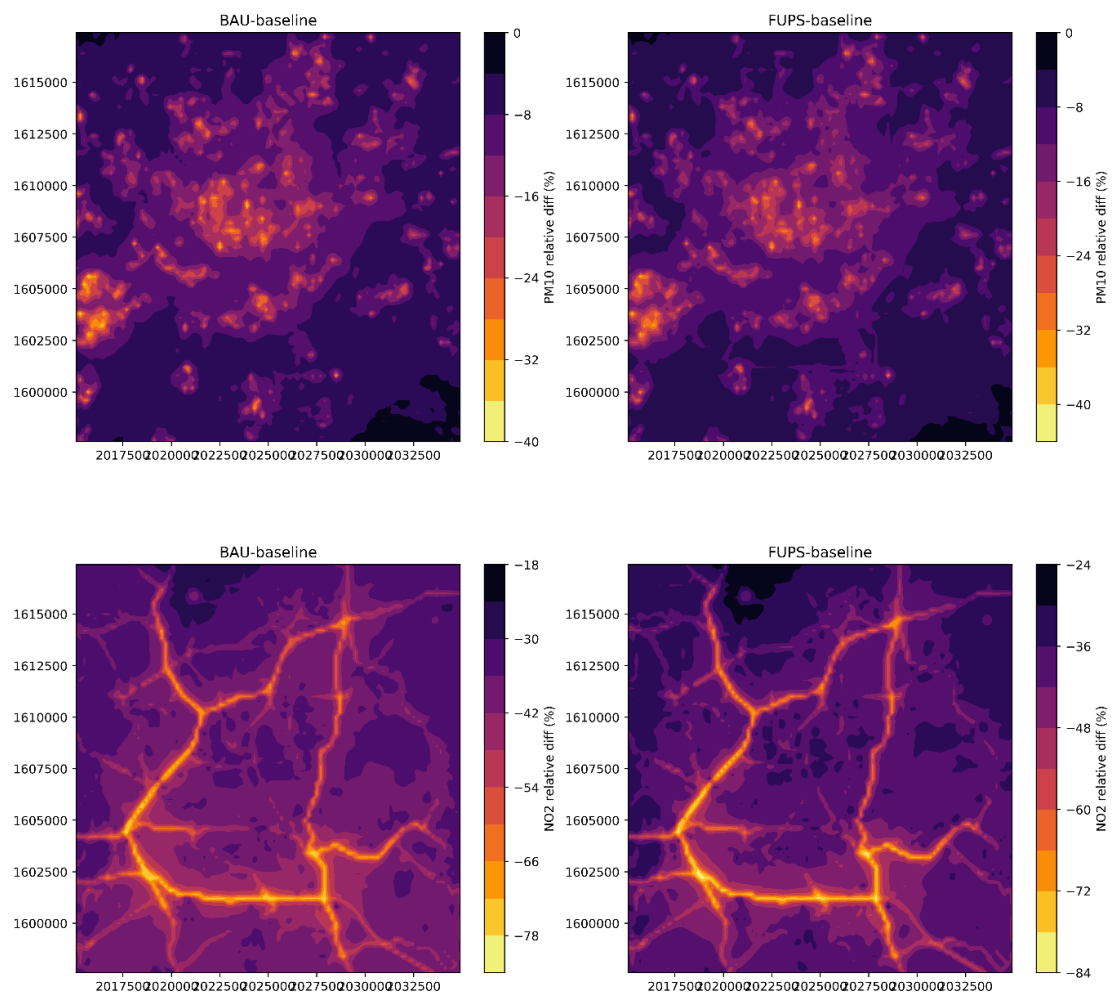
Figure 3-79: Air quality impact benefits of implementing emission control measures in 2050 for Sosnowiec, BAU vs baseline on the left and UPS vs baseline on the right for PM2.5 (top), PM10 (centre), and NO₂ (bottom).

4 Conclusions

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

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