ClairCity: Citizen-led air pollution reduction in cities

Deliverable 5.7: City Impact Analysis Report

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Document Details

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V1.1	Kris Vanherle	12/11/2019	Added content by Peter (TML) and An (DTU)
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V2.1	Vera Rodrigues	17/01/2020	Added inputs from UAVR and NILU and updated as stand-alone document
V2.2	Vera Rodrigues	14/02/2020	Completed for Bristol
V2.3	Vera Rodrigues	28/02/2020	Revised for Bristol

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Quality Assurance	Enda Hayes (UWE)
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Table of Content

In this chapter, we dive into the results for the Bristol 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/d5-5-assessment-of-impacts-first-city. 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

The source for the transport volume in Bristol, is data from the traffic model of the greater Bristol area. This data holds traffic intensity at link level, by mode. As indicated in the chapter on the general methodology, we use this data as input for transport emission estimates.

There are 2 modules that hold specific methodological features for the Bristol case: the mode choice module and the approach in the integrated land use module.

1.1 Transport: Mode choice model

As Bristol was the basis of building a mode choice model that we used also later on (after calibrating it to the observed local mode choices), we discuss here the process in detail.

1.1.1 Travel diary data processing

As explained, we need a comprehensive, representative database of trips made in, from, to, and across the region in question. A publicly available database that comes closest to our needs is the annual National Travel Survey[1] of the UK.

The survey data[2] along with an extensive set of documentation (including definitions of all terms and variables used below in the text) can be downloaded from https://beta.ukdataservice.ac.uk/datacatalogue/studies/study?id=5340 after a free registration. The data consists of a set of data tables for each survey period (year), among which are tables on trips, stages, individuals, and households.

To understand the difference between the first two datasets, we need to define trips and stages. The basic unit of travel, a trip, is defined as a one-way course of travel with a single main purpose. A trip consists of one or more stages. A new stage is defined when there is a change in the form of transport or when there is a change of vehicle requiring a separate ticket.

By combining data from these four databases, we created an individual and stage level database of all movements in the survey (using simple lookup functions, and some minimal processing that was necessary to calculate all variables for each stage and each individual). We used the last four available years, from 2012 to 2015. There were only minor differences in the structure and methodology of these years, therefore homogenising the database was not too difficult. For all calculations we used weights W5, which is the Trip/stage weight which needs to be applied to all analysis of trip and stage data. (Short walks were given a

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[1] https://www.gov.uk/government/collections/national-travel-survey-statistics

[2] Department for Transport. (2017). National Travel Survey, 2002-2016. [data collection]. 12th Edition. UK Data Service. SN: 5340, http://doi.org/10.5255/UKDA-SN-5340-8

seven times highest weight to compensate for the fact that they are only reported for one day of the travel week.)

At this stage – in preparation for the construction of a mode choice model – we also created some new binned variables (with the naming convention of adding an extra _OD tag behind the name of the original variable, sometimes starting from already binned ones variables), namely:

- Age_OD ['1|0-15 years', '2|16-25 years', '3|26-49 years', '4|50-69 years', |70 years +'] is the age of the respondent
- StageDay_OD ['1|Weekday','2|Weekend'] telling us if the stage started on a weekday or on a weekend
- StageStartHour_OD ['1|Night (20:00-6:59)', '2|Morning (07:00-8:59)', '3|Midday (09:00-15:59)', '4|Afternoon (16:00-19:59)'] is the departure time for a given stage
- StageMode_OD ['1|Walk', '2|Bicycle', '3|Car/van', '4|Bus/metro', '5|Train/surface rail', '6|Taxi', '7|Other (incl. motor, long-distance bus, others)'] is the travel mode of a given stage

Some further original important variables were:

- TripPurpose_B04ID ['1|Commuting', '2|Business', '3|Education/escort education', '4|Shopping', '5|Other escort', '6|Personal business', '7|Leisure', '8|Other including just walk'] is the motivation for a trip
- Sex_B01ID ['1|Male','2|Female'] is the gender of the traveller
- HHIncome2002_B02ID ['1|Less than £25,000','2|£25,000 to £49,999','3|£50,000 and over'] is the income bands for the households
- 'NumCarVan_B02ID' ['1|None','2|One','3|Two or more'] is the total number of cars and vans at the household of the respondent
- StageDistance is the stage distance in miles
- StageTime is the stage duration in minutes
- StageCost is the cost of a given stage (this data was unfortunately quite patchy, mostly because cost is often difficult to derive, for example for public transport if the respondent has a monthly pass, then giving the price of a single trip is not straightforward)

We also calculated average speeds for each stage from the available data (which we would need later on for additional calculations), and finally defined a filter to a) remove entries that were deemed low quality or had missing entries for important variables, and b) to only take into consideration entries from respondents that live in an urban area (here urban includes ‘Urban Conurbation’ and ‘Urban City and Town’, and excludes ‘Rural Town and Fringe’, ‘Rural Village, Hamlet and Isolated Dwelling’ and ‘Scotland’ according to the 2011 Census Output Area Classification variable Settlement2011EW_B04ID).

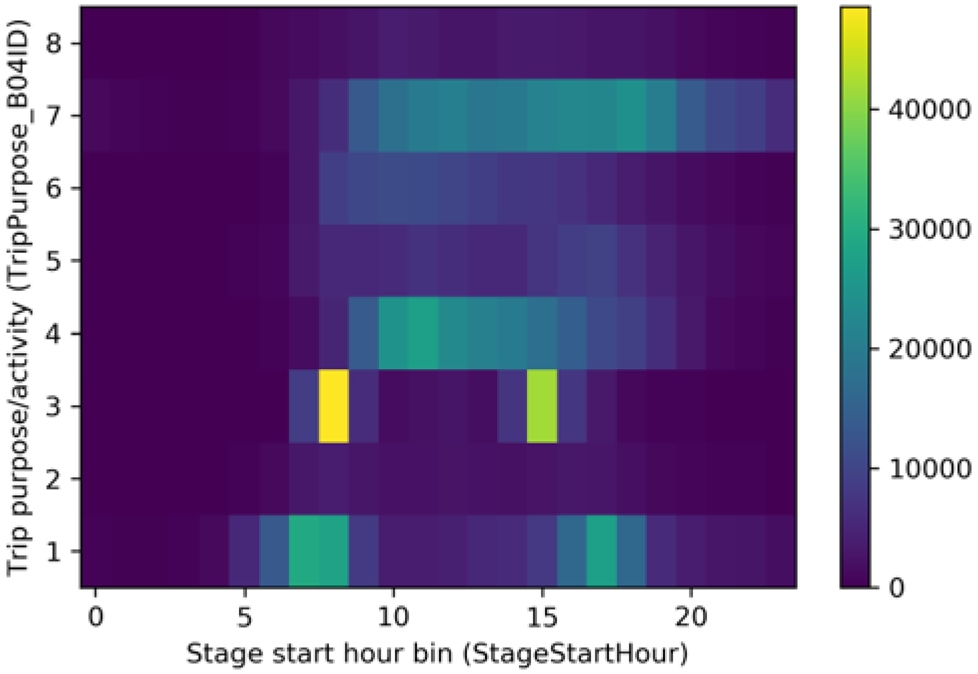

Figure 1-1: An example visualisation of the survey data, a 2D histogram showing a different temporal distribution of trips based on the corresponding activity. For example commuting trips and education oriented trips (purpose 1 and 3) group tightly around the morning and evening peak hours, while shopping and leisure (purpose 4 and 7) are more spread out during the day

This way we ended up with 806290 entries (stages) (For an illustrative visualisation of the data see Figure 1-1). For each stage, we have the following columns in the database:

Sex_B01ID, HHIncome2002_B02ID, Age_OD, NumCarVan_B02ID, TripPurpose_B04ID, StageStartHour_OD, StageDay_OD, StageTime, StageDistance, StageCost, StageMode_OD.

To make the dataset ready to be used in BIOGEME (see Section 1.1.2 for further details), we had to add some extra columns to the data. These columns were StageTime_i and StageCost_i for all i modes (so StageTime_1, StageTime_2, …, to StageCost_7), meaning that we calculated estimates for the stage durations and costs for all of the observed actual stages, but over other (non-observed, but assumed available) modes of transportation. In short we estimated how long a trip would have taken using a different mode, and what the involved cost would have been. This is necessary because, especially in an urban environment, most of the time many modes are available, and the choice is often made based strongly on travel time (which includes the combined effects of distance and average speed) and cost considerations, and these will be important parameters in the mode choice model.

To be able to estimate stage durations, we derived average speed functions (average speed in function of trip distance). We did this by fitting a scaled power function ($y = ax^b$) to the observed speed distributions (see example on Figure 1-2:) for each mode (except for walking, where we assumed a typical walking pace that is independent of the distance). Then durations could be simply calculated from distance (that was assumed to not change from the one of the observed stage and mode).

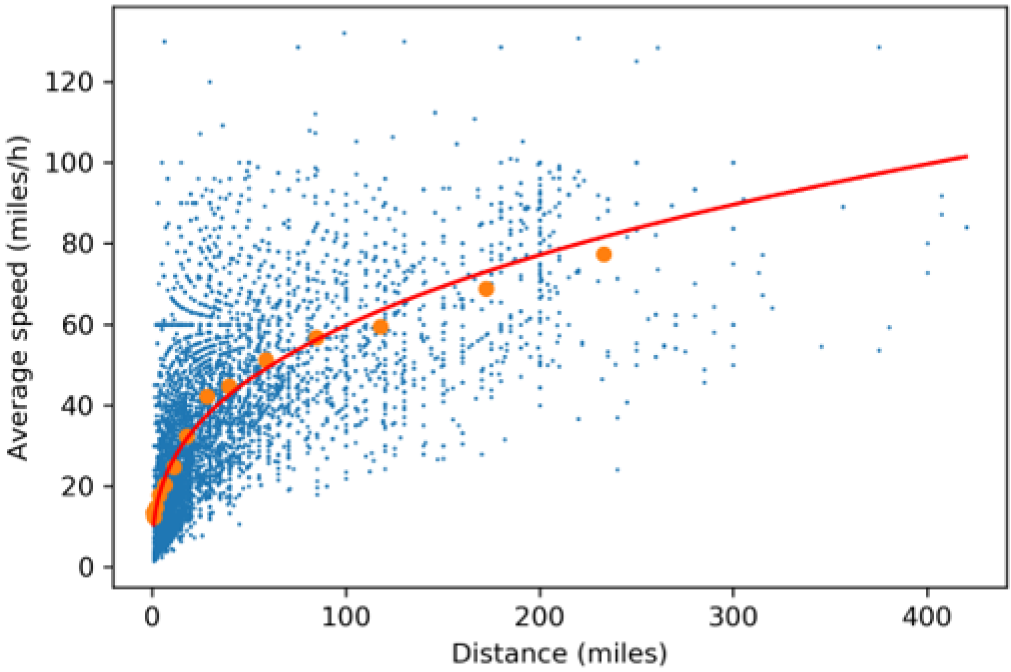

Figure 1-2: An example of the fitted average speed functions. Here we see the observed average speeds (in blue) of train and surface rail trips in the database. Orange dots represent averages in distance bins, and the red solid line is the fitted power law. It is clear that average speeds on long distance trains are much higher than on light rails or trams, especially since waiting times are also included in stage durations, and for a short stage the waiting time can be relatively longer compared to long stages.

First of all, observed costs are always kept as they are listed in the observed data. To calculate estimated costs for the non-observed modes, we use the following logic:

- Modes 1 and 2 (walking and cycling) are free.
- Mode 3 (car/van) has a constant price per mile, from TREMOVE (specific to urban traffic in the UK).
- For the rest of the modes, we calculate an average price per mile from all observed stages that have a non-zero price in the survey, and use these as constants.
- Moreover we assume that individuals that have reported zero costs on public transport stages own a pass, therefore any other theoretical public transport stage should be free for them.

Beyond this we also created some BIOGEME format-specific columns translating entries from earlier columns to a binary (0 or 1) format. For example a column Age_1 is 1 if Age_OD was 1, and 0 if Age_OD was anything else. Later this large data table (matrix) is simply referred as data in equations, and data['VARIABLE'] refers to the values of the column that corresponds to the given VARIABLE in the data matrix.

1.1.2 BIOGEME model

We use the package BIOGEME[3] (Pythonbiogeme[4] version 2.6a) to specify a suitable discrete choice model and estimate its parameters using a maximum likelihood estimation. For more details on the package and its usage we refer to the cited articles and websites.

After some initial tests (on the effect of including various number and selection of variables), we decided to include five variables in the model: duration (StageTime), cost (StageCost), number of cars or vans owned by the household (NumCarVan), purpose (TripPurpose), and age (Age).

The model is a logit model with 7 alternatives (seven modes of transportation), where the utility functions are defined as follows:

> V1 = ASC_1 + B_TIME * StageTime_1_SCALED + B_COST_1 * StageCost_1_SCALED + B_CAR_1_1 * NumCarVan_1 + B_CAR_M_1 * NumCarVan_M + B_MOTIV_2_1 * TripPurpose_2 + B_MOTIV_3_1 * TripPurpose_3 + B_MOTIV_4_1 * TripPurpose_4 + B_MOTIV_5_1 * TripPurpose_5 + B_MOTIV_6_1 * TripPurpose_6 + B_MOTIV_7_1 * TripPurpose_7 + B_AGE_2_1 * Age_2 + B_AGE_3_1 * Age_3 + B_AGE_4_1 * Age_4 + B_AGE_5_1 * Age_5
>
> V2 = ASC_2 + B_TIME * StageTime_2_SCALED + B_COST_2 * StageCost_2_SCALED + B_CAR_1_2 * NumCarVan_1 + B_CAR_M_2 * NumCarVan_M + B_MOTIV_2_2 * TripPurpose_2 + B_MOTIV_3_2 * TripPurpose_3 + B_MOTIV_4_2 * TripPurpose_4 + B_MOTIV_5_2 * TripPurpose_5 + B_MOTIV_6_2 * TripPurpose_6 + B_MOTIV_7_2 * TripPurpose_7 + B_AGE_2_2 * Age_2 + B_AGE_3_2 * Age_3 + B_AGE_4_2 * Age_4 + B_AGE_5_2 * Age_5
>
> …
>
> V7 = ASC_7 + B_TIME * StageTime_7_SCALED + B_COST_7 * StageCost_7_SCALED + B_CAR_1_7 * NumCarVan_1 + B_CAR_M_7 * NumCarVan_M + B_MOTIV_2_7 * TripPurpose_2 + B_MOTIV_3_7 * TripPurpose_3 + B_MOTIV_4_7 * TripPurpose_4 + B_MOTIV_5_7 * TripPurpose_5 + B_MOTIV_6_7 * TripPurpose_6 + B_MOTIV_7_7 * TripPurpose_7 + B_AGE_2_7 * Age_2 + B_AGE_3_7 * Age_3 + B_AGE_4_7 * Age_4 + B_AGE_5_7 * Age_5

All ASC (alternative specific constant) and B_ (beta) parameters are the ones that need to be estimated using BIOGEME. Some of these is set and fixed to zero during the model specification process, while others are let to vary.

After running BIOGEME we obtained 74 estimated parameter values, these are listed (along with their error estimates, and a few statistical test values) in Section 1.2. The resulting model has a Rho-square of 0.566.

While the resulting model behaves very well on a global level (it recreates the observed trip distributions over the various modes perfectly well), it has its shortcomings too. As mentioned earlier we did not specify the availability of each alternative separately partly due to lack of

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[3] Bierlaire, M. (2003). BIOGEME: A free package for the estimation of discrete choice models , Proceedings of the 3rd Swiss Transportation Research Conference, Ascona, Switzerland. http://transp-or.epfl.ch/pythonbiogeme/

[4] Bierlaire, M. (2016) PythonBiogeme: a short introduction. Report TRANSP-OR 160706 ,Series on Biogeme. Transport and Mobility Laboratory, School of Architecture, Civil and Environmental Engineering, Ecole Polytechnique Fédérale de Lausanne, Switzerland.

data, and the (non-observed) alternatives have estimated travel durations and costs in our input data file. Nevertheless the resulting parameters make sense, and the output model behaves and reacts to changes in the input variables as one would expect. Of course since there is a huge difference in the number of observed modes in the input data (see Figure 1-3), some modes are modelled more reliably than others.

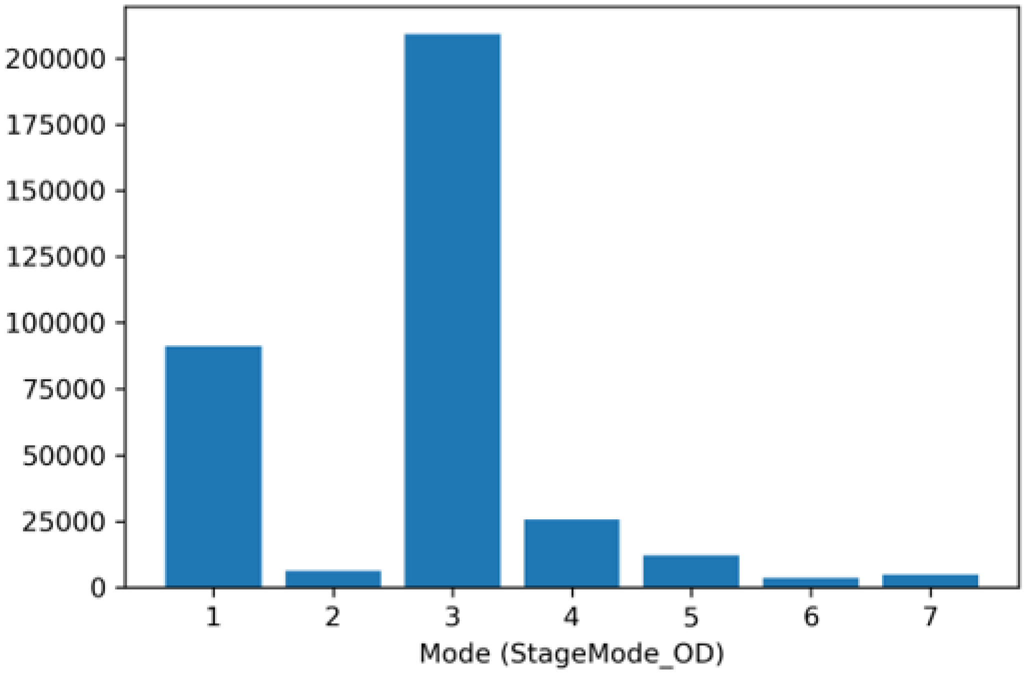
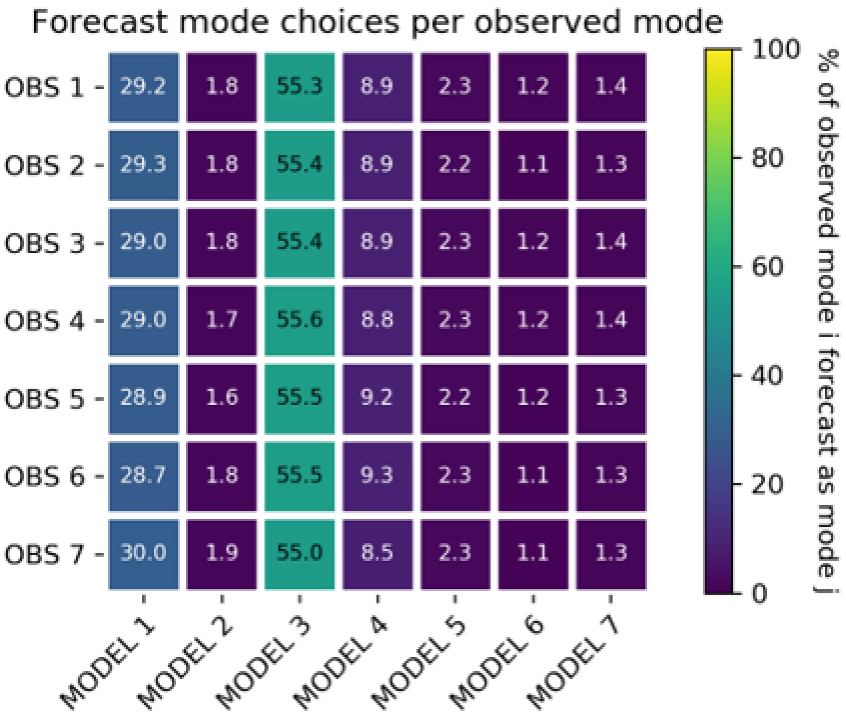


Figure 1-3: Histogram of all stages in the database showing the dominancy of car trips (mode 3) and walks (mode 1)

A good test of the mode choice model is evaluating the model on the actual observed travel behaviour, and comparing the modelled mode choice with the observed one. To illustrate this, consider the following: if we were to specify a logit model where each utility function is a constant (V1 = ASC_1, V2 = ASC_2, etc.) then the model would return the same chance prediction for any stage. Looking at the model evaluations stage-by-stage we would see large errors (a mismatch between predicted and observed modes) everywhere, but looking at the overall result, we would see that the total predicted trip distribution by mode matches the observed distribution – since we calibrated the model to that. (See visualisation in Figure 1-4)



	MODEL 1	MODEL 2	MODEL 3	MODEL 4	MODEL 5	MODEL 6	MODEL 7
OBS 1	29.2	1.8	55.3	8.9	2.3	1.2	1.4
OBS 2	29.3	1.8	55.4	8.9	2.2	1.1	1.3
OBS 3	29.0	1.8	55.4	8.9	2.3	1.2	1.4
OBS 4	29.0	1.7	55.6	8.8	2.3	1.2	1.4
OBS 5	28.9	1.6	55.5	9.2	2.2	1.2	1.3
OBS 6	28.7	1.8	55.5	9.3	2.3	1.1	1.3
OBS 7	30.0	1.9	55.0	8.5	2.3	1.1	1.3

Figure 1-4: A visualisation of the mode choice of a toy model with only alternative specific constants. Clearly no matter what the observed mode was, the forecast mode distributions are the same, since the utility functions are constant

Therefore the total distributions will always match, but including more and more parameters we try to uncover differences in the behaviours connected to different modes. For example that people have different perceived time costs across the various modes, or that people with different purposes or age groups have different preferences. The more predictable people are (and the more suitably specified our model is) the better the match between predicted and observed mode choices will be.

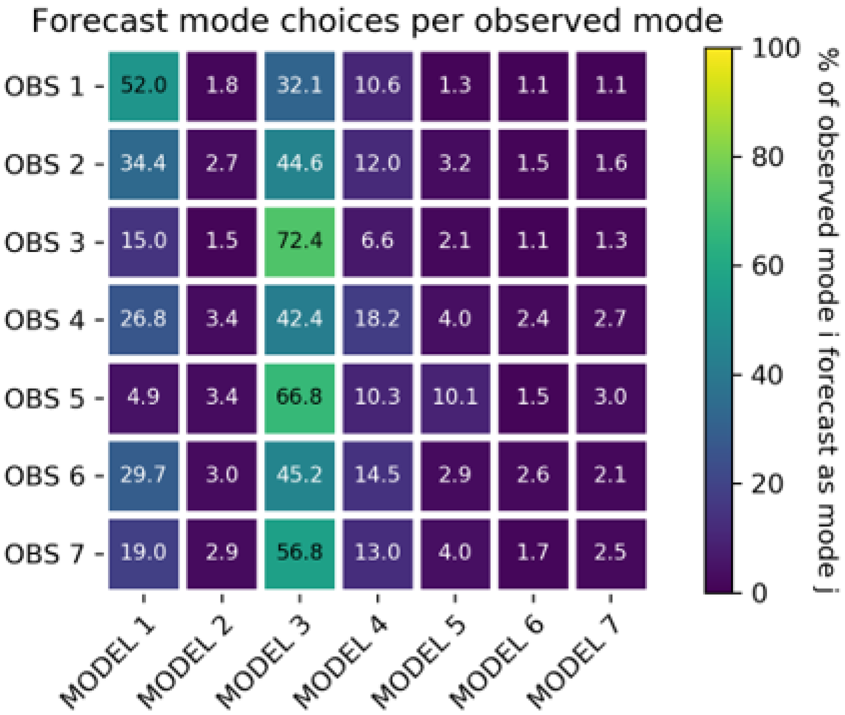


Figure 1-5: Visualisation of the mode choice per observed mode for the final model.

Figure 1-5 is equal to Figure 1-4 but for our final model. In an optimal world (all modes always available, model perfectly specified, and people make fully rational decisions at all times) all diagonal cells would be 100%. We see that 72.4% of stages that are observed as car stages were also predicted to be car stages. This value for walks in 52%, while for example 32.1% of walks is predicted to rather happen as a car drive. The matches are generally worse for modes where availability of actual observed stages was much more limited.

We can see on

Figure 1-5 that our model works best in predicting car trips, but for example predicting an actual bike trip is very difficult. This is partly because there are very few bike trips in the input data set, partly because bike usage is probably influenced by variables that are not included in our model.

To illustrate how we would use this model consider the following example: let’s assume a policy that aims to reduce the public transport prices by 50%. To test the effect of such a measure we would evaluate the mode choice model on the observed database of stages, but first modify the price variable of all stages where the mode was public transport with a 0.5 multiplier. Since price has a negative beta in the mode choice model, this means that a lower price results in a higher utility value for public transport modes, therefore the chance that the chosen mode is public transport will grow.

1.2 Integrated model

The development of an integrated module for Bristol, in the same way as for Amsterdam, has not been possible. The reason has been the lack of access to activity and mobility data. However, we have been able to simulate household energy use, by means again of a synthesized population. The Bristol synthetic population was generated combining 2011 Census data with data from the Living Costs and Food Survey. This latter survey collects information on spending patterns and the cost of living that reflect household budgets. It is conducted throughout the year, across the whole of the UK, and is the most significant survey on household spending in the UK. The survey provides essential information for various social and economic measures, most them not relevant to the purposes of our work. However, it contains enough socio-economic and demographic data to be able to be use in conjunction with the data from the UK Census. Fortunately, as it contains data on household expenditure, some of these expenditure data pertain to energy.

The synthesis process emulated the one of Amsterdam, resulting in a synthetic population of approximately 188.000 households. This was generated using the IPU algorithm and constraints variables from the 2015 Bristol census data. The data include information on central heating, fuel use (in case of central heating), dwelling type, tenure, vehicle ownership, household composition (size and members by age), as in Table 1-1.

Table 1-1: 2015 Bristol census data

Variable Name	Description	Notes
electricity	Dummy - central heating fuel type	
gas	Dummy - central heating fuel type	
solid_fuel	Dummy - central heating fuel type	
oil	Dummy - central heating fuel type	
two_types_chfuel	Dummy - Two types of central heating fuel	
other_chfuel	Dummy - Other central heating fuel	
detached	Dummy - Residence type	
semi_detached	Dummy - Residence type	
flat	Dummy - Residence type	
other_dwelling_type	Dummy - Residence type	
tenant	Dummy - Ownership status	
owner	Dummy - Ownership status	
rent_free	Dummy - Ownership status	
no_vehicle	Dummy - possession of vehicle in the household	
one_vehicle	Dummy - possession of vehicle in the household	
two_more_vehic	Dummy - possession of vehicle in the household	
total_number_of_dwellings	Total number of dwellings	
zone	City zone number	
hhid	Household ID	
numless_5	Number of children under 5 years olf	
between5and44	Number of household members between 5 and 44	

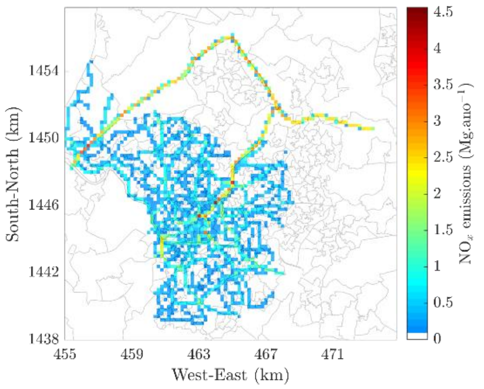
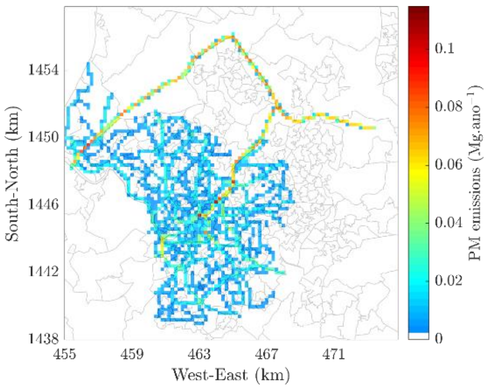
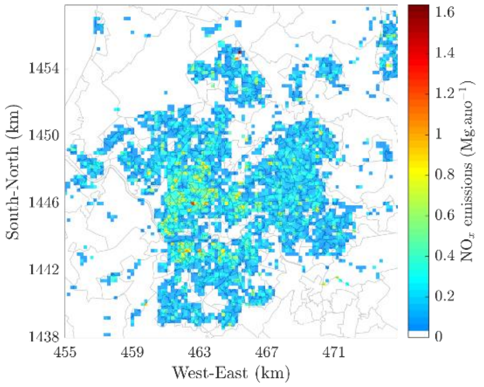
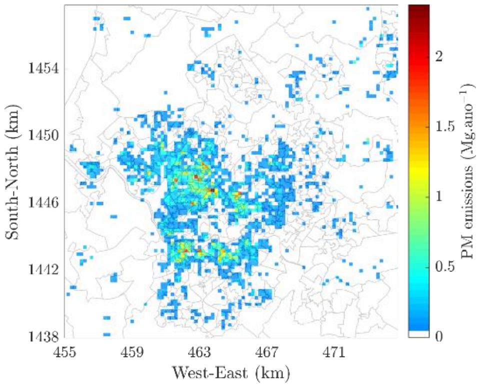
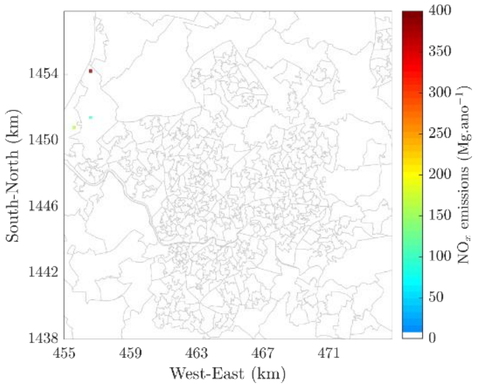
between45and64	Number of household members between 45 and 64	
above64	Number of household members above 64	
code	Area Code	
oil_use_GJ	Household oil consumption	
gas_use_GJ	Household gas consumption	
wood_use_GJ	Household wood consumption	
lon	Longitute of household	simulated
lat	Latitute of household	simulated
no_central_heating	Dummy - household has not cetrnal heating	
gas_use_m3	Household gas consumption	
oil_use_m3	Household oil consumption	
electr_kwh	Household electricity consumption	predicted

Fuel use was made consistent with TECHNE's LSOA-level emissions using the emission factors from the document uploaded to the data portal by TECHNE (ECH.MA.15 - WP5 IRC Rev1 .pdf). Electricity use was predicted on the basis of a linear regression model of electricity expenditure from the LCFS and adjusted to conform to total electricity use from the 2015 Bristol Census. Latitude and longitude coordinates were simulated using a random sampling technique, sampling within residential areas from the COPERNICUS urban atlas.

1.3 Air quality modelling

1.3.1 Annual emissions input of AQ simulations

Figure 1-6 shows the emission values for NOx and PM in Mg.year^{-1} for each sector.

	NOx	PM
Transport		
Commercial and Residential		
Industrial point		

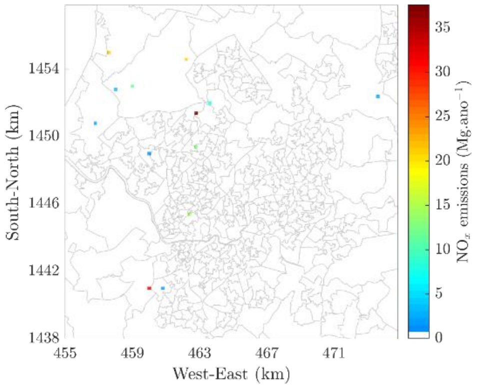
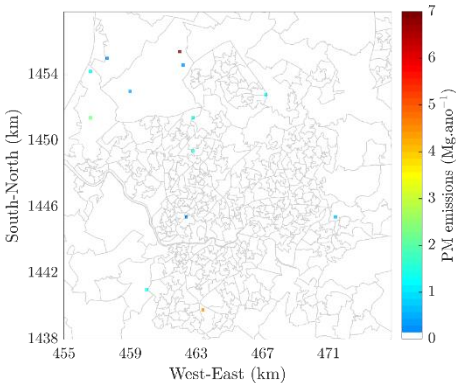
Industrial area		

Figure 1-6: Emission values for NOx and PM by sector, in Mg.year^{-1}.

The absence of PM industrial point sources indicates that the industrial sources were all assumed as area sources due to the annual emission rate being lower than 100 Mg.year^{-1}, as established by ClairCity.

1.3.2 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, a procedure was defined to account for the background concentrations and other remaining sources, following the background concentration maps published by the UK's Department for Environment Food & Rural Affairs (DEFRA). The background air pollution maps made available by DEFRA are the total annual mean concentrations based on modelled data on 1 km x 1 km grid squares. The background concentrations added to the NO_2 concentrations simulated with URBAIR model included the contributions from the following categories: aircraft, rail, other and rural, while for PM_{10} and $PM_{2.5}$ the added background accounted for the following categories: rail, other, secondary PM, residual and salt.

Figure 1-7 shows for each pollutant the background concentration maps added to the simulated results.

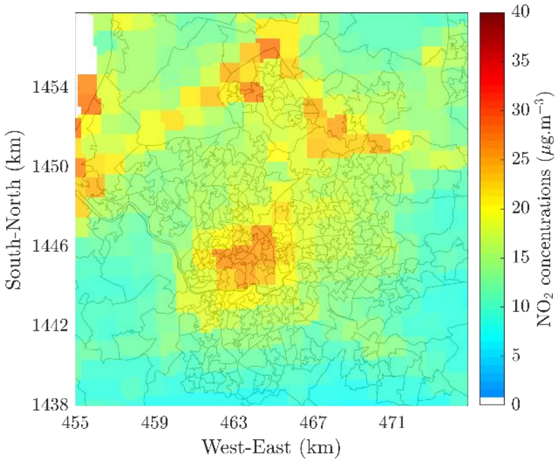
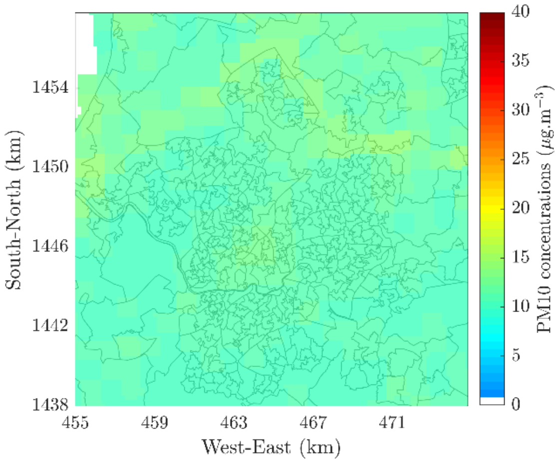
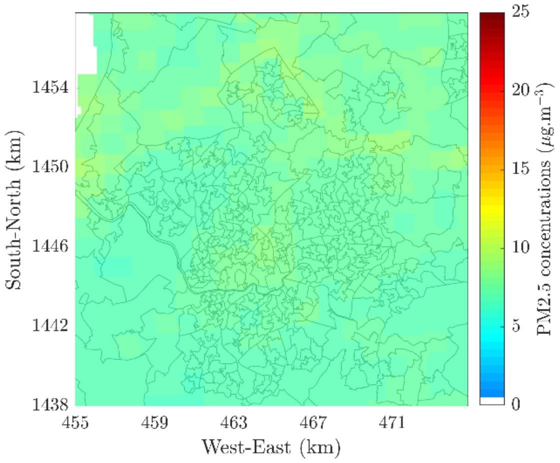
NO_2 concentrations	
PM_{10} concentrations	
$PM_{2.5}$ concentrations	

Figure 1-7: NO_2, PM_{10} and $PM_{2.5}$ background concentrations added to the simulated results with URBAIR model.

1.3.3 Summary of measuring data

In order to compare and calibrate the modelling results for the year of 2015, for NO_2 a total of 107 diffuse tubes were used combined with 5 continuous measuring points (2 Urban Background, 2 Roadside and 1 Kerbside). For PM_{10} and $PM_{2.5}$, the modelling results could only be compared with 1 continuous monitoring site, the St. Pauls station which is an urban background station type, which is part of the Automatic Urban and Rural Network (AURN), the UK's automatic monitoring network used for compliance reporting.

Figure 1-8 shows the location of the equipment providing continuous measurements, with the NO_2 concentrations in $\mu g.m^{-3}$ measured in 2015, a) by the diffusion tubes and b) by the continuous monitoring equipment. Figure 1-8-b is a zoomed area of the city center where the continuous sites are located.

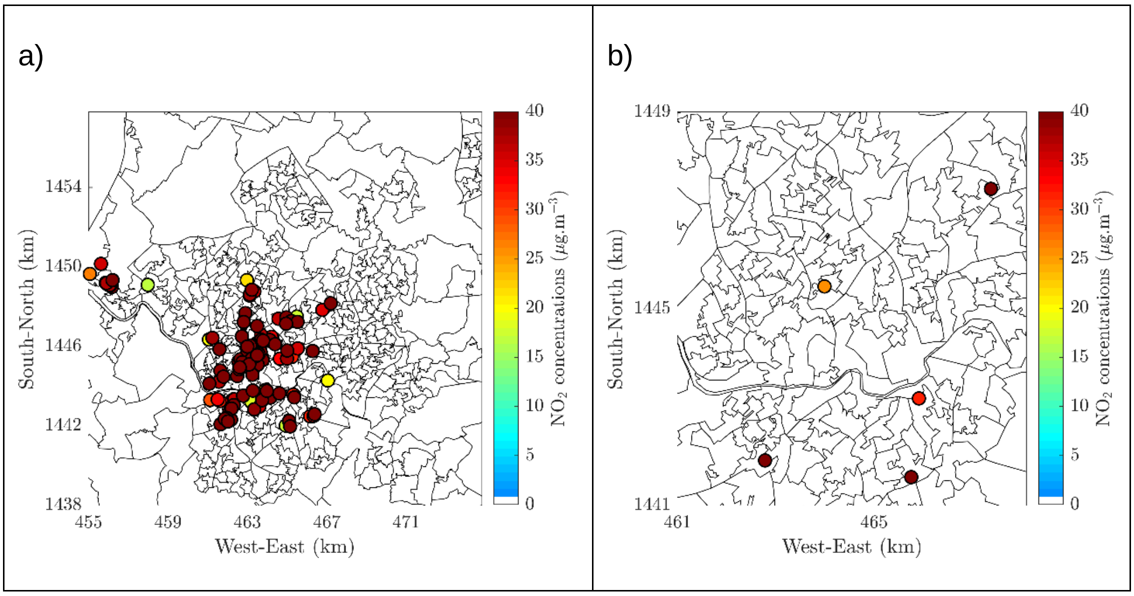


Figure 1-8: Summary data for 2015 with the location of the measurement points: a) the diffusion tubes with information about the annual average of the NO_2 concentrations in $\mu g.m^{-3}$; b) the continuous monitoring sites with information about the annual average of the NO_2 concentrations in $\mu g.m^{-3}$.

The majority of the diffusion tubes are located within the city center, providing a good overview of the NO_2 concentrations in areas most influenced by road traffic The maximum value monitored in 2015 by the diffusion tubes is 91.2 $\mu g.m^{-3}$, while for the continuous sites is 44.2 $\mu g.m^{-3}$.

1.3.4 Adjustment procedure

The adjustment procedure is based on the linear regression between the measurements, including the continuous and diffusion tubes, 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 all the domain.

For NO_2 concentrations, the slope obtained from the linear regression is equal to 1.62. For PM_{10} concentrations the resulting slope is equal to 0.85 and for $PM_{2.5}$ the slope is 0.92.

2 Description and modelling of the scenario's

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

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

This section mainly describes the assumption made in the modelling to estimate the scenarios

The SDW resulted in three proposed scenarios which differ mainly in the strength 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. Some policies are not modelled separately but their effect is taken into account within (as an enabler) others, and the modelling approach might slightly differ from the initial definition when it was deemed necessary (to match our modelling tools or experience with real cities and their possibilities better – by revising impossible timelines, or by modifying some of the measures slightly).

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

Policy	Scenario 1	Scenario 2	Scenario 3	Final Scenario
Ban/phase out most polluting vehicles (not just charge more)	Total ban of polluting vehicles from Bristol/Greater Bristol (Diesel and IC) Taper from clean air zone, to congestion charge, to total ban increasing vehicles included in ban up to 2030 - Euro 5 to Euro 6 to Evs.	Based on real world emissions - should include diesel cars. Phased approach. Ban diesel vehicles including cars and buses. (2023)	Ban all diesel cars and trains, but phase out diesel buses more gradually. (2018)	2023 ban Euro 5 and worse diesel (euro 4 and worse for Petrol); Full ban on diesel and petrol cars by 2030.

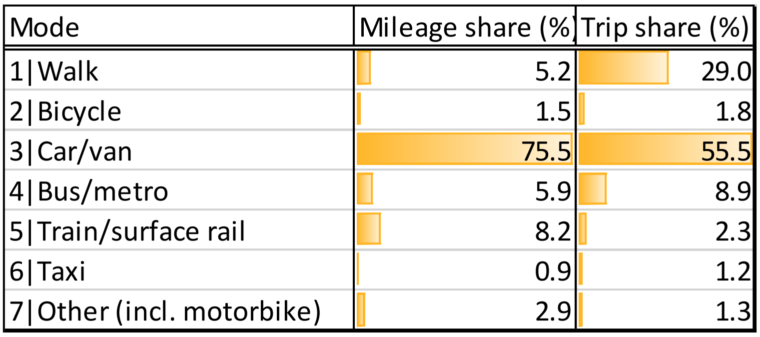
Cheaper public transport	Cheaper/affordable bus fares relative to car ownership and clean air/congestion charging costs (2023)	Free for school kids - under 18. More attractive than the unsustainable alternatives. Free on bad air days sooner than 2028. (2020)	First mile - Bristol will have a policy that will give people free/cheap transport to the bus station. Bus fares - low flat fare (£1-2). (2018)	£1 flat fare for as of 2025 for buses and Park and Ride.
Create good alternatives to car use - walking & cycling infrastructure	Create segregated cycle routes e.g. Gloucester road with no parking allowed, create segregated walking routes, increase pedestrian access to shopping centres, Double Bristol - Bath cycle path (2030)	People must feel safe. Be like Copenhagen and Amsterdam. But better than Amsterdam for walking. More space so it feels safe and welcoming. 80% trips sustainable transport. (2025)	Local Emission Mobility as a Service (MaaS) (Car club). Segregated subjectively safe cycle path. Safe walking environment (by extending 20 mph speed limits across the city). (2025)	65% sustainable travel (active + buses) by 2030,
Make bus cleaner and greener	Buses electric, hydrogen or biofuel (2023)	Not diesel. Electric if possible and biomethane. Evidence led approach in terms of technology being used to make cleaner/greener. (2023)	Electric hybrid/Hydrogen fleet. Enforce green wave traffic lights (SCOOT) across Bristol. (2027)	Bus fleet Euro-6 diesel as of 2023; Model 2035 100% LNG.
Improve energy efficiency of housing (rented/existing/new)			Ban all new developments from solid fuel. (2018)	Carbon neutral by 2030.
Charge older/more polluting vehicles entering the city	Enabler for Ban/phase out most polluting vehicles (2020)		(2020)	1£ congestion charge. (2027)
Reducing private vehicle road space - increase public transport space		Keep road space for essential user groups only. Deliveries included. (2025)	Create more shared/flexible transport - should happen gradually to counter opposition. (2025)	(2030)
Promote electric vehicles	Develop charging infrastructure using street lighting (don't sell off), Bristol energy deliver EV charging system and control local distribution. (2030)		(2025)	All public sector vehicles electric by 2025.
Increased generation of solar and wind power	Require new developments (no date)		Example enabler/policy: Build integrated PVs in new developments, discourage/ban wood burners. (2026)	To be modelled along with the improved energy efficiency and housing policy.
Make property developers consider air pollution and climate change			Example enabler/policy: Build housing close to major employment zones. (2030)	Only included in qualitative policy discussion.

Spread economic opportunities across different areas of the city			People living closer to their employment reduces travel (pollution) and opens employment opportunities to more people e.g. with caring responsibilities. (2030)	Reduce commuting distances. (2030)
Improve walking environment in Bristol			(2035)	
Awareness raising to promote active travel and public transport	Enabler for Ban/phase out most polluting vehicles (2030)			
Build housing close to major employment zones	Stronger planning locally (no date)			

2.1 Transport

2.1.1 Baseline and BAU

The baseline modal share (and mileages by mode) is according to the observed shares in the processed and filtered National Travel Survey data as discussed in Section 1.1.1 – see Figure 2-1.



Mode	Mileage share (%)	Trip share (%)
1|Walk	5.2	29.0
2|Bicycle	1.5	1.8
3|Car/van	75.5	55.5
4|Bus/metro	5.9	8.9
5|Train/surface rail	8.2	2.3
6|Taxi	0.9	1.2
7|Other (incl. motorbike)	2.9	1.3

Figure 2-1: Mileage and trip share in the National Travel Survey data (after filtering)

The baseline fleet and vehicle kilometre demand is according to our original MOVEET model. In the BAU there is no change assumed in the modal split, and the fleet evolves in agreement with the Under 100 scenario from McKinsey&Company: *Boost! Transforming the powertrain value chain – a portfolio challenge*.

Proposed Scenario 1

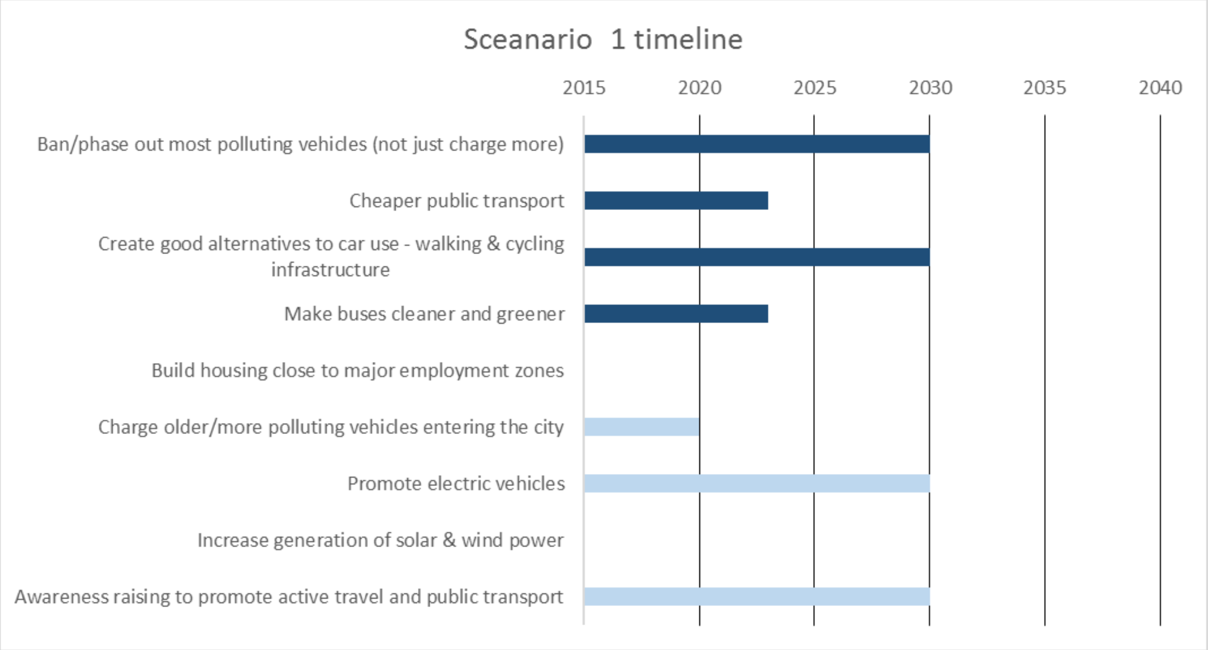


Figure 2-2: Overview of the Scenario 1 timeline.

Ban/phase out most polluting vehicles (not just charge more): we model the effect of this policy by measures in the fleet model. We keep the Under 100 baseline, but make the following changes:

Scrappage is modelled in multiple steps (which is often observed in actual bans lately in several European cities), based on vintage (e.g., the registration of Euro 5 diesel vehicles started in January 2011[5], so we assume that all cars registered before 2011 were Euro 4 or worse, etc.):

- 2020 ban Euro 3 and worse diesel (Euro 2 and worse for Petrol)
- 2025 ban Euro 4 and worse diesel (Euro 3 and worse for Petrol)
- 2030 ban Euro 5 and worse diesel (Euro 4 and worse for Petrol)

Modelling such forced scrappage is easy in the fleet model, simply setting the survival rate to zero for the vintages that need to be scrapped at the end of a given year. For example, in 2020 we ban Euro 3 diesel, which means that at the end of 2019 we need to scrap all diesel cars that are older than the oldest Euro 4 diesel car. Of course due to the nature of our fleet model such scrappage can create shocks in the demand gap (and then this gap being filled by a much larger than usual amount of new vehicles), but implementing a gradual scrappage means that this is limited and does not influence the calculations significantly.

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[5] https://www.acea.be/industry-topics/tag/category/euro-standards

Cheaper public transport: this is mainly a mode choice influencing policy, therefore we use our mode choice model to test its effects. We do the following changes:

- Scale public transport (train not) prices x0.8
    - This means that during the evaluation of the mode choice model we multiply all public transport stage prices by 0.8, which positively influences the utility of public transport options, therefore more people will choose these, while for example car usage will slightly drop.
- As a balancing measure we also add a 1 GBP per trip for cars (count it as tax revenue from 2023 in the MOVEET cost calculations too)
    - While not strictly the topic of this exercise, we calculated that the original observed car/van cost per stage was 3.25 GBP for an average stage of 7.91 miles, which is 0.41 GBP/mile. With the extra GBP per trip the observed rate would be 0.54 GBP/mile, meaning that on average the variable cost of cars grows by 31%. Of course the growth is much more significant for short trips (since the charging is per trip and not per mile), which causes a stronger shift away from cars for short trips than for long ones.
- In the model this means[6]:
    - StageCost_3 = data['StageCost_3'] +1
    - StageCost_4 = data['StageCost_4'] *0.8

Create good alternatives to car use – walking and cycling infrastructure: This is a policy that aims to boost the share of slow modes, but an improvement of such infrastructure is very difficult to translate to model parameters. These kind of policies boost the attractiveness of walking and cycling (but will not change the average speed or the monetary aspects of them), so we can only translate this to a growth of the corresponding alternative specific constants in the utility functions. The only thing to note here is that in this case we need to pick goal values for the modal shares of walking and cycling, and change the ASC values accordingly, which is the other way around of the effect of a price change, where we know the actual measure, and the resulting modal shift is a consequence. Since most policy workshops did not provide goals along with these kind of policies, we had to rely on our own experience to pick values that are reasonable in a given situation and in line with the ambition level of a given scenario.

- We choose to set the ASCs of walking and cycling to bring up cycling (that was observed to be only 1.8%) to half of what is typical in The Netherlands (26.1%), while keeping walking on the observed 29% level, or at least above the Dutch value (26.1%).
- In the model:
    - ASC_2 = ASC_2+2.2

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[6] We give these equations throughout the text as they would appear in our python code. Most of the time this is understandable for the reader without any knowledge in the programming language since simple arithmetic conventions are kept in the code too, and the variables were all explained in earlier Sections of the text. Should an equation need comments they are given in line after a # character (that denotes that anytthing that follows later is a comment and not part of the code).

To calculate the actual results for the reporting years, we evaluate the modified mode choice model at the three reporting years of 2025, 2035, and 2050, always including all active modifiers (based on their individual timelines). We compare the mileages per mode to the baseline mileages, and their ratio provides a multiplier for calculating the final per mode emissions. For example, for cars we get emissions from MOVEET for any given year, and then we need to scale these emissions according to the change in car driven mileage coming from the mode choice calculations. The MOVEET calculations make sure that the original demand change, the change in fuel efficiency, carbon content, emission factors, and so on are all taken into account, while the change in mileage in the mode choice tells us how much less (or more) people will drive compared to the expected amount, which then scales the emission results from MOVEET.

2.1.2 Proposed Scenario 2

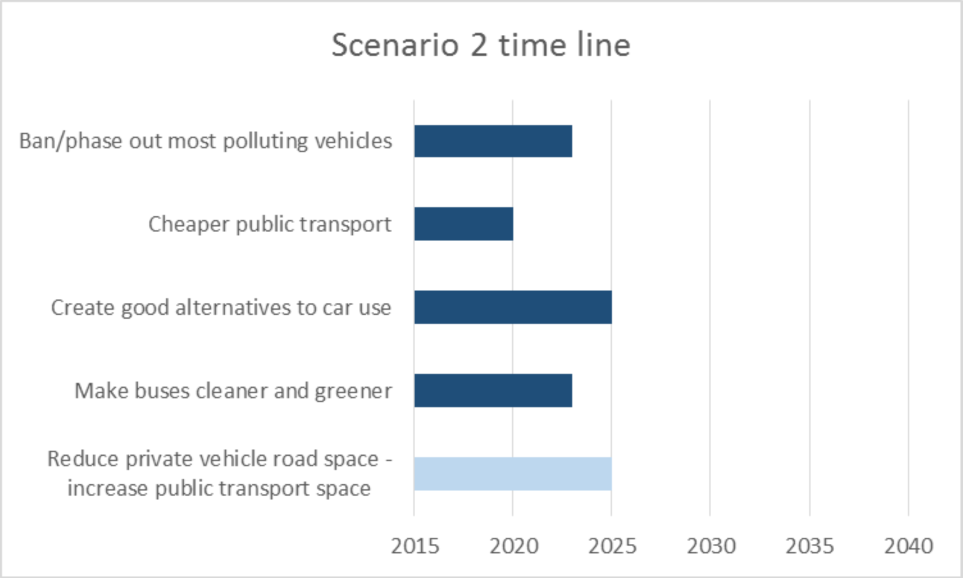

Figure 2-3: Overview of the Scenario 2 timeline.

Ban/phase out most polluting vehicles (not just charge more): The implementation is the same as in Scenario 1 but with a different timeline:

- 2019 ban Euro 3 and worse diesel (euro 2 and worse for Petrol)
- 2021 ban Euro 4 and worse diesel (euro 3 and worse for Petrol)
- 2023 ban Euro 5 and worse diesel (euro 4 and worse for Petrol**)**

Cheaper public transport: As an extra to what is done in Scenario 1, we make public transport free for everybody under the age of 16, and also for everyone whose motivation is education. This way we are catering to not only all the young people, but also cover a lot of high school or university students, who will have passes or significantly reduced fares at least on their home-school trajectory.

- In the model:
    - StageCost_3 = data['StageCost_3'] +1
    - StageCost_4 = data['StageCost_4'] *0.8

    - StageCost_4[Age_OD==1]=0 #For everyone under 16 bus/metro is free
    - StageCost_4[TripPurpose_B04ID==3]=0 #For everyone that is taking the public transport for education it is free

Create good alternatives to car use – walking and cycling infrastructure: similar to as in Scenario 1, but with the goal of matching the Dutch level for cycling (instead of reaching only half of it).

- In the model (this time we also need to make walking more attractive otherwise the share of walking drops because of the growth in cycling):
    - ASC_1 = ASC_1+0.35
    - ASC_2 = ASC_2+3.30

Proposed Scenario 3

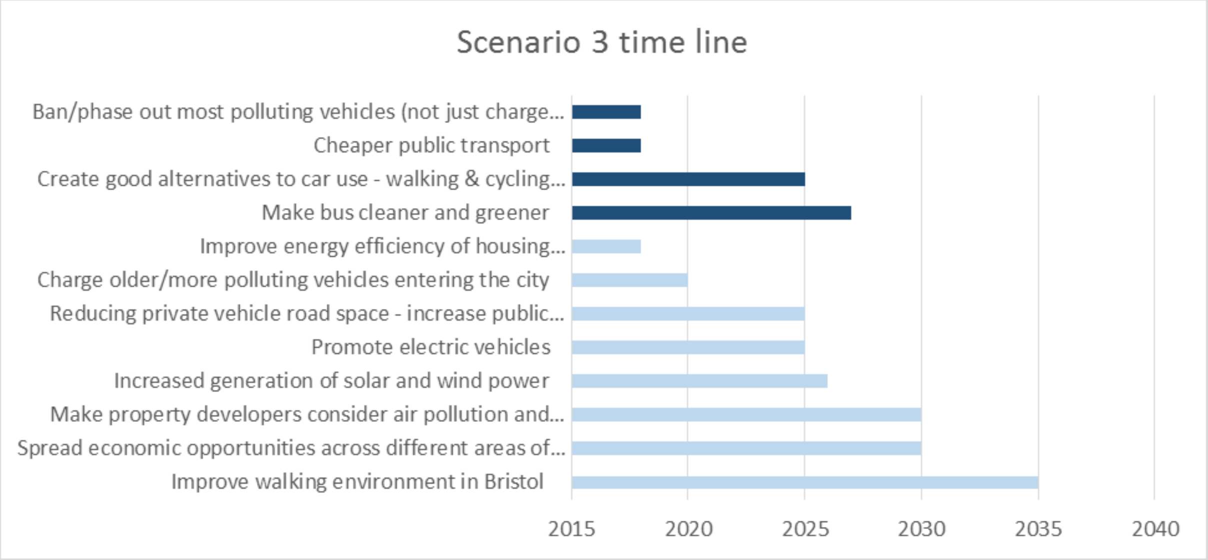

Figure 2-4: Overview of the Scenario 3 timeline.

Ban/phase out most polluting vehicles (not just charge more): here we set the fleet sale shares according to the Under 40 scenario in McKinsey&Company: *Boost! Transforming the powertrain value chain – a portfolio challenge* to represent the faster uptake of electric vehicles caused by the extra policy promoting them. We also implement a faster and more radical scrappage scheme:

- 2019 ban Euro 4 and worse diesel (euro 3 and worse for Petrol)
- 2021 ban Euro 5 and worse diesel (euro 4 and worse for Petrol)
- 2023 ban Euro 6 and worse diesel (euro 5 and worse for Petrol)
    - When Euro 6 diesel is banned that means that no diesel vehicle sales are possible anymore, so we set the sales of diesel vehicles to zero (by setting the preference parameter in the utility function of diesel vehicles to -9999).

Cheaper public transport:

- Flat 1 GBP rate for all trips from 2018

- The same 1 GBP per stage charge for cars as before.
- In model:
    - StageCost_3 = data['StageCost_3'] +1
    - StageCost_4 = np.ones_like(StageCost_3) #Flat 1 pound rate for all trips on public transport

Create good alternatives to car use – walking and cycling infrastructure: the modelled effects are the following

- Match the share of active modes with the shares observed in The Netherlands
- Lengthen the duration of car based trips by a multiplier of 1.5 (because of the speed limit plus city reorganisation, etc.)
- Make public transport faster (an improvement in network organisation, better infrastructure, etc.) by setting a multiplier of 0.8 for the duration of PT stages.
- 2025 time horizon
- In the model this means:
    - ASC_1 = ASC_1+0.35
    - ASC_2 = ASC_2+3.17
    - StageTime_3 = data['StageTime_3'] *1.5
    - StageTime_4 = data['StageTime_4'] *0.8

Spread economic opportunities across different areas: The main idea behind this measure is making it possible for people to cut down on their commuting distances by making sure that offices are better spread out in the city. We simply model this measure by scaling the distance of commuting trips by 0.75.

- In the model this is a bit more complex, since we actually need to calculate the duration of the stages over the new modified distances, since average speed depends on distance, therefore duration cannot be scaled linearly with distance (modeaveragespeed_fromfun here is a lookup function that calculates the average speed according to the average speed function – see Section 1.1.1 – of the given mode, for a given distance):
    - StageDistanceMultiplier = 0.75
    - StageTime_1[TripPurpose_B04ID==1] = (StageDistance[TripPurpose_B04ID==1] * StageDistanceMultiplier / modeaveragespeed_fromfunc(StageDistance[TripPurpose_B04ID==1] * StageDistanceMultiplier,1))*60.
    - StageTime_2[TripPurpose_B04ID==1] = (StageDistance[TripPurpose_B04ID==1] * StageDistanceMultiplier / modeaveragespeed_fromfunc(StageDistance[TripPurpose_B04ID==1] * StageDistanceMultiplier,2))*60.
    - StageTime_3[TripPurpose_B04ID==1] = (StageDistance[TripPurpose_B04ID==1] * StageDistanceMultiplier / modeaveragespeed_fromfunc(StageDistance[TripPurpose_B04ID==1] * StageDistanceMultiplier,3))*60.
    - StageTime_4[TripPurpose_B04ID==1] = (StageDistance[TripPurpose_B04ID==1] * StageDistanceMultiplier /

modeaveragespeed_fromfunc(StageDistance[TripPurpose_B04ID==1] * StageDistanceMultiplier,4))*60.

  - StageTime_5[TripPurpose_B04ID==1] = (StageDistance[TripPurpose_B04ID==1] * StageDistanceMultiplier / modeaveragespeed_fromfunc(StageDistance[TripPurpose_B04ID==1] * StageDistanceMultiplier,5))*60.
  - StageTime_6[TripPurpose_B04ID==1] = (StageDistance[TripPurpose_B04ID==1] * StageDistanceMultiplier / modeaveragespeed_fromfunc(StageDistance[TripPurpose_B04ID==1] * StageDistanceMultiplier,6))*60.
  - StageTime_7[TripPurpose_B04ID==1] = (StageDistance[TripPurpose_B04ID==1] * StageDistanceMultiplier / modeaveragespeed_fromfunc(StageDistance[TripPurpose_B04ID==1] * StageDistanceMultiplier,7))*60.

2.1.3 Final Scenario

We calculate with two fleet models for the final scenario, a base and a version B. Latter is valid for the zone outside the low emission zone. Below we list the policies that had an effect on transport along with the corresponding modelling approach that we used to model them one-by-one.

Ban polluting cars: the effects of this policy were modelled on the fleet level. First or all, we changed the underlying assumption on the fleet evolution, since an announced ban parallel with incentives (subsidies, advertisement, environmental considerations, etc.) will boost the uptake of vehicles with electric and hybrid powertrains. Therefore, we set the sale shares according to a mixture between the Under 40 and Under 10 scenarios with the sales of hybrid (HEV) vehicles temporarily boosted by the sudden ban of internal combustion engine (IC) vehicles

Scrappage is modelled in multiple as before:

- 2019 ban Euro 3 and worse diesel (Euro 2 and worse for Petrol)
- 2021 ban Euro 4 and worse diesel (Euro 3 and worse for Petrol)
- 2023 ban Euro 5 and worse diesel (Euro 4 and worse for Petrol)

As an extra step, in 2030 we ban all IC vehicles. This is implemented by scrapping out all ICE vehicles at the end of 2029 and banning all IC sales starting in 2030.

This results in an extremely strong effect, since originally in 2029 still 73% of the fleet is IC, and almost 40% of sales is IC. So, to make things a bit more realistic we need to modify the sales in the 5 years leading up to the ban so that in 2029 basically nobody is buying an IC car anymore. Even so, 66% of the fleet in 2029 is still IC. Therefore, we note that it is very unrealistic to assume that a full ban would be possible without any supporting incentives. Another effect is a boost in hybrid sales around these bans as IC vehicles do not seem so attractive anymore, by pure battery electric (BEV) vehicles are not fully accepted yet (or are still too expensive), therefore people are choosing an in-between solution.

In version B valid for the zone outside of the low emission zone we apply a smooth scrappage strengthening in the 5 years starting from 2030 (2029, since that is scrappage from 2029 to 2030) where the original scrappage values if IC cars are multiplied by a factor every year that is a linearly interpolated value between 1 (for Age0) and 0.8,0.6,0.4,0.2,0 (at Age29) depending on the year. This creates a nice and smooth transition.

Make public transport 50% cheaper: this is modelled in the mode choice model by using a multiplier of 0.5 on the Bus/metro prices. This is the only policy affecting the 2025 reporting year (on the mode choice side).

- In the model:
    - StageCost_4 = data['StageCost_4'] * 0.5

Congestion charge: as in the proposed scenarios, we take 1 GBP per trip.

- In the model:
    - StageCost_3 = data['StageCost_3'] + 1

Reduce private car road space: we model it by adding 20% travel time to car trips (result of more one way streets and search for parking, reduced speed limits, etc.) and making PT trips 20% faster by 2030 (by bus lanes, traffic light priority, denser infrastructure, etc.).

- In model:
    - StageTime_3 = data['StageTime_3'] * 1.2
    - StageTime_4 = data['StageTime_4'] * 0.8

Spread economic opportunities: we model it by reducing all commuting distances (actually we use the reduce times, but we calculate these from the reduced distances) to 75% of original by 2030. Modelled the same way as in Proposed Scenario 3.

Walking and cycling: like many times before, we change the ASC values to meet the shares observed in the Netherlands. We also make sure to not take travellers away from public transport, so we change the ASC of that too, reflecting for example that public transport became more attractive as the vehicles got modernised, clean, and the provided service is more on time than before.

- In the model:
    - ASC_1 = ASC_1+0.50
    - ASC_2 = ASC_2+3.35
    - ASC_4 = ASC_4+0.40
- It is worth noting that such a large change in the ASC values – especially for cycling – means that we get very far from the equilibrium of the logit model, so the resulting values are less realistic. To illustrate this we can try other methods besides changing the ASC values to achieve a similar modal split as a result:
    - To maintain the same share of public transport while we make cycling and walking more appealing by changing their ASC values, we would need to make public transport almost free.

- Since walking is free and it already takes the shortest route, it cannot be made more appealing in any other way than using the ASC, this means this can only be achieved by publicity campaigns, etc, or by making the other modes less appealing. This means penalizing car use even more, etc.
- Cycling is indeed the biggest issue, since we need to somehow make up for +3.35 in its ASC. Without this artificial ASC change, the share of cycling would only be 1.4%. To pump this up to 25%, huge changes are necessary. The problem is that this is impossible to model, because a) it is very far from the observed behaviour from which the logit model was built, b) the observed behaviour contains very few bike trips, so the model is not a very good representation of this mode. For example penalizing car trips two times harder only raises the bike trip 0.1%... If – just theoretically – we could half the time a bike trip takes (by providing speed pedelecs, a.k.a. electric bikes that are capable of 45 km/h speeds, to everyone), the model forecasts would only growth to 3.9%...

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 Bristol. 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);
- Aggregate fuel consumptions data subdivision (Table 2-5);
- LSOA disaggregation variables (
- Table 2-6).

Table 2-2: Methodology and source of data for Bristol emissions evaluation - Industrial sources

Activity	Data availability	Source	Publication	Reference
Industrial sector	Single facility	UK Department for Environment Food & Rural Affairs	Emissions from NAEI large point sources	http://naei.beis.gov.uk/data/map-large-source

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

Activity	Energy vector	Data availability	Source	Publication	Reference	Field	Disaggregation variable
Residential sector	Natural Gas	Level 3 (LSOA)	UK Department for Business, Energy & Industrial Strategy	Lower and Middle Super Output Areas gas consumption 2018 update	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/676340/LSOA_domestic_gas_2015.xlsx	Consumption (kWh)	None
	Wood	Level 1,5 (LA)	UK Department for Business, Energy & Industrial Strategy	Residual fuel consumption at regional and local authority level	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/647698/residual_fuels_2005-2015.xlsx	56% of Column M (Bioenergy & Waste) [see Share of wood on biomass in Table 2-4 for technology spit]	households not connected to the gas network (Table 2-6)

	LPG	Level 1,5 (LA)	UK Department for Business, Energy & Industrial Strategy	Residual fuel consumption at regional and local authority level	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/647698/residual_fuels_2005-2015.xlsx	10% of Column D (Petroleum; domestic) [see Table 2-5 for percentage]	households not connected to the gas network (Table 2-6)
	Gasoil	Level 1,5 (LA)	UK Department for Business, Energy & Industrial Strategy	Residual fuel consumption at regional and local authority level	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/647698/residual_fuels_2005-2015.xlsx	90% of Column D (Petroleum; domestic) [see Table 2-5 for percentage]	households not connected to the gas network (Table 2-6)
	Coal	Level 1,5 (LA)	UK Department for Business, Energy & Industrial Strategy	Residual fuel consumption at regional and local authority level	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/647698/residual_fuels_2005-2015.xlsx	Columns J+L (Coal+ Manufactured Solid Fuels; domestic) [see Table 2-5 for percentage]	households not connected to the gas network (Table 2-6)
Service sector	Natural gas	Level 2 (MSOA)	UK Department for Business, Energy & Industrial Strategy	Lower and Middle Super Output Areas gas consumption 2018 update	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/676344/MSOA_non_dom_gas_2015.xlsx	Consumption (kWh) 42% [see Table 2-5 for percentage]; totals at LA level obtained as sum from MSOA data are	Employees (Table 2-6)

						directly allocated to LSOA (°)	
	LPG	Level 1,5 (LA)	UK Department for Business, Energy & Industrial Strategy	Residual fuel consumption at regional and local authority level	https://www.gov.uk/government/statistical-data-sets/estimates-of-non-gas-non-electricity-and-non-road-transport-fuels-at-regional-and-local-authority-level	30% of Column F+G (Petroleum; Public Administration + Commercial) [see Table 2-5 for percentage]	Employees (Table 2-6)
	Gasoil	Level 1,5 (LA)	UK Department for Business, Energy & Industrial Strategy	Residual fuel consumption at regional and local authority level	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/647698/residual_fuels_2005-2015.xlsx	70% of Column F+G (Petroleum; Public Administration +Commercial) [see Table 2-5 for percentage]	Employees (Table 2-6)
	Wood	Level 1,5 (LA)	UK Department for Business, Energy & Industrial Strategy	Residual fuel consumption at regional and local authority level	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/647698/residual_fuels_2005-2015.xlsx	Negligible share of Column M (Bioenergy & Waste) [see Share of wood on biomass in Table 2-4 for percentage]	Value=0 no disaggregation
	Coal	Level 1,5 (LA)	UK Department for Business,	Residual fuel consumption at	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/647	Columns I (Coal; Industrial & Commercial)	Employees (

			Energy & Industrial Strategy	regional and local authority level	698/residual_fuels_2005-2015.xlsx	[Commercial share 1,5%; see Table 2-5 for percentage]	Table 2-6)

(°) if MSOA data are used to evaluate LSOA a bias is introduced due to different distribution industry/services in different MSOA

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

Variable	Data availability	Sources	Publication	Reference	Note
Share of wood on biomass	Level 1,5 (LA)	Ricardo Energy & Environment	Personal communication		The following share is evaluated: wood domestic 20%. In commercial sector only, wood wastes and plant biomass assumed included in point sources and globally negligible
Technologies split	Level 3 (National)	UK Department for Business, Energy & Industrial Strategy	Summary results of the domestic wood use survey Table 2.7 Final energy calculation	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/576953/Summary_Tables_Domestic_Wood_Survey.xlsx	On the basis of available data, the following shares are evaluated: conventional stoves 16%, high efficiency stoves 17%, advanced stoves 13%, conventional fireplaces 43%, high efficiency fireplaces 4%, advanced fireplaces 4%, boilers 4%.

Table 2-5: Methodology and source of data for Bristol fuel consumptions evaluation – Aggregate fuel consumptions data subdivision

Energy vector	Data availability	Source	Publication	Reference	Note
Natural Gas	Level 3 (National)	UK Department for Business, Energy & Industrial Strategy	Digest of UK Energy Statistics: natural gas: commodity balances (DUKES 4.1)	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/632524/DUKES_4.1.xls	On the basis of available data, the following share is evaluated: SERVICES Natural gas 42%, industrial 52%, others (agriculture, miscellaneous) 6%
LPG, Gasoil	Level 3 (National)	UK Department for Business, Energy & Industrial Strategy	Digest of UK Energy Statistics: Petroleum products: commodity balances (DUKES 3.2-3.4)	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/632507/DUKES_3.2-3.4.xls	On the basis of available data, the following shares are evaluated: SERVICES LPG 30% Gasoil 70% (in gasoil we include also an 8% of fuel oil) RESIDENTIAL LPG 10% Gasoil 90% (in gasoil kerosene is included).
Coal	Level 3 (National)	UK Department for Business, Energy & Industrial Strategy	Digest of UK Energy Statistics: : solid fuels and derived gases: commodity balances (DUKES)	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/632497/DUKES_2.4.xls	On the basis of available data, the following shares are evaluated for Coal: SERVICES 1,5% INDUSTRIAL 98,5%

Table 2-6: Methodology and source of data for Bristol fuel consumptions evaluation – LSOA disaggregation variables

Variable	Data availability	Sources	Publication	Reference	Fields
Households not connected to the gas network	Level 3 (LSOA)	UK Department for Business, Energy & Industrial Strategy	Lower and Middle Super Output Areas gas consumption, 2018 update	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/676466/LSOA_domestic_nongas_2016.xlsx	Estimated number of households not connected to the gas network
Employees	Level 3 (LSOA)	UK Office for National Statistics	All people aged 16 to 74 in employment the week before the Census Occupation by industry 2011 Occupies	https://www.nomisweb.co.uk/census/2011/ks605uk	Geography All of the following: 2001 super output areas - lower layer Cell SERVICE SECTOR Table CAS039 Occupation by industry select columns • G Wholesale and retail trade; repair of motor vehicles and motor cycles • H Transport and storage • I Accommodation and food service activities • J Information and communication • K Financial and insurance activities • L Real estate activities

					• M Professional, scientific and technical activities • N Administrative and support service activities • O Public administration and defense; compulsory social security • P Education • Q Human health and social work activities • R, S, T, U Other INDUSTRIAL SECTOR select columns • B Mining and quarrying • C Manufacturing • D Electricity, gas, steam and air conditioning supply • E Water supply; sewerage, waste management and remediation activities • F Construction The table provides information that classifies usual residents aged 16 to 74 in employment the week before the census by the industry in which they work, for United Kingdom as at census day, 27 March 2011.

properties with heating fuel oil	LSOA	The non-gas map	Kiln for Affordable Warmth Solutions, in conjunction with the Department for Business, Energy and Industrial Strategy	https://www.nongasmap.org.uk	Heating fuel oil

2.2.2 BAU

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

We combine 2 sources for projections: national & Bristol specific projections.

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

The scenario was built in two steps using:

- the projections of greenhouse gas emissions and energy demand from 2016 to 2035 from UK Department for Business, Energy & Industrial Strategy (BEIS)[7];
- the national measures defined in the 'with measures' (adopted measures) projection in the frame of NECD[8]

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 projections of greenhouse gas emissions and energy demand are based on central estimates of economic growth and fossil fuel prices in the original *Reference scenario*. It contains all agreed policies where decisions on policy design are sufficiently advanced to allow robust estimates of impact (i.e. including "planned" policies).

The **Bristol** BAU projections consider:

Demographic evolution [DVEL].

The city will grow9 with time (5% by 2020, and 20% by 2036 on 2015 levels). 33,500 new dwellings are expected by 2036, land at bath road Brislington, green belt Thornbury/ Buckover and Nailsea/Backwell. Regarding new houses, there is a programme to increase housing supply in Bristol10. There were 30,600 homes envisaged to be delivered in the city between 2006 and 2026, with a minimum target of 26,400 set out in the adopted Local Plan. Between 2006 and 2015, 16,300 homes have been built in the city.

Bristol Council Framework for Climate and Energy Security[11].

The Bristol Council Framework for Climate and Energy Security translates existing 2050 CO_2 reduction target of 80% into key milestones of 50% reduction by 2025 and 60% by 2035. In BAU, only already delivered initiatives are considered, and particularly:

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[7] UK Department for Business, Energy & Industrial Strategy Updated Energy and Emissions Projections 2017, January 2018

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

[9] Bristol City Council, The Population of Bristol, July 2018

[10] Bristol's Housing Strategy, 2016 – 2020

[11] Bristol Council Our Resilient Future: A Framework for Climate and Energy Security

- *Warmer Homes*: Will bring improvements to certain types of council homes, including numbers of low-rise flats, houses and bungalows, and blocks of high-rise flats. Over a nine to 10-year period it's planned to:
    - repair and improve 30 blocks of flats;
    - repair and improve 3,200 homes which were built using the *No-fines* and *Easiform* construction methods;

      Cabinet approval has been given for up to £45m of external wall insulation for low rise homes and up to £60.5m for tower block external wall insulation projects, both subject to the capacity of the Housing Delivery Business Plan.
- *Warm Up Bristol:* Delivers energy efficiency improvements to privately owned homes, through assessing home energy performance, identification of improvements, provision of options and advice for grant funding and manages the installations. £40m of capital investment and circa £11m of ECO funding to support this investment.
- *Heat Networks: City Centre, Redcliffe & Temple Quarter Enterprise Zone.* The first sections of the Redcliffe & Temple Heat Network were installed in Summer 2015 (as part of a General-Purpose Service Trench that also included Superfast broad band ducting); this first section included Heat mains on the new Arena Island bridge to enable the Arena development to be connected; construction has also been started on the first Energy Centre to supply the network incorporating a 1MW biomass boiler to supply zero Carbon heat; in addition to Redcliffe & Temple, BCC is also planning a City Centre network (in association with the University of Bristol and University Hospitals Bristol Foundation Trust); the programme for the City Centre, and the Redcliffe and Temple areas forms the first phase of wider plans for a City-wide Heat network that will take a number of years to develop and incorporates the delivery of a number of Gas CHP and biomass energy centres to supply council, public and private buildings; £13million is allocated to developing and installing Heat Networks, but it is subject to change depending upon opportunities; the following targets are reported:
    - Completion of Redcliffe & Temple Heat network Phase 1 – February 2016;
    - Redcliffe Phase 2 (expanded R&T Heat network – 2020);
    - City Centre Phase 1 Heat network completed – 2019;
- *Energy Efficiency Improvements to BCC Corporate Buildings:* a programme of corporate energy efficiency projects that includes:
    - Finalizing a major retrofit of City Hall which is currently underway;
    - Retrofitting the M-Shed, Central Library, City Museum and Colston Hall;
    - Retrofitting two exemplar schools to attract other schools to do similar work;
    - Upgrading the core BMS system to improve energy management across 8 core BCC buildings;
    - Developing an overarching strategy for retrofitting the Council's remaining buildings;
    - Creating an energy efficiency procurement framework to allow for large-scale cost-effective delivery;
    - Working with Bristol Workplace, Property, Housing, and Education work streams to increase energy efficiency by adding capital funding to exiting programmes.
    - *Solar Photovoltaic Programme:* A programme to secure funding and deliver solar photovoltaic (PV) on council land, buildings, including homes, schools and council's corporate properties, and further investment in public buildings including University of Bristol.

A gross evaluation of the CO_2 reduction is about 20,000 Mg/CO_2 year corresponding to about 5% of City of Bristol residential fuel consumptions. With the information available it is not possible to allocate these reductions at the LSOA or MSOA level for which they have been allocated uniformly throughout the territory of City of Bristol Local Authority District.

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

Table **2-8**.

For drivers coming from EU NEC "with measures" data, as it's impossible to derive from available information the split between socio-economic measures, such as for example fuel consumptions reductions, and technological measures, such as for example advanced combustion technologies, all the measures are inserted as technological ones. The NEC measures are evaluated net of BEIS ones.

While the BEIS and NEC drivers are applied to all the area of the simulation City population variation (CITYPOP) and District heating (DH) drivers are applied only to City of Bristol Local Authority District.

Table 2-7: Bristol: Socio-economic drivers used to project emissions in industrial, residential and commercial sector

Code	Name	Domain
020131A0	BEIS 2017: Commercial boilers - Hard Coal	All MSOAs
020131F0	BEIS 2017: Commercial boilers – LPG	All MSOAs
020131I0	BEIS 2017: Commercial boilers – Gasoil	All MSOAs
020131M1	BEIS 2017: Commercial boilers - Natural gas	All MSOAs
020220A0	BEIS 2017: Residential boilers - Hard Coal	All MSOAs
020220F0	BEIS 2017: Residential boilers – LPG	All MSOAs
020220I0	BEIS 2017: Residential boilers – Gasoil	All MSOAs
020220M1	BEIS 2017: Residential boilers - Natural gas	All MSOAs
CITYPOP	City population variation	Only Bristol MSOA
DH	Bristol Council Framework for Climate and Energy Security	Only Bristol MSOA

Table 2-8: Bristol: Technological drivers used to project emissions in industrial, residential and commercial sector

Code	Name	Domain
NEC_B_PM	NEC Building PM	All LSOAs
NEC_I_PM	NEC Industry PM	All LSOAs
NEC_I_NOx	NEC Industry NOx	All LSOAs
NEC_B_NOx	NEC Building NOx	All LSOAs

2.2.3 SDW scenarios

Bristol City Council (BCC) has reviewed its existing commitments, has reflected upon its progress against these commitments, and has decided to incorporate milestone targets for citywide emissions and energy demand reduction (Table 2-9).

Table 2-9: City Of Bristol Proposed Reduction Targets on 2005 baseline

	2020	2025	2035	2050
Citywide CO_2 emissions	40%	50%	60%	80%
Citywide Energy consumption	30%	35%	45%	55%
Citywide Renewable Energy	To be developed thorough consultation			

At the citywide level these targets are designed to broadly align with the West of England's Joint Local Transport Plan (2011-2026) and the West of England's Joint Spatial Plan (2036) cycles so that the contributions of these processes can be measured against the revised targets.

BCC proposes to adopt the targets of from the 2005 baseline, in the context of those targets already adopted for 2020 and 2050. The overall planning was conjugated into local one where the Local Plan[12] includes policies for deciding planning applications in Bristol.

The strategy highlights how, within the city centre[13], there is significant potential for climate change mitigation and adaptation through sustainable energy measures and building design Policy. BCS14 measure of the Core Strategy sets out requirements relating to on-site renewable energy in new development and is applicable within the Central Area Plan area. The policy also places the whole of central Bristol within a Heat Priority Area. Some of the highest demands for heat in Bristol exist in the central area, and as such this area will be one of the key starting points from which the council will seek to grow a district heating network.

Scenarios from the Stakeholder dialog workshop (SWD) includes the measures of Table 2-10 relating to the IRCI sector (the codes are defined in this report).

Table 2-10: Bristol: Measures coming from the Stakeholder dialog workshop

Code	Description
B_SWD_B_1	Increase generation of solar and wind power (Scenario 1 & Scenario 3)
B_SWB_B_2	Make property developers consider air pollution and climate change (Scenario 3)

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[12] Bristol City Council, Bristol Development Framework Core Strategy – Adopted June 2011

[13] Bristol Local Plan – Bristol Central Area Plan – Adopted March 2015

B_SWB_B_3	Improve energy efficiency of housing (rented/existing/new) (Scenario 3)

Without any policy to limit or prohibit the most polluting fuels, no change in the share of use of the different fuels has been foreseen.

We assume that:

- the Residential, Commercial & Institutional sector percentage reductions are the same as the total figures of Table 2-9;
- the measures SW_B_3 will drive the reduction of Citywide Energy consumption and include also services fuel consumptions,
- the measures SW_B_2 will counterbalance the growth in the number of dwellings and population with a goal of almost zero fossil energy consumption of new dwellings;
- the measure SWD_B_1 will drive the increase in the share of renewables over total consumption; therefore, the further reduction of carbon footprint will mainly reduce emission factor of electricity but it does not affect the reduction of fuel consumptions of housing already considered in SW_B_3;
- there will be no promotion of wood combustion in the domestic sector.

Unified Policy Scenario

The final Unified Policy Scenario includes the measures of Table 2-11 relating to the IRCI sector (the codes are defined in this report). For the supplemental measure *Bristol Carbon Neutral* we assume the results of the Bristol City Council strategy[14] for carbon neutrality on 2050

Table 2-11: Bristol: Measures for the Unified Policy Scenario

Code	Description
B_SWD_B_1	Increase generation of solar and wind power
B_SWB_B_2	Make property developers consider air pollution and climate change
B_SWB_B_3	Improve energy efficiency of housing (rented/existing/new)
BRI_CN	Bristol Carbon Neutral

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[14] Element Energy Limited, An evidence based strategy for delivering zero carbon heat in Bristol. A report for Bristol City Council, October 2018

2.3 Carbon footprint

2.3.1 Baseline

The following tables document the methodology and data used for:

- Industrial sources (Table 2-12)
- Residential and commercial sources (Table 2-13)
- Aggregate fuel consumptions data subdivision (Table 2-14)
- LSOA disaggregation variables (
- Table 2-15).

Table 2-12: Methodology and source of data for Bristol fuel consumptions evaluation - Industrial sources

Activity	Energy vector	Data availability	Source	Publication	Reference	Field	Disaggregation variable
Industrial sector	Natural Gas	Level 2 (MSOA)	UK Department for Business, Energy & Industrial Strategy	Lower and Middle Super Output Areas gas consumption 2018 update	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/676344/MSOA_non_dom_gas_2015.xlsx	52% of non-domestic Consumption (kWh) [see Table 2-14 for percentage]; totals at LA level obtained as sum from MSOA data are directly allocated to LSOA (°)	Employees (Table 2-14)
	LPG	Level 1,5 (LA)	UK Department for Business, Energy & Industrial Strategy	Residual fuel consumption at regional and local authority level	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/647698/residual_fuels_2005-2015.xlsx	11% of Column D (Petroleum; Industrial) [see Table 2-14 for percentage]	Employees (Table 2-14)
	Gasoil	Level 1,5 (LA)	UK Department for Business, Energy & Industrial Strategy	Residual fuel consumption at regional and local authority level	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/647698/residual_fuels_2005-2015.xlsx	89% of Column D (Petroleum; Industrial) [see Table 2-14 for percentage]	Employees (Table 2-14)
	Coal	Level 1,5 (LA)	UK Department for Business, Energy &	Residual fuel consumption at	https://www.gov.uk/government/uploads/system/uploads/attachmen	98,5% of Columns I+K (Coal+ Manufactured Solid Fuels;	Employees (Table 2-14)

			Industrial Strategy	regional and local authority level	t_data/file/647698/residual_fuels_2005-2015.xlsx	Industrial+Commercial) [see Table 2-14 for percentage]	
	Electricity	Level 1,5 (LA)	UK Department for Business, Energy & Industrial Strategy	Lower and Middle Super Output Areas electricity consumption - MSOA non domestic electricity 2015	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/676475/MSOA_non_dom_electricity_2015.xlsx	Consumption (kWh) 50% [see Table 2-14for percentage]; totals at LA level obtained as sum from MSOA data are directly allocated to LSOA (°)	Employees (Table 2-14)

(°) if MSOA data are used to evaluate LSOA a bias is introduced due to different distribution industry/services in different MSOA

Table 2-13: Methodology and source of data for Bristol fuel consumptions evaluation - Residential and services sources

Activity	Energy vector	Data availability	Source	Publication	Reference	Field	Disaggregation variable
Residential sector	Natural gas	Level 3 (LSOA)	UK Department for Business, Energy & Industrial Strategy	Lower and Middle Super Output Areas gas consumption 2018 update	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/676340/LSOA_domestic_gas_2015.xlsx	Consumption (kWh) 42% [see Table 2-14 for percentage]	None
	Wood	Level 1,5 (LA)	UK Department for Business, Energy &	Residual fuel consumption at regional and local authority level	https://www.gov.uk/government/uploads/system/uploads/attachment_dat	56% of Column M (Bioenergy & Waste) [see Share of wood on biomass	households not connected to the gas network (

Table 2-13: Methodology and source of data for Bristol fuel consumptions evaluation - Residential and services sources

Activity	Energy vector	Data availability	Source	Publication	Reference	Field	Disaggregation variable
			Industrial Strategy		a/file/647698/residual_fuels_2005-2015.xlsx	in Table 2-14 for percentage]	Table 2-15)
	LPG	Level 1,5 (LA)	UK Department for Business, Energy & Industrial Strategy	Residual fuel consumption at regional and local authority level	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/647698/residual_fuels_2005-2015.xlsx	10% of Column D (Petroleum; domestic) [see Table 2-14 for percentage]	households not connected to the gas network (Table 2-15)
	Gasoil	Level 1,5 (LA)	UK Department for Business, Energy & Industrial Strategy	Residual fuel consumption at regional and local authority level	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/647698/residual_fuels_2005-2015.xlsx	90% of Column D (Petroleum; domestic) [seeTable 2-14 for percentage]	households not connected to the gas network (Table 2-15)
	Coal	Level 1,5 (LA)	UK Department for Business, Energy & Industrial Strategy	Residual fuel consumption at regional and local authority level	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/647698/residual_fuels_2005-2015.xlsx	Columns J+L (Coal+ Manufactured Solid Fuels; domestic) [see Table 2-14 for percentage]	households not connected to the gas network (Table 2-15)
	Electricity	Level 3 (LSOA)	UK Department for Business, Energy &	Lower and Middle Super Output Areas	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/676473/LSOA_do	Consumption (kWh)	None

Table 2-13: Methodology and source of data for Bristol fuel consumptions evaluation - Residential and services sources

Activity	Energy vector	Data availability	Source	Publication	Reference	Field	Disaggregation variable
			Industrial Strategy	electricity consumption - MSOA non domestic electricity 2015	mestic_electricity_2015.xlsx		
Service sector	Natural gas	Level 2 (MSOA)	UK Department for Business, Energy & Industrial Strategy	Lower and Middle Super Output Areas gas consumption 2018 update	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/676344/MSOA_non_dom_gas_2015.xlsx	Consumption (kWh) 42% [see Table 2-14 for percentage]; totals at LA level obtained as sum from MSOA data are directly allocated to LSOA (°)	Employees (Table 2-15)
	LPG	Level 1,5 (LA)	UK Department for Business, Energy & Industrial Strategy	Residual fuel consumption at regional and local authority level	https://www.gov.uk/government/statistical-data-sets/estimates-of-non-gas-non-electricity-and-non-road-transport-fuels-at-regional-and-local-authority-level	30% of Column F+G (Petroleum; Public Administration + Commercial) [see Table 2-14 for percentage]	Employees (Table 2-15)
	Gasoil	Level 1,5 (LA)	UK Department for Business, Energy &	Residual fuel consumption at	https://www.gov.uk/government/uploads/system/uploads/attachment_dat	70% of Column F+G (Petroleum; Public	Employees (Table 2-15)

Table 2-13: Methodology and source of data for Bristol fuel consumptions evaluation - Residential and services sources

Activity	Energy vector	Data availability	Source	Publication	Reference	Field	Disaggregation variable
			Industrial Strategy	regional and local authority level	a/file/647698/residual_fuels_2005-2015.xlsx	Administration+Commercial) [see Table 2-14 for percentage]	
	Wood	Level 1,5 (LA)	UK Department for Business, Energy & Industrial Strategy	Residual fuel consumption at regional and local authority level	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/647698/residual_fuels_2005-2015.xlsx	Negligible share of Column M (Bioenergy & Waste) [see Table 2-14 for percentage)	Value=0 no disaggregation
	Coal	Level 1,5 (LA)	UK Department for Business, Energy & Industrial Strategy	Residual fuel consumption at regional and local authority level	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/647698/residual_fuels_2005-2015.xlsx	Columns I (Coal; Industrial & Commercial) [Commercial share 1,5%; see Table 2-14 for percentage]	Employees (Table 2-15)
	Electricity	Level 2 (MSOA)	UK Department for Business, Energy & Industrial Strategy	Lower and Middle Super Output Areas electricity consumption - MSOA non domestic electricity 2015	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/676475/MSOA_non_dom_electricity_2015.xlsx	Consumption (kWh) 50% [see Table 2-14 for percentage]; totals at LA level obtained as sum from MSOA data are directly allocated to LSOA (°)	Employees (Table 2-15)

(°) if MSOA data are used to evaluate LSOA a bias is introduced due to different distribution industry/services in different MSOA

Table 2-14: Methodology and source of data for Bristol fuel consumptions evaluation – aggregate fuel consumptions data subdivision

Energy vector	Data availability	Source	Publication	Reference	Note
Wood	Level 3 (National)	UK Department for Business, Energy & Industrial Strategy	Digest of UK Energy Statistics (DUKES): renewable sources of energy	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/632546/DUKES_6.1-6.3.xls	On the basis of available data the following share is evaluated: wood domestic 56%. In commercial sector only wood wastes and plant biomass assumed; consumptions evaluated as included in point sources and globally negligible
Natural Gas	Level 3 (National)	UK Department for Business, Energy & Industrial Strategy	Digest of UK Energy Statistics: natural gas: commodity balances (DUKES 4.1)	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/632524/DUKES_4.1.xls	On the basis of available data the following share is evaluated: SERVICES Natural gas 42%, industrial 52%, others (agriculture, miscellaneous) 6%
LPG, Gaoil	Level 3 (National)	UK Department for Business, Energy & Industrial Strategy	Digest of UK Energy Statistics: Petroleum products: commodity balances (DUKES 3.2-3.4)	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/632507/DUKES_3.2-3.4.xls	On the basis of available data the following shares are evaluated: SERVICES LPG 30% Gasoil 70% (in gasoil we include also a 8% of fuel oil) RESIDENTIAL LPG 10% Gasoil 90% (in gasoil kerosene is included). INDUSTRIAL LPG 11% Gasoil 89% (in gasoil we include also a 5% of fuel oil)

Coal	Level 3 (National)	UK Department for Business, Energy & Industrial Strategy	Digest of UK Energy Statistics: : solid fuels and derived gases: commodity balances (DUKES)	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/632497/DUKES_2.4.xls	On the basis of available data the following shares are evaluated for Coal: SERVICES 1,5% INDUSTRIAL 98,5%
Electricity	Level 3 (National)	UK Department for Business, Energy & Industrial Strategy	Digest of UK Energy Statistics: Electricity: commodity balances (DUKES 5.1)	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/632598/DUKES_5.1.xls	On the basis of available data the following shares are evaluated for electricity: SERVICES 50% INDUSTRIAL 50%

Table 2-15: Methodology and source of data for Bristol fuel consumptions evaluation – LSOA disaggregation variables

Variable	Data availability	Sources	Publication	Reference	Fields
households not connected to the gas network	Level 3 (LSOA)	UK Department for Business, Energy & Industrial Strategy	Lower and Middle Super Output Areas gas consumption 2018 update	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/676466/LSOA_domestic_nongas_2016.xlsx	Estimated number of households not connected to the gas network
Employees	Level 3 (LSOA)	UK Office for National Statistics	All people aged 16 to 74 in employment the week before the Census	https://www.nomisweb.co.uk/census/2011/ks605uk	Geography All of the following: 2001 super output areas - lower layer Cell SERVICE SECTOR Table CAS039 Occupation by industry

			Occupation by industry 2011 Occupies		select columns • G Wholesale and retail trade; repair of motor vehicles and motor cycles • H Transport and storage • I Accommodation and food service activities • J Information and communication • K Financial and insurance activities • L Real estate activities • M Professional, scientific and technical activities • N Administrative and support service activities • O Public administration and defence; compulsory social security • P Education • Q Human health and social work activities • R, S, T, U Other INDUSTRIAL SECTOR select columns • B Mining and quarrying • C Manufacturing • D Electricity, gas, steam and air conditioning supply • E Water supply; sewerage, waste management and remediation activities • F Construction The table provides information that classifies usual residents aged 16 to 74 in employment the week before the census by the industry in which they work, for United Kingdom as at census day, 27 March 2011.

2.3.2 BAU

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

As a general input to the projection model, results from IRCI and Traffic models have been assumed for fuel consumptions.

For electricity emission factors an additional driver was introduced to take into consideration the evolution of carbon footprint from electricity generation. The driver is defined using official UK projection data up to 2035[15]. For 2050 we assume near-zero emissions for electricity according to the UK Committee on Climate Change that has recently fixed as a policy requirement that the power sector should be close to zero-carbon by 2030[16]. In the same document are also hypotheses of near-zero emissions for residential and domestic transport. However, some more cautious consideration has been recently reported[17], so in the projections the near-zero emissions hypothesis has been inserted only for the power sector.

2.3.3 SDW Scenarios

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

2.3.4 Final Unified Policy Scenario

The final Unified Policy Scenario includes the measures of Scenario 3 and a supplemental measure *Bristol Carbon Neutral* where we assume the results of the Bristol City Council strategy[18] for carbon neutrality in 2050.

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[15] UK Department for Business, Energy & Industrial Strategy, Projections of greenhouse gas emissions and energy demand from 2016 to 2035, Updated energy and emissions projections: 2016, March 2017

[16] Committee on Climate Change, UK climate action following the Paris Agreement, October 2016

[17] Committee on Climate Change, Reducing UK emissions, 2018 Progress Report to Parliament, June 2018

[18] Element Energy Limited, An evidence based strategy for delivering zero carbon heat in Bristol. A report for Bristol City Council, October 2018

3 Results

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

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

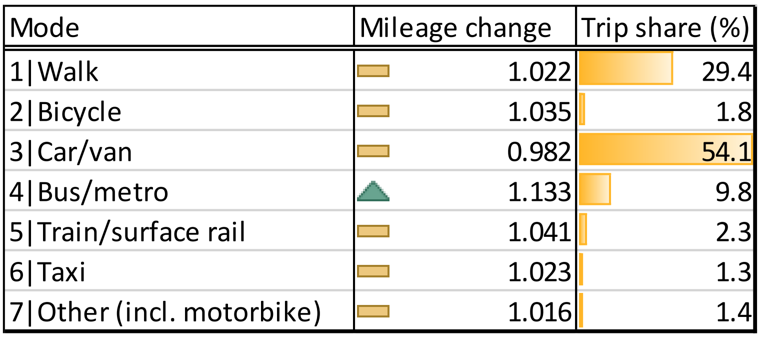
Emissions for other sectors are reported in the section on the IRCI-module results.

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

3.1 Transport

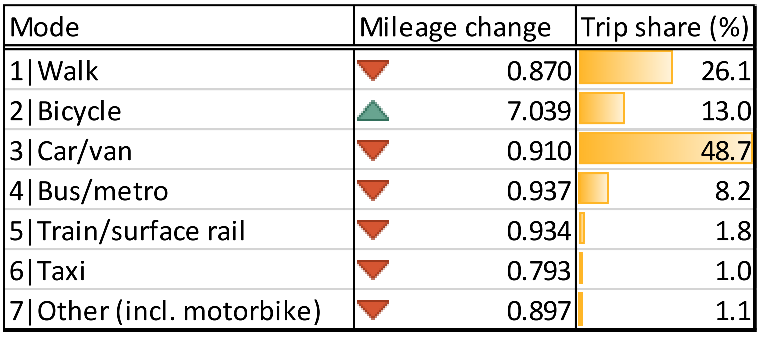
3.1.1 Mode choice changes

We present here the tables containing the relative mileage changes (compared to the Baseline) and the resulting modal split for various reporting years in each scenario.



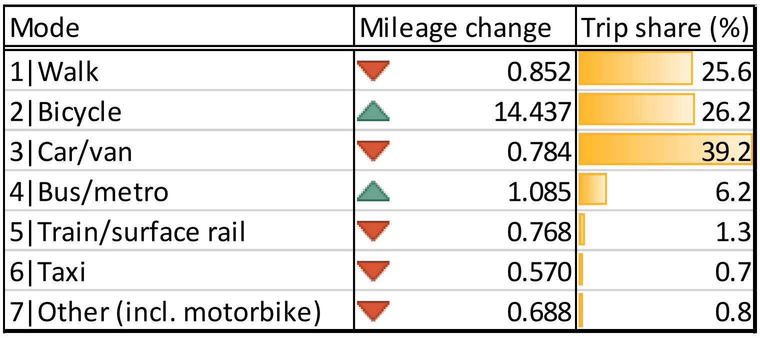
Mode	Mileage change	Trip share (%)
1|Walk	▬ 1.022	29.4
2|Bicycle	▬ 1.035	1.8
3|Car/van	▬ 0.982	54.1
4|Bus/metro	▲ 1.133	9.8
5|Train/surface rail	▬ 1.041	2.3
6|Taxi	▬ 1.023	1.3
7|Other (incl. motorbike)	▬ 1.016	1.4

Figure 3-1: Proposed Scenario 1 (2025).



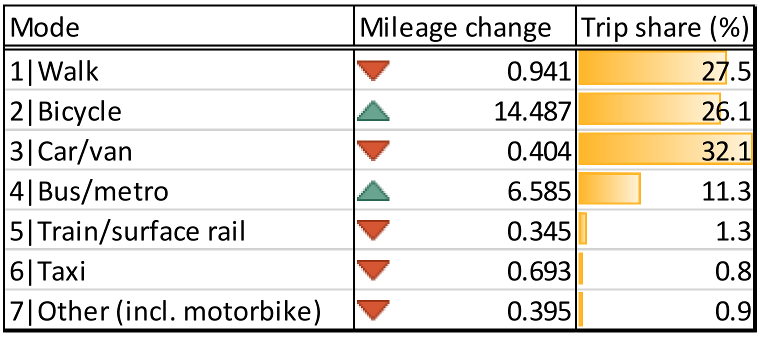
Mode	Mileage change	Trip share (%)
1|Walk	▼ 0.870	26.1
2|Bicycle	▲ 7.039	13.0
3|Car/van	▼ 0.910	48.7
4|Bus/metro	▼ 0.937	8.2
5|Train/surface rail	▼ 0.934	1.8
6|Taxi	▼ 0.793	1.0
7|Other (incl. motorbike)	▼ 0.897	1.1

Figure 3-2: Proposed Scenario 1 (2035-2050).



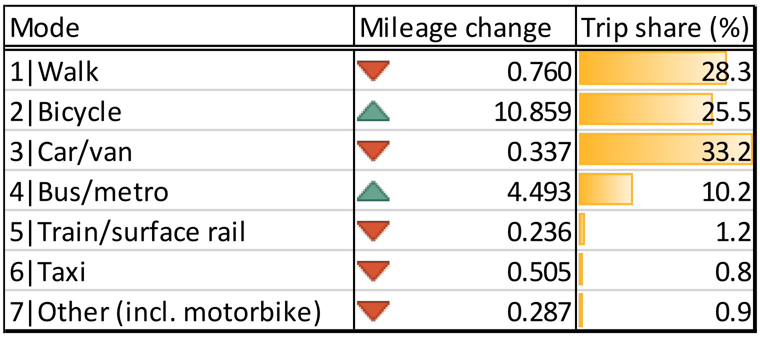
Mode	Mileage change	Trip share (%)
1|Walk	▼ 0.852	25.6
2|Bicycle	▲ 14.437	26.2
3|Car/van	▼ 0.784	39.2
4|Bus/metro	▲ 1.085	6.2
5|Train/surface rail	▼ 0.768	1.3
6|Taxi	▼ 0.570	0.7
7|Other (incl. motorbike)	▼ 0.688	0.8

Figure 3-3: Proposed Scenario 2 (2025-2050).



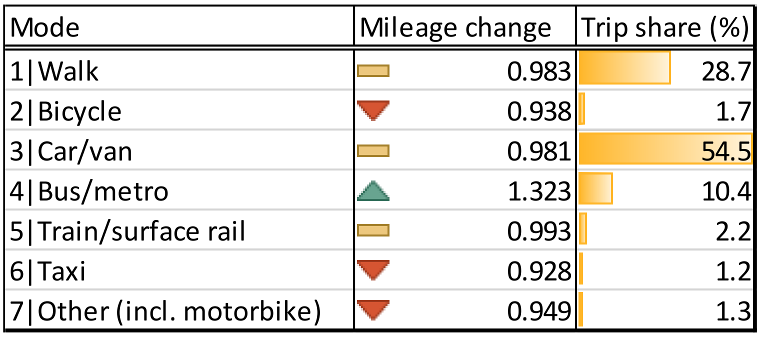
Mode	Mileage change	Trip share (%)
1|Walk	▼ 0.941	27.5
2|Bicycle	▲ 14.487	26.1
3|Car/van	▼ 0.404	32.1
4|Bus/metro	▲ 6.585	11.3
5|Train/surface rail	▼ 0.345	1.3
6|Taxi	▼ 0.693	0.8
7|Other (incl. motorbike)	▼ 0.395	0.9

Figure 3-4: Proposed Scenario 3 (2025).



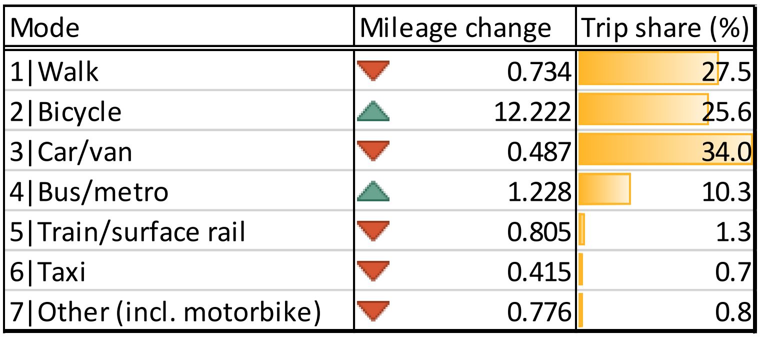
Mode	Mileage change	Trip share (%)
1|Walk	▼ 0.760	28.3
2|Bicycle	▲ 10.859	25.5
3|Car/van	▼ 0.337	33.2
4|Bus/metro	▲ 4.493	10.2
5|Train/surface rail	▼ 0.236	1.2
6|Taxi	▼ 0.505	0.8
7|Other (incl. motorbike)	▼ 0.287	0.9

Figure 3-5: Proposed Scenario 3 (2035-2050).



Mode	Mileage change	Trip share (%)
1|Walk	▬ 0.983	28.7
2|Bicycle	▼ 0.938	1.7
3|Car/van	▬ 0.981	54.5
4|Bus/metro	▲ 1.323	10.4
5|Train/surface rail	▬ 0.993	2.2
6|Taxi	▼ 0.928	1.2
7|Other (incl. motorbike)	▼ 0.949	1.3

Figure 3-6: Final Scenario (2025).



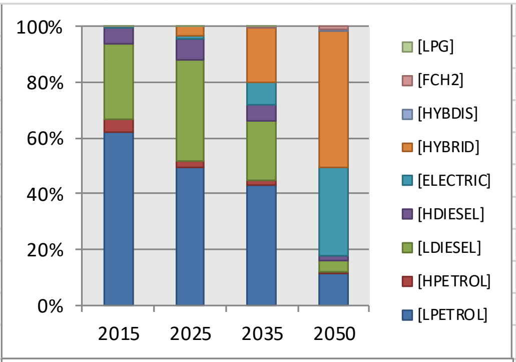
Mode	Mileage change	Trip share (%)
1|Walk	▼ 0.734	27.5
2|Bicycle	▲ 12.222	25.6
3|Car/van	▼ 0.487	34.0
4|Bus/metro	▲ 1.228	10.3
5|Train/surface rail	▼ 0.805	1.3
6|Taxi	▼ 0.415	0.7
7|Other (incl. motorbike)	▼ 0.776	0.8

Figure 3-7: Final Scenario (2035-2050).

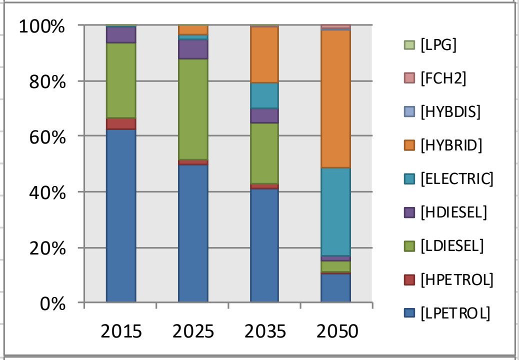
3.1.2 Fleet and Emissions

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

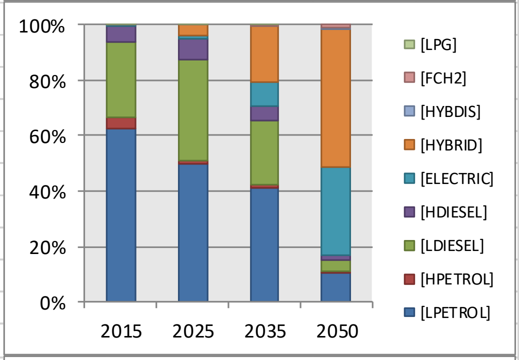
VENSIM model in percentage of total fleet per reporting year				
BAU	2015	2025	2035	2050
[LPETROL]	62.42%	49.76%	43.42%	11.24%
[HPETROL]	4.19%	1.74%	1.43%	0.57%
[LDIESEL]	27.15%	36.68%	21.32%	4.23%
[HDIESEL]	6.07%	7.62%	5.56%	1.63%
[ELECTRIC]	0.08%	1.16%	8.49%	31.60%
[HYBRID]	0.09%	2.95%	19.24%	49.23%
[HYBDIS]	0.00%	0.05%	0.22%	0.35%
[FCH2]	0.00%	0.03%	0.32%	1.16%
[LPG]	0.00%	0.00%	0.00%	0.00%



VENSIM model in percentage of total fleet per reporting year				
Scenario 1	2015	2025	2035	2050
[LPETROL]	62.42%	49.92%	41.42%	10.48%
[HPETROL]	4.19%	1.60%	1.47%	0.57%
[LDIESEL]	27.15%	36.28%	21.81%	4.28%
[HDIESEL]	6.07%	7.41%	5.66%	1.64%
[ELECTRIC]	0.08%	1.32%	8.74%	31.54%
[HYBRID]	0.09%	3.38%	20.35%	49.97%
[HYBDIS]	0.00%	0.06%	0.23%	0.35%
[FCH2]	0.00%	0.04%	0.32%	1.16%
[LPG]	0.00%	0.00%	0.00%	0.00%



VENSIM model in percentage of total fleet per reporting year				
Scenario 2	2015	2025	2035	2050
[LPETROL]	62.42%	49.67%	41.05%	10.43%
[HPETROL]	4.19%	1.55%	1.47%	0.57%
[LDIESEL]	27.15%	36.20%	22.69%	4.26%
[HDIESEL]	6.07%	7.35%	5.68%	1.63%
[ELECTRIC]	0.08%	1.44%	8.51%	31.66%
[HYBRID]	0.09%	3.68%	20.05%	49.93%
[HYBDIS]	0.00%	0.06%	0.23%	0.35%
[FCH2]	0.00%	0.04%	0.32%	1.16%
[LPG]	0.00%	0.00%	0.00%	0.00%



VENSIM model in percentage of total fleet per reporting year				
Scenario 3	2015	2025	2035	2050
[LPETROL]	62.42%	60.08%	36.17%	4.65%
[HPETROL]	4.19%	2.22%	1.53%	0.29%
[LDIESEL]	27.15%	0.00%	0.00%	0.00%
[HDIESEL]	6.07%	0.00%	0.00%	0.00%
[ELECTRIC]	0.11%	7.52%	22.82%	76.01%
[HYBRID]	0.06%	29.80%	37.13%	9.52%
[HYBDIS]	0.00%	0.00%	0.00%	0.00%
[FCH2]	0.00%	0.37%	2.35%	9.52%
[LPG]	0.00%	0.00%	0.00%	0.00%

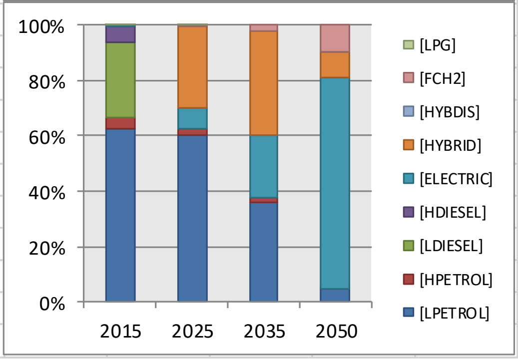


Figure 3-8: Passenger car fleet composition in the BAU and in the Proposed Scenarios 1-2-3.

	VENSIM model in percentage of total fleet per reporting year			
BAU	2015	2025	2035	2050
[LPETROL]	62.42%	49.76%	43.42%	11.24%
[HPETROL]	4.19%	1.74%	1.43%	0.57%
[LDIESEL]	27.15%	36.68%	21.32%	4.23%
[HDIESEL]	6.07%	7.62%	5.56%	1.63%
[ELECTRIC]	0.08%	1.16%	8.49%	31.60%
[HYBRID]	0.09%	2.95%	19.24%	49.23%
[HYBDIS]	0.00%	0.05%	0.22%	0.35%
[FCH2]	0.00%	0.03%	0.32%	1.16%
[LPG]	0.00%	0.00%	0.00%	0.00%

	VENSIM model in percentage of total fleet per reporting year			
Final	2015	2025	2035	2050
[LPETROL]	62.42%	45.57%	0.00%	0.00%
[HPETROL]	4.19%	1.45%	0.00%	0.00%
[LDIESEL]	27.15%	29.35%	0.00%	0.00%
[HDIESEL]	6.07%	6.57%	0.00%	0.00%
[ELECTRIC]	0.08%	3.60%	32.17%	77.61%
[HYBRID]	0.09%	13.13%	64.35%	12.99%
[HYBDIS]	0.00%	0.17%	0.40%	0.12%
[FCH2]	0.00%	0.17%	3.08%	9.29%
[LPG]	0.00%	0.00%	0.00%	0.00%

	VENSIM model in percentage of total fleet per reporting year			
Final B	2015	2025	2035	2050
[LPETROL]	62.42%	45.57%	3.72%	0.00%
[HPETROL]	4.19%	1.45%	0.16%	0.00%
[LDIESEL]	27.15%	29.35%	2.24%	0.00%
[HDIESEL]	6.07%	6.57%	0.60%	0.00%
[ELECTRIC]	0.08%	3.60%	35.31%	77.64%
[HYBRID]	0.09%	13.13%	53.92%	13.31%
[HYBDIS]	0.00%	0.17%	0.37%	0.12%
[FCH2]	0.00%	0.17%	3.69%	8.93%
[LPG]	0.00%	0.00%	0.00%	0.00%

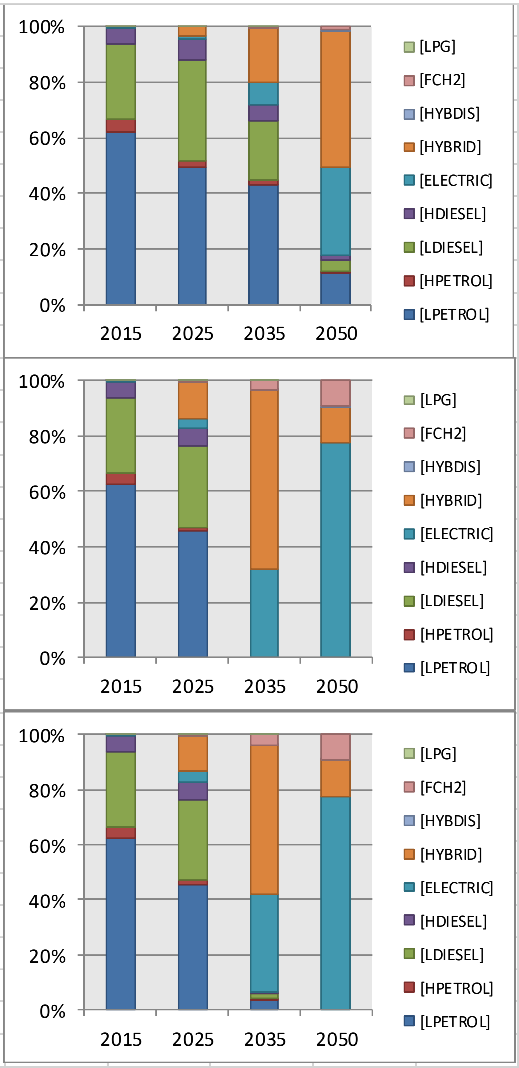


Figure 3-9: Passenger car fleet composition in the BAU and in the Final Scenario (base and B version).

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%	26.85%	19.68%	20.37%
Scenario 1		26.85%	19.68%	20.37%
Scenario 2		26.85%	19.68%	20.37%
Scenario 3		26.85%	19.68%	20.37%

PM

Year	2015	2025	2035	2050
BAU	100.00%	19.00%	11.13%	11.30%
Scenario 1		19.00%	11.13%	11.30%
Scenario 2		19.00%	11.13%	11.30%
Scenario 3		19.00%	11.13%	11.30%

ZWVR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	17.62%	15.85%	16.95%
Scenario 1		17.62%	15.85%	16.95%
Scenario 2		17.62%	15.85%	16.95%
Scenario 3		17.62%	15.85%	16.95%

PM

Year	2015	2025	2035	2050
BAU	100.00%	16.70%	15.62%	16.71%
Scenario 1		16.70%	15.62%	16.71%
Scenario 2		16.70%	15.62%	16.71%
Scenario 3		16.70%	15.62%	16.71%

BUS

Nox

Year	2015	2025	2035	2050
BAU	100.00%	15.92%	15.01%	16.16%
Scenario 1		15.44%	3.77%	2.01%
Scenario 2		9.30%	5.23%	2.60%
Scenario 3		61.25%	23.49%	11.69%

PM

Year	2015	2025	2035	2050
BAU	100.00%	15.78%	15.39%	16.56%
Scenario 1		15.47%	4.21%	2.25%
Scenario 2		10.44%	5.87%	2.92%
Scenario 3		68.75%	26.37%	13.13%

MOTO

Nox

Year	2015	2025	2035	2050
BAU	100.00%	28.19%	24.36%	28.17%
Scenario 1		27.69%	22.16%	25.62%
Scenario 2		22.10%	19.09%	22.08%
Scenario 3		11.38%	8.21%	9.49%

PM

Year	2015	2025	2035	2050
BAU	100.00%	13.33%	6.77%	7.83%
Scenario 1		13.09%	6.16%	7.12%
Scenario 2		10.44%	5.30%	6.13%
Scenario 3		5.38%	2.28%	2.64%

CAR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	57.05%	28.72%	26.72%
Scenario 1		50.55%	25.82%	24.49%
Scenario 2		32.21%	22.60%	21.06%
Scenario 3		7.88%	6.65%	1.34%

PM

Year	2015	2025	2035	2050
BAU	100.00%	36.06%	27.88%	25.22%
Scenario 1		26.51%	25.36%	23.14%
Scenario 2		21.00%	22.02%	19.95%
Scenario 3		9.38%	7.38%	1.34%

VAN

Nox

Year	2015	2025	2035	2050
BAU	100.00%	41.95%	24.20%	23.54%
Scenario 1		38.70%	22.75%	22.43%
Scenario 2		29.53%	21.14%	20.71%
Scenario 3		17.36%	13.16%	10.85%

PM

Year	2015	2025	2035	2050
BAU	100.00%	27.53%	19.51%	18.26%
Scenario 1		22.75%	18.25%	17.22%
Scenario 2		20.00%	16.58%	15.63%
Scenario 3		14.19%	9.26%	6.32%

MIDZWVR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	26.85%	19.68%	20.37%
Final		26.85%	19.68%	20.37%
Final B		26.85%	19.68%	20.37%

PM

Year	2015	2025	2035	2050
BAU	100.00%	19.00%	11.13%	11.30%
Final		19.00%	11.13%	11.30%
Final B		19.00%	11.13%	11.30%

ZWVR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	17.62%	15.85%	16.95%
Final		17.62%	15.85%	16.95%
Final B		17.62%	15.85%	16.95%

PM

Year	2015	2025	2035	2050
BAU	100.00%	16.70%	15.62%	16.71%
Final		16.70%	15.62%	16.71%
Final B		16.70%	15.62%	16.71%

BUS

Nox

Year	2015	2025	2035	2050
BAU	100.00%	15.92%	15.01%	16.16%
Final		16.94%	12.69%	0.24%
Final B		16.94%	12.69%	0.24%

PM

Year	2015	2025	2035	2050
BAU	100.00%	15.78%	15.39%	16.56%
Final		17.41%	13.59%	0.27%
Final B		17.41%	13.59%	0.27%

MOTO

Nox

Year	2015	2025	2035	2050
BAU	100.00%	28.19%	24.36%	28.17%
Final		28.19%	24.36%	28.17%
Final B		28.19%	24.36%	28.17%

PM

Year	2015	2025	2035	2050
BAU	100.00%	13.33%	6.77%	7.83%
Scenario 1		13.33%	6.77%	7.83%
Scenario 2		13.33%	6.77%	7.83%

CAR

Nox

Year	2015	2025	2035	2050
BAU	100.00%	57.05%	28.72%	26.72%
Final		39.90%	12.07%	1.96%
Final B		39.90%	10.95%	2.09%

PM

Year	2015	2025	2035	2050
BAU	100.00%	36.06%	27.88%	25.22%
Final		25.82%	10.67%	1.72%
Final B		25.82%	9.81%	1.83%

VAN

Nox

Year	2015	2025	2035	2050
BAU	100.00%	41.95%	24.20%	23.54%
Final		33.38%	15.87%	11.16%
Final B		33.38%	15.31%	11.23%

PM

Year	2015	2025	2035	2050
BAU	100.00%	27.53%	19.51%	18.26%
Final		22.41%	10.90%	6.51%
Final B		22.41%	10.47%	6.57%

3.2 Spatial-temporal

A temporal resolution approach is applied to distribute the annual emissions based on energy consumption into an hourly resolution, where the precision of energy consumption and emissions are measured per unit with respect to time. In modelling the temporal resolution, the nature of our data is a panel data set, where the data is retrieved from multiple sources in a specific point of time. For reasons of efficiency, we evaluate the input data with the aim of identifying the data that have a significant influence on our goal of generating emission load profiles for regions and cities. Therefore, these are the related input data**:**

1. Monthly gas pattern is available at Eurostat's energy database,
2. Hourly local temperature is obtained from the UK's Meteorological Office,
3. Hourly national electricity load is available at open power system data and
4. The share of fuel resources (%), especially wood heaters is calculated from TECHNE's emission area dataset.

For the residential sector, we propose a simplified approach which uses a Weighted proportion (Wepro) model to synthesise the residential energy load profile at the city level, by utilising an existing household load profile generators like Load Profile Generator (LPG). The model requires some limited input parameters at the city level: the citizens's age groups (AG), gender (GD) structure, and labour force (LF) composition. Therefore, it presents a combination of a top-down approach with a few input parameters, which use general statistics information of a city and a bottom-up load model with high temporal resolution data. It simply utilises the existing household load profile generators that have covered the detailed disaggregated input data in relation with behaviour, occupancy, time-use, appliances and other related variables.

The temporal resolution of Bristol's residential sector and commercial sector are provided in daily emission load profiles, typical days emission load profiles and hourly typical days emission load profiles of PM_{10} and NO_x variables. In case of monthly load profile, the emissions load profiles reflect the domestic heating pattern and the daily load profile reflects the domestic consumption in relation with the daily average temperature.

As a result, the hourly load profiles reflect the hourly local temperature and domestic electricity load. Furthermore, based on the seasonal variation of residential and commercial sectors, winter profile indicates the highest emission share, which concurs with the known seasonal pattern in energy demands studies. In addition of the typical days profiles of residential sector and commercial sector, weekdays show lower emission shares than weekends in both winter and summer period.

3.3 IRCI

3.3.1 Baseline

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

- Bristol LSOA Residential, Commercial & Institutional NO_x emissions for all sectors and fuel (Figure 3-10),

- Bristol LSOA Residential, Commercial & Institutional PM_{10} emissions for all sectors and fuels (Figure 3-11),
- Bristol LSOA Residential, Commercial & Institutional PM_{10} emissions from biomass use (Figure 3-12),
- Bristol LSOA Residential, Commercial & Institutional PM_{10} emissions from hard coal use (Figure 3-13),
- Bristol Industry NO_x emissions (Figure 3-14)
- Bristol Industry PM_{10} emissions (Figure 3-15).

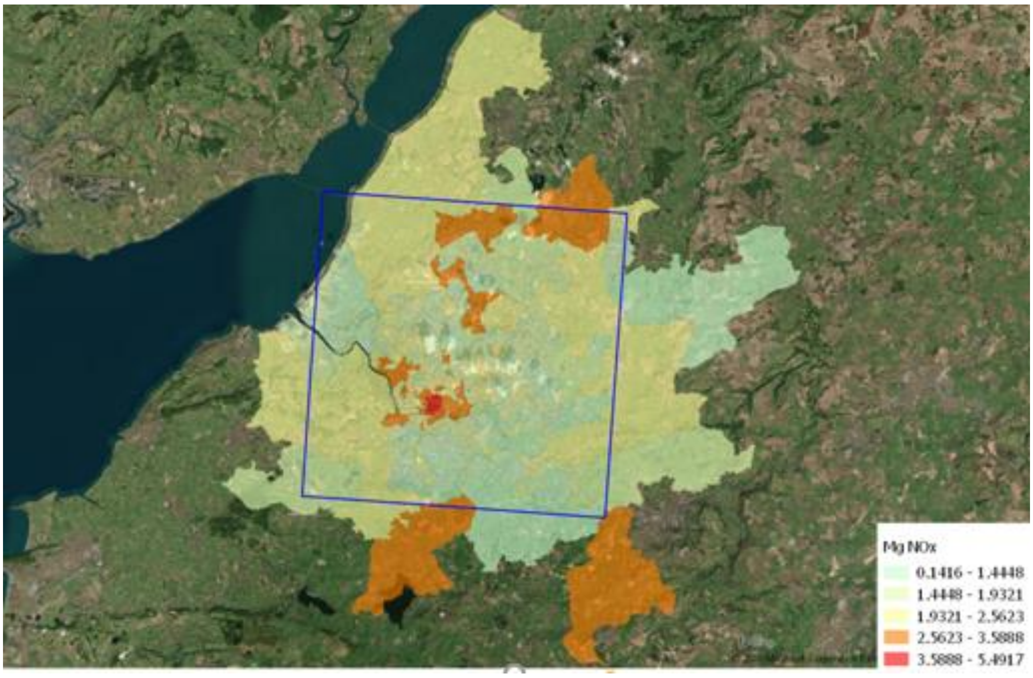


Figure 3-10: Bristol baseline LSOA Residential, Commercial & Institutional NO_x emissions – all sectors and fuels.

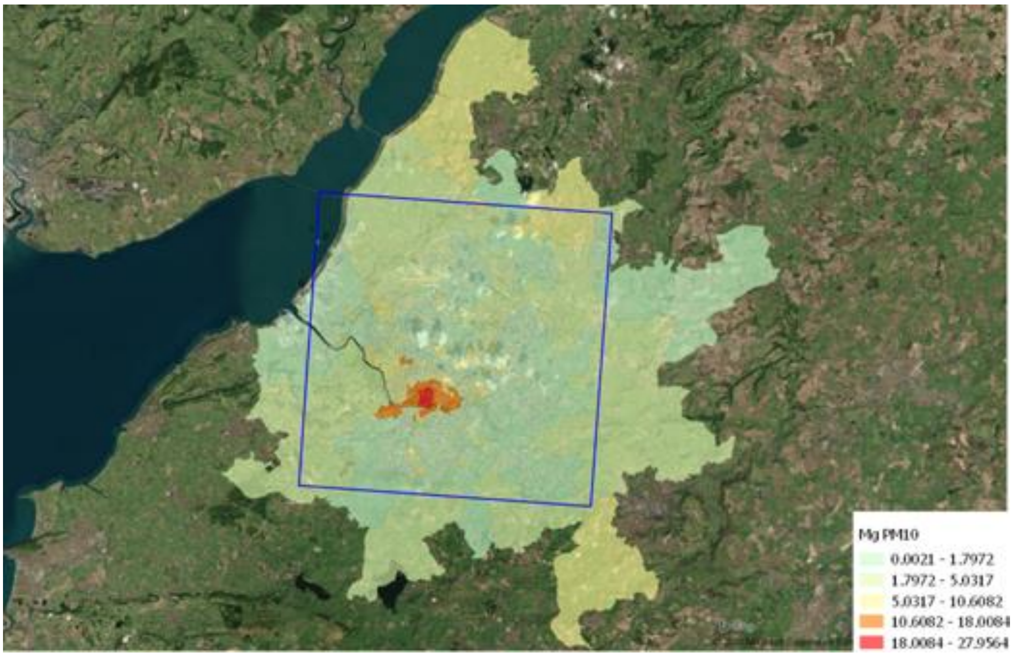


Figure 3-11: Bristol baseline LSOA Residential, Commercial & Institutional PM_{10} emissions – all sectors and fuels.

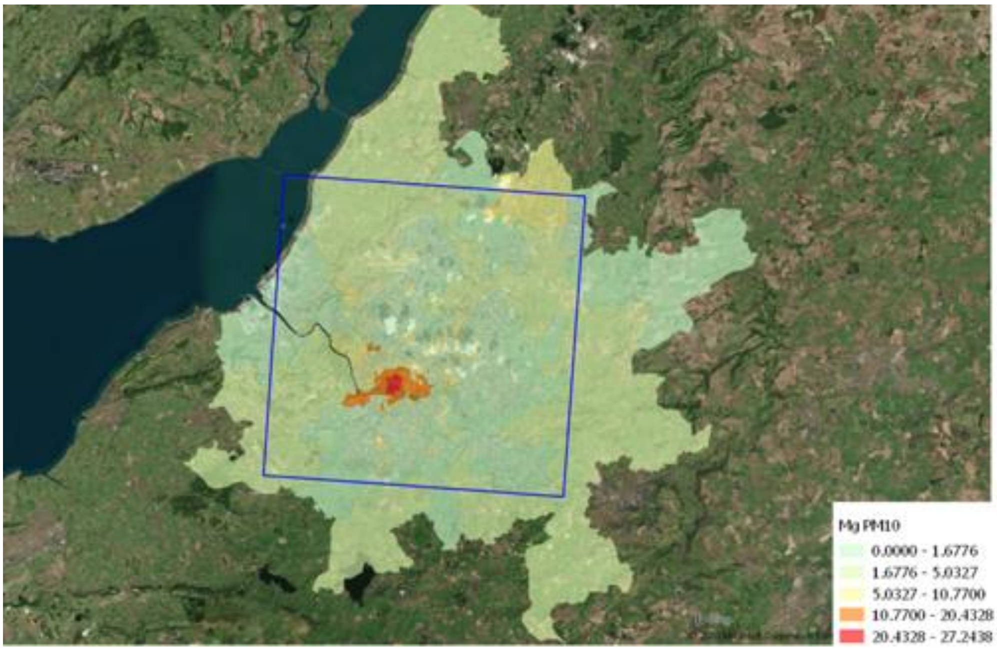


Figure 3-12: Bristol baseline LSOA Residential, Commercial & Institutional PM_{10} emissions – biomass.

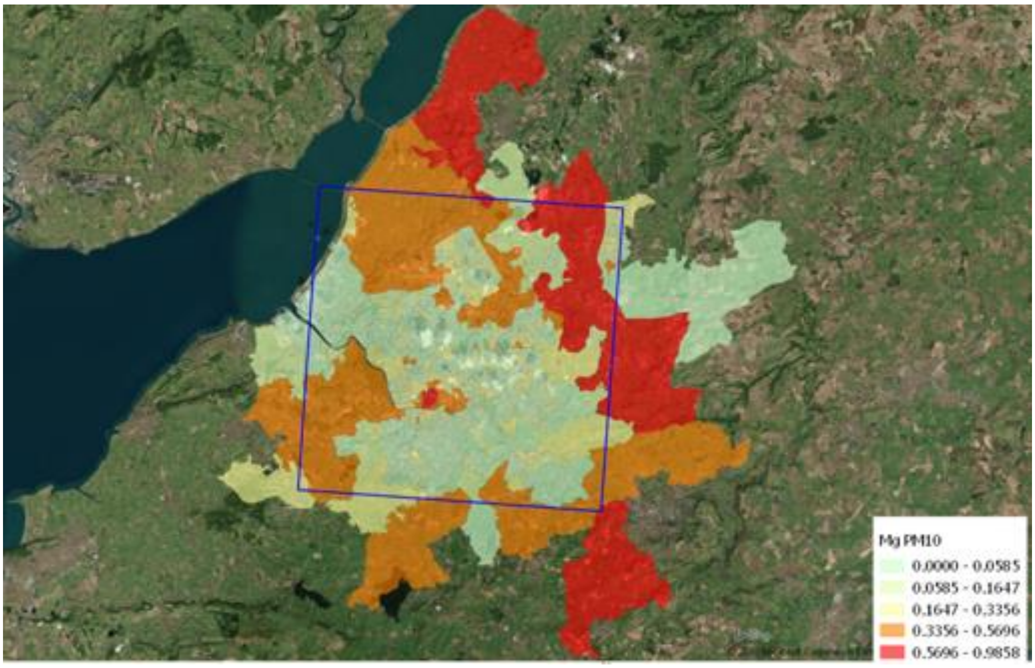


Figure 3-13: Bristol baseline LSOA Residential, Commercial & Institutional PM_{10} emissions – hard coal.

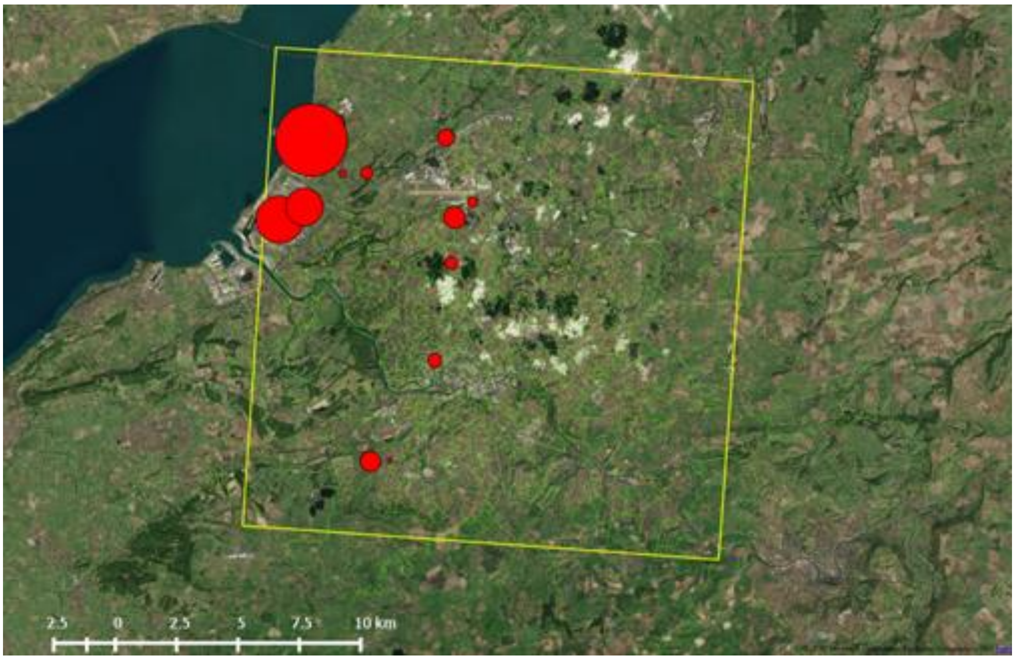


Figure 3-14: Bristol baseline Industry NO_x emissions.

Figure 3-15: Bristol baseline Industry PM_{10} emissions.

Finally, in the following Figure 3-16 and Figure 3-17 the emissions for the different activities & fuels in the only City of Bristol MSOA are reported.

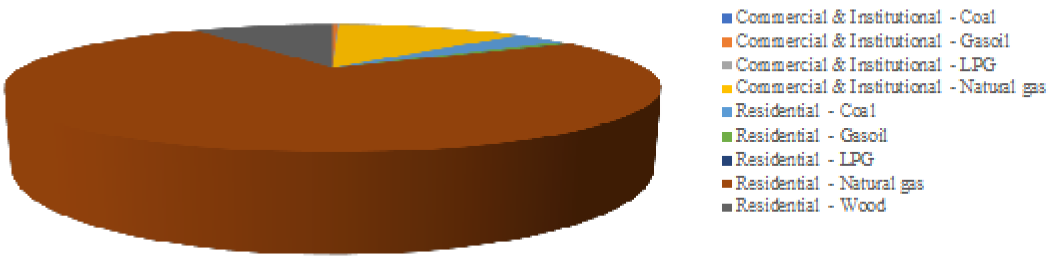


Figure 3-16: City of Bristol baseline MSOA Residential, Commercial & Institutional NO_x emissions.

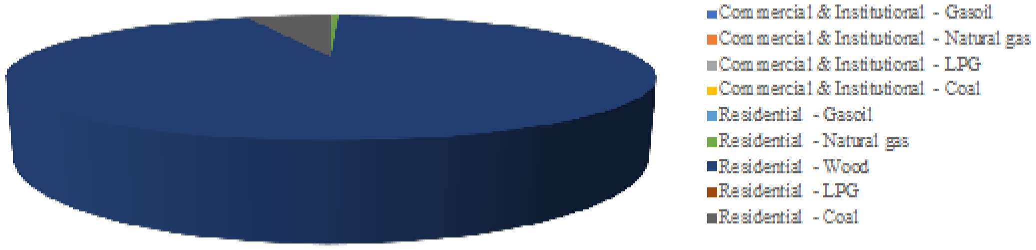


Figure 3-17: City of Bristol MSOA baseline Residential, Commercial & Institutional PM_{10} emissions.

3.3.2 BAU

The evolutions of industrial area emissions are reported in Figure 3-18 for nitrogen oxides (NO_x) and in Figure 3-19 for suspended particles with diameter less than 10µ (PM_{10}).

In Figure 3-20 the evolution of emissions for nitrogen oxides (NO_x) are reported for main point sources. For the Seabank Power Station in Severnside there is a proposal to extend the plant with two additional CCGTs in a project known as Seabank 3. The proposal includes the development of two additional combined cycle gas turbines (CCGT) with a combined capacity of up to 1,400 MW integrated with existing gas and electricity transmission infrastructure. During late 2014 the decision was taken to pause the development of the Seabank 3 project. This situation remains unchanged, stakeholders will be updated should the development of the project recommence[19].

More information is necessary to evaluate the state of evolution of new sections planned in Avonmouth Bio Power Energy Limited, while no notice is available about the evolution of Wessex Water Services Ltd. Both are considered constant in BAU.

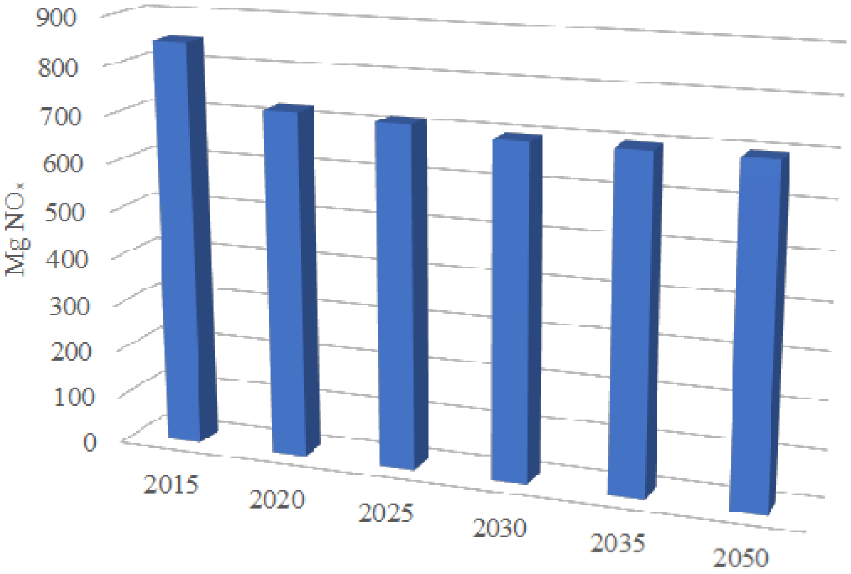


Figure 3-18: Bristol BAU NO_x Industrial area emissions.

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[19] Sebank 3

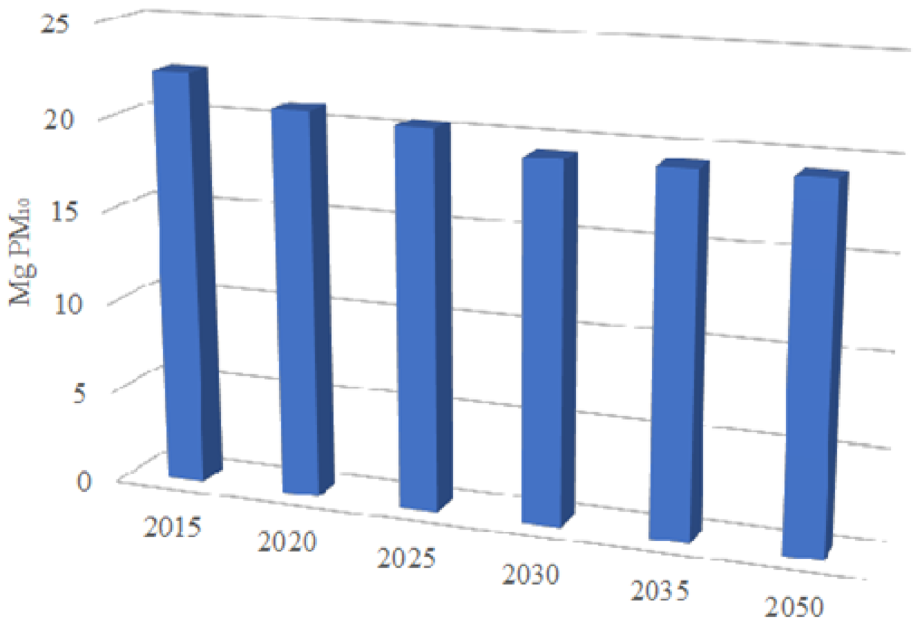


Figure 3-19: Bristol BAU PM_{10} Industrial area emissions.

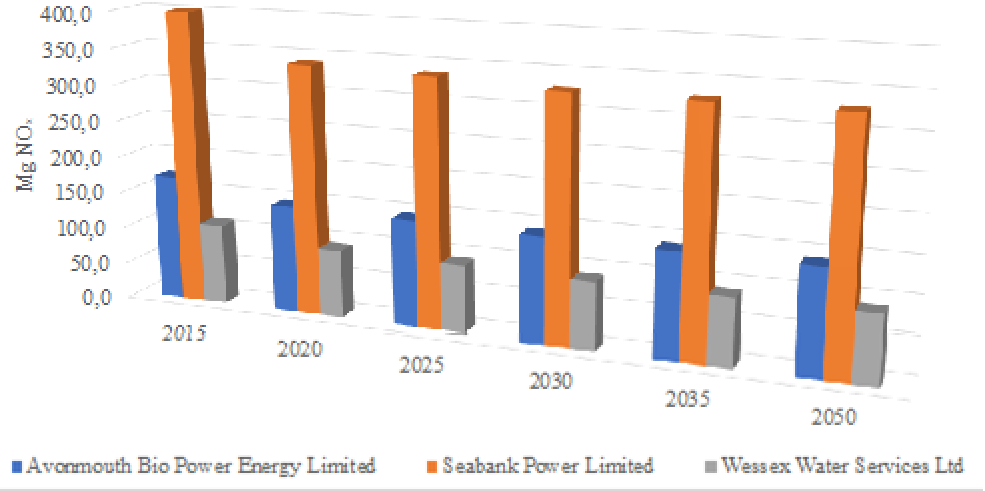


Figure 3-20: Bristol BAU Industrial NO_x emissions: main point sources.

In Figure 3-21 for nitrogen oxides (NO_x) and in Figure 3-22 for suspended particles with diameter less than 10μ (PM_{10}) the evolutions of emissions are reported.

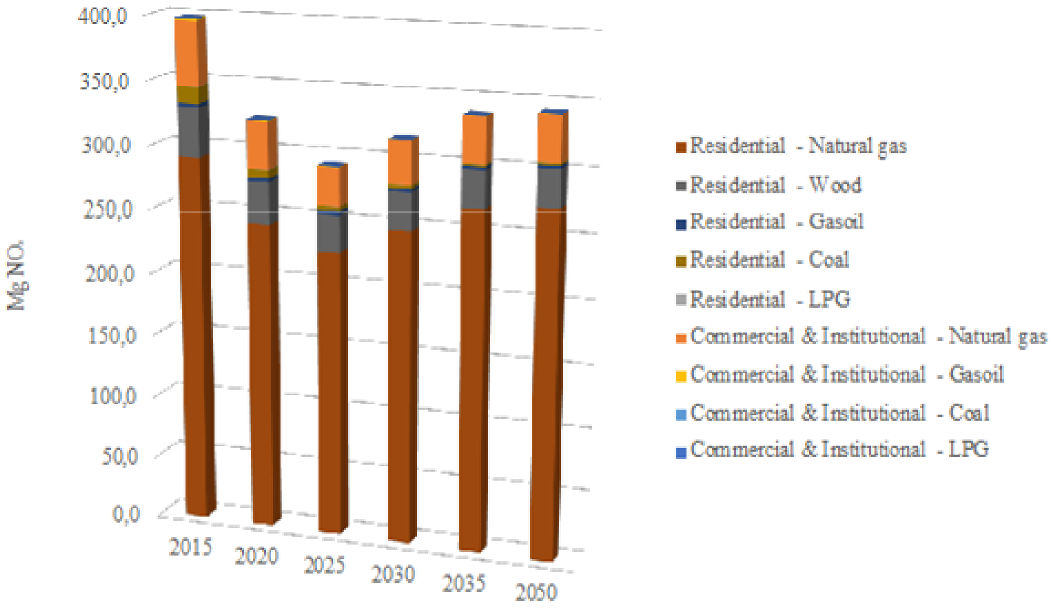


Figure 3-21: Bristol BAU total Residential, Commercial & Institutional NO_x emissions.

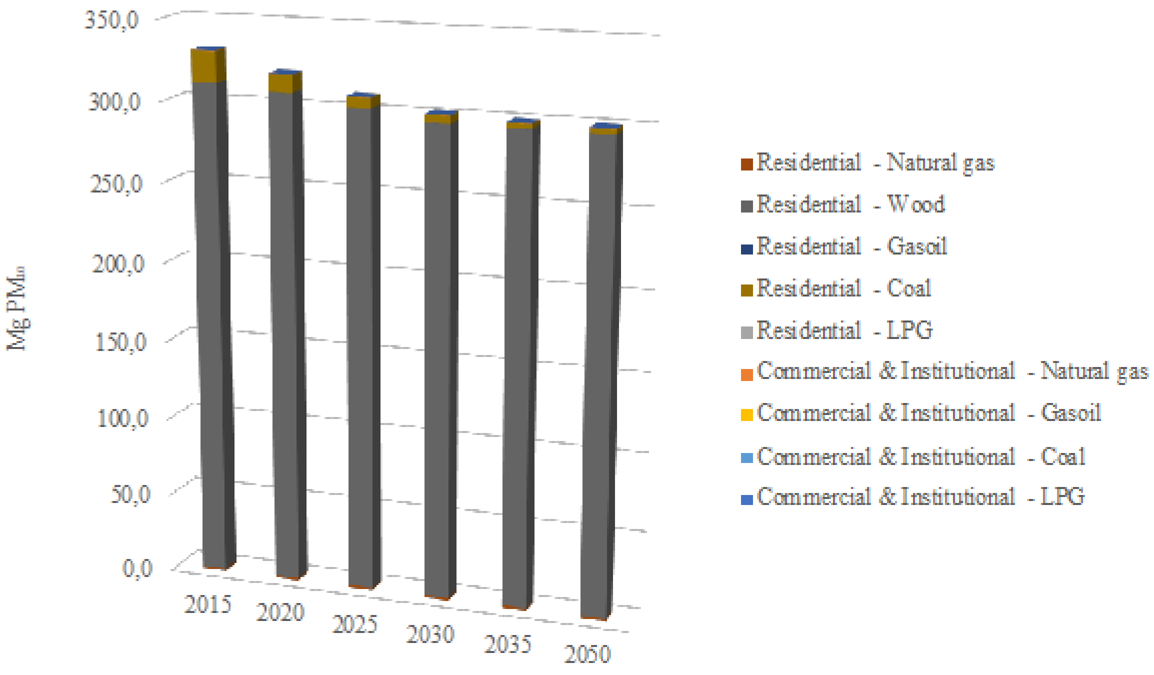


Figure 3-22: Bristol BAU Residential, Commercial & Institutional PM_{10} emissions.

3.3.3 Stakeholder dialog workshop Scenarios

In the following the results for the Scenario 3 are reported. Scenario 2 has no measures affecting the IRCI sector while Scenario 1 has only measures that affect the carbon footprint and not the pollutant emissions. We indicate as “renewables and efficiency” the Scenario 3.

As no indications are available for industrial emissions, in scenario analysis, were kept constant with respect to the BAU scenario.

The only scenario from the stakeholder dialog workshop that include measures about Residential, commercial & institutional sector is the Scenario 3, while no indications are available for industrial emissions that, in scenario analysis, were kept constant with respect to the BAU scenario. In the following we discuss in consequence the results for Scenario 3 in Residential, commercial & institutional sector.

The Scenario include only the Bristol MSOA while the emissions from surrounding MSOA are kept constant. As a consequence, in the following figures emissions trend are reported for the Bristol MSOA only.

In Figure 3-23 for nitrogen oxides (NO_x) and Figure 3-24 for suspended particles with diameter less than 10μ (PM_{10}) the trends of emissions are reported for scenario 3.

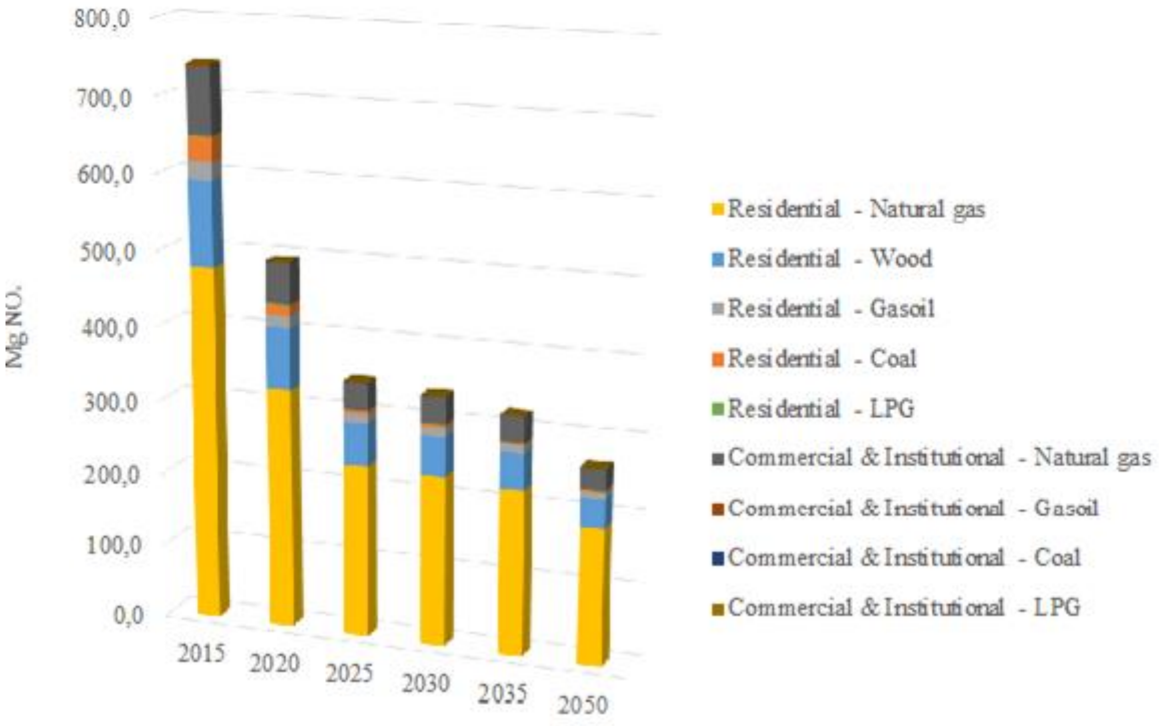


Figure 3-23: Bristol Scenario 3 (renewables & efficiency): Residential, Commercial & Institutional NO_x emissions – all sectors and fuels.

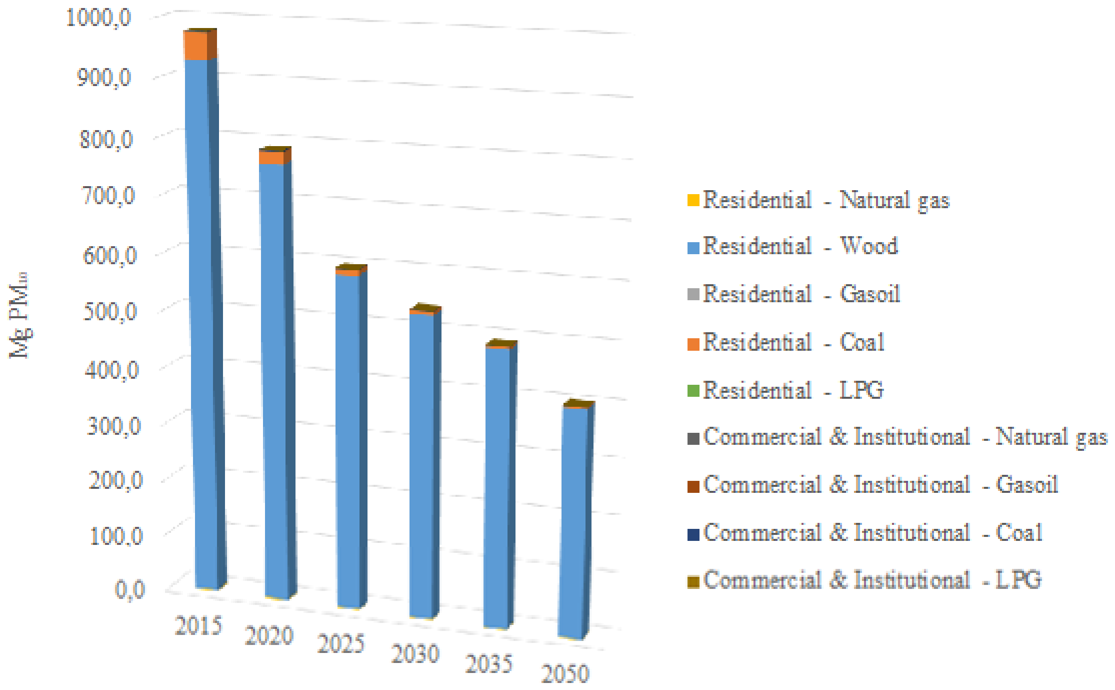


Figure 3-24: Bristol Scenario 3 (renewables & efficiency): Residential, Commercial & Institutional PM_{10} emissions – all sectors and fuels.

In Figure 3-25 for nitrogen oxides (NO_x) and in Figure 3-26 for suspended particles with diameter less than 10µ (PM_{10}) the comparison of the trends of emissions are reported for the different scenarios.

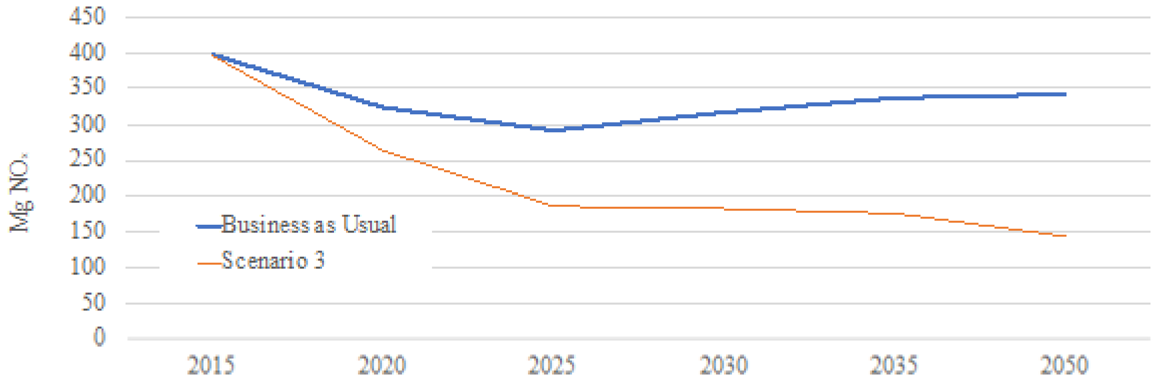


Figure 3-25: Bristol BAU & Scenario 3 (renewables & efficiency) comparison: Residential, Commercial & Institutional NO_x emissions – all sectors and fuels.

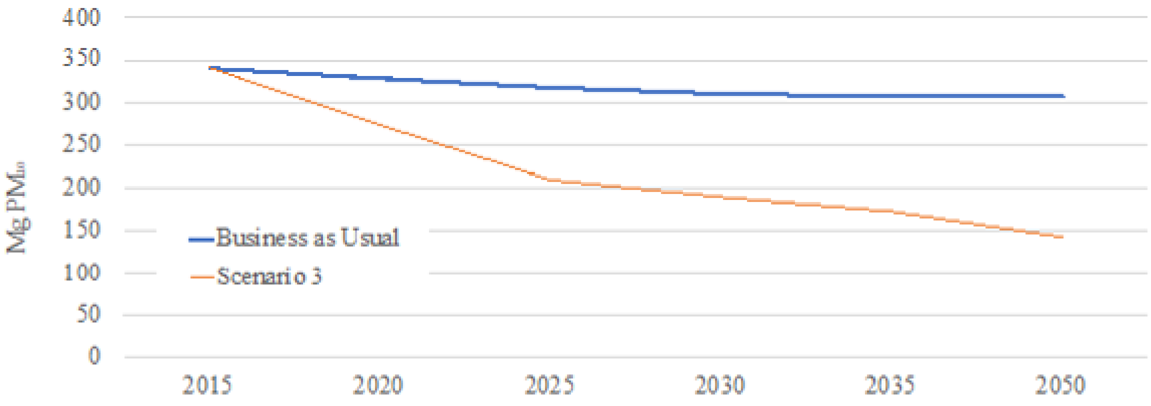


Figure 3-26: Bristol BAU & Scenario 3 (renewables & efficiency) comparison: Residential, Commercial & Institutional PM_{10} emissions – all sectors and fuels.

3.3.4 Unified Policy Scenario

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

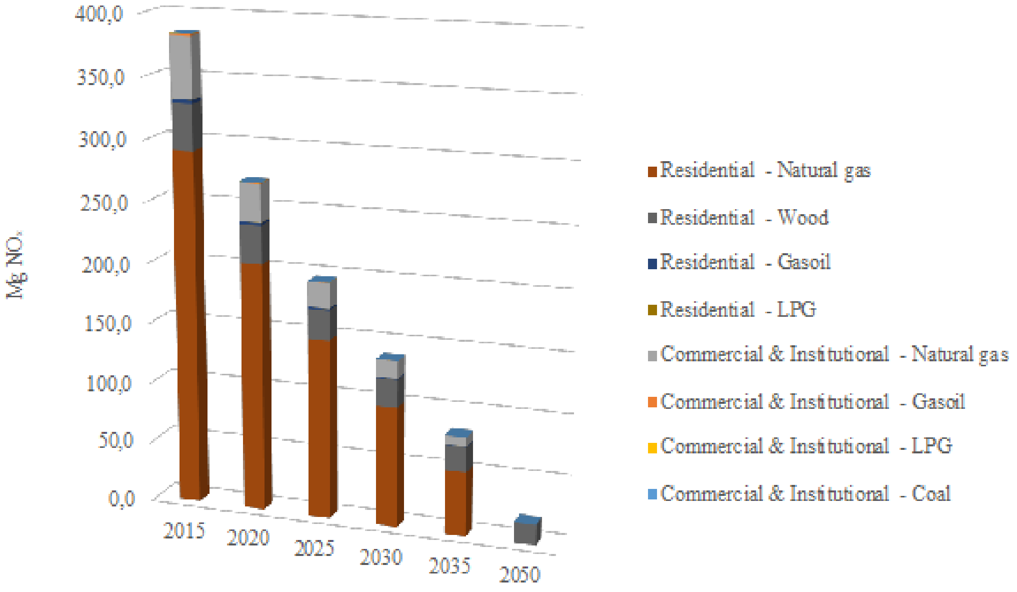


Figure 3-27: Bristol Unified Policy Scenario: Residential, Commercial & Institutional NO_x emissions – all sectors and fuels.

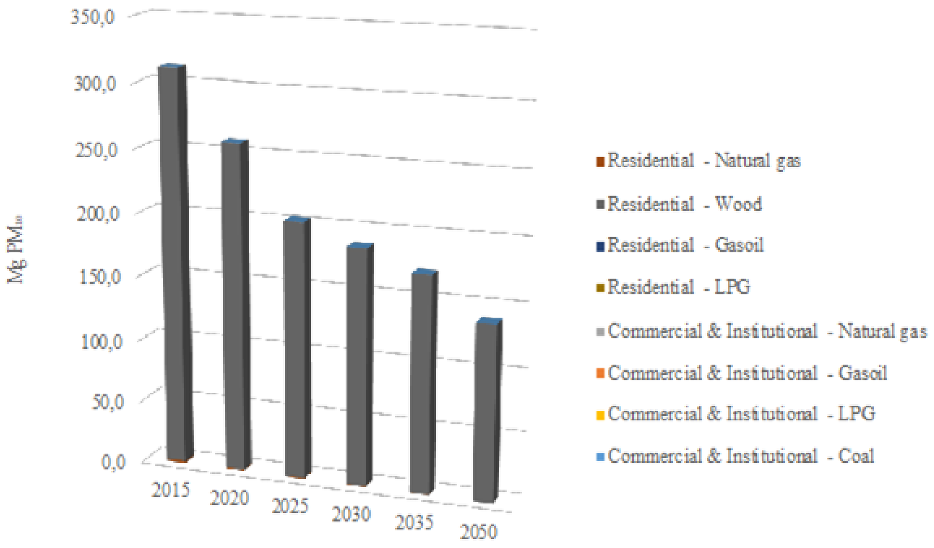


Figure 3-28: Bristol Unified Policy Scenario: Residential, Commercial & Institutional PM_{10} emissions – all sectors and fuels.

In Figure 3-29 for nitrogen oxides (NO_x) and in Figure 3-30 for suspended particles with diameter less than 10µ (PM_{10}) the comparison of the trends of emissions are reported for Business As Usual (BAU) and Unified Policy (UP) scenarios.

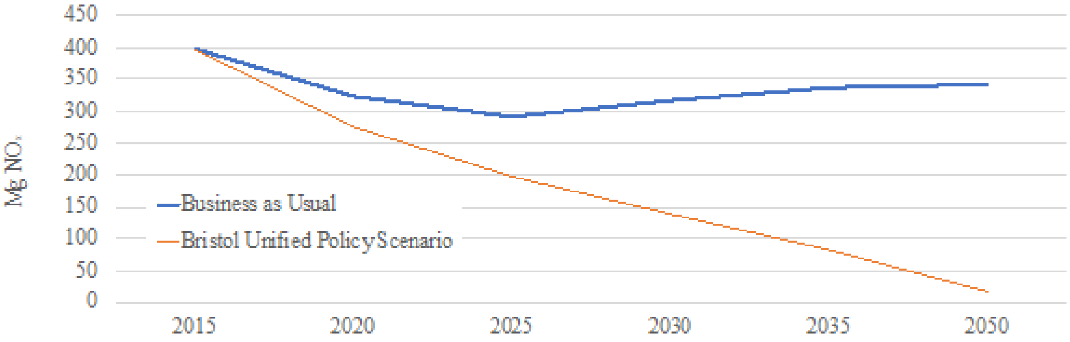


Figure 3-29: Bristol BAU & Unified Policy Scenario comparison: Residential, Commercial & Institutional NO_x emissions – all sectors and fuels.

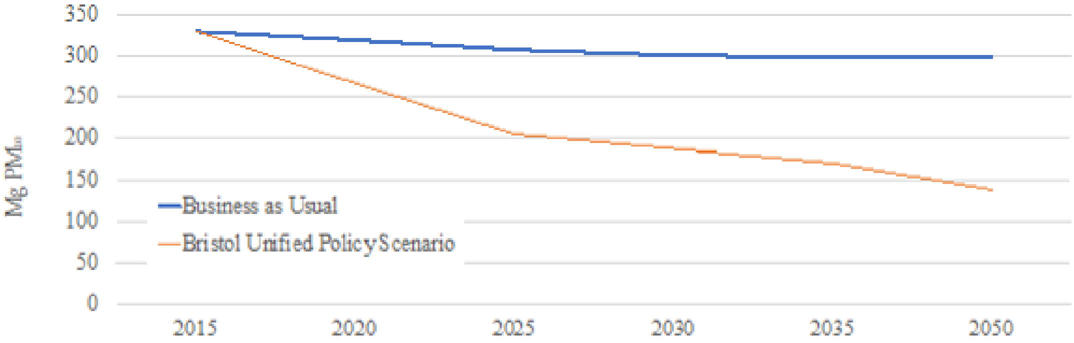


Figure 3-30: Bristol BAU & Unified Policy Scenario comparison: Residential, Commercial & Institutional PM_{10} emissions – all sectors and fuels.

3.4 Carbon footprint

3.4.1 Baseline

In Table 3-2, the Carbon Footprint by fuel is reported for Bristol expressed as CO_2, CO_2 equivalent and CO_2 equivalent on Life Cycle.

Table 3-2: Bristol Carbon Footprint by Fuel (Mg).

Energy Vector	CO_2	CO_{2eq}	$CO_{2eq,LCA}$
Biomass	-	2.711	6.706
Gasoil/diesel	210.902	211.471	241.599
Gasoline	160.192	160.655	201.860
Hard Coal	9.037	9.093	9.479
LPG	3.678	3.678	4.552
Natural gas	544.097	544.097	646.903
Electricity	953.299	956.630	1.089.865
Total	1.881.204	1.888.334	2.200.964

In Figure 1-31 Carbon Footprint expressed as CO_2 equivalent on Life Cycle is reported by fuel and sector.

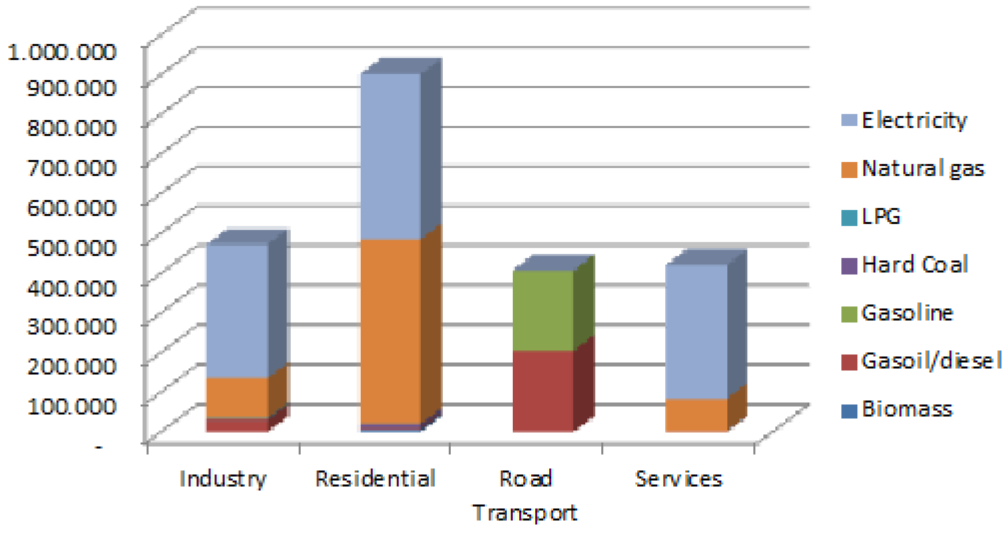


Figure 1-31: Carbon Footprint expressed as CO_2 equivalent on Life Cycle by fuel and sector.

3.4.2 BAU

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

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

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide (CO_2)						
Residential	767,4	556,6	519,6	537,9	533,2	479,8
Services	364,8	199,8	146,6	141,9	115,5	65,8
Transport	339,6	336,6	331,1	308,2	276,3	135,3
Industry	409,4	232,2	173,2	151,9	130,3	97,7
Total	***1881,2***	***1325,1***	***1170,5***	***1139,9***	***1055,3***	***778,7***
Carbon dioxide equivalent (CO_{2eq})						
Industry	771,5	559,9	522,8	541,0	536,1	482,6
Services	365,9	200,3	146,9	142,2	115,7	65,8
Transport	340,5	337,5	332,0	309,0	277,1	135,7
Residential	410,5	232,7	173,6	152,2	130,5	97,8
Total	***1888,3***	***1330,4***	***1175,3***	***1144,5***	***1059,4***	***781,9***

	Carbon dioxide equivalent on life cycle (CO_{2eq})					
Residential	901,1	659,7	618,5	640,9	637,2	576,6
Services	420,3	231,0	170,1	165,0	134,9	78,0
Transport	407,4	403,5	396,7	370,6	334,3	168,2
Industry	472,2	269,3	201,5	176,8	152,2	115,0
Total	***2201,1***	***1563,6***	***1386,8***	***1353,4***	***1258,7***	***937,9***

Table 3-4: Bristol 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	73	68	70	69	63
Services	100	55	40	39	32	18
Transport	100	99	97	91	81	40
Industry	100	57	42	37	32	24
Total	***100***	***70***	***62***	***61***	***56***	***41***

Carbon Footprint, expressed as CO_2 equivalent on Life Cycle, is reported in

Figure 3-32: Bristol BAU Carbon Footprint by sector (Gg CO_2 equivalent on Life Cycle).

by sector and in Figure 3-33 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.

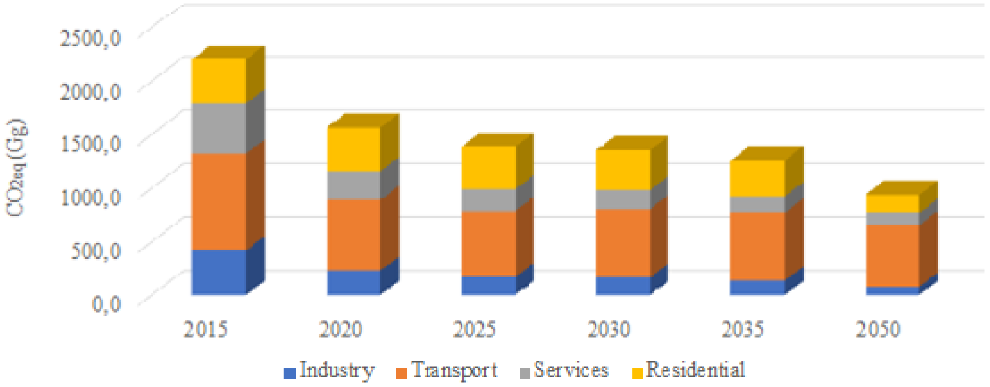


Figure 3-32: Bristol BAU Carbon Footprint by sector (Gg CO_2 equivalent on Life Cycle).

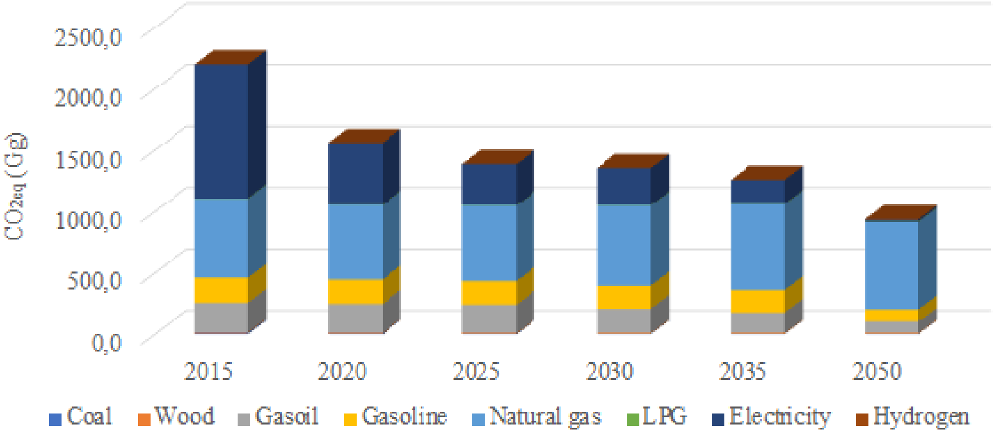


Figure 3-33: Bristol BAU Carbon Footprint by fuel (Gg CO_2 equivalent on Life Cycle).

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 3-5 Carbon Footprint by sector is reported for Bristol Scenario 1 expressed as CO_2, CO_2 equivalent and CO_2 equivalent on Life Cycle. In Table 3-6 CO_2 equivalent on Life Cycle reductions on 2015 are reported.

For the Scenario 1, Carbon Footprint, expressed as CO_2 equivalent on Life Cycle, is reported in Figure 3-34 by sector and in Figure 3-35 by fuel.

Table 3-5: Bristol Scenario 1 Carbon Footprint by Sector (Gg).

Year	2015	2020	2025	2030	2035	2050
		Carbon dioxide (CO_2)				
Residential	767,4	553,1	513,7	532,6	529,8	479,4
Services	364,8	196,9	142,0	137,8	112,8	65,4
Transport	339,6	333,8	323,3	299,9	266,7	124,2
Industry	409,4	229,7	169,4	148,9	128,5	97,5
Total	***1881,2***	***1313,6***	***1148,4***	***1119,2***	***1037,9***	***766,4***
		Carbon dioxide equivalent (CO_{2eq})				
Residential	771,5	556,5	516,8	535,7	532,8	482,1
Services	365,9	197,4	142,3	138,1	113,0	65,4
Transport	340,5	334,7	324,2	300,7	267,4	124,6
Industry	410,5	230,2	169,8	149,2	128,7	97,6
Total	***1888,3***	***1318,8***	***1153,0***	***1123,7***	***1042,0***	***769,6***
		Carbon dioxide equivalent on life cycle (CO_{2eq})				
Residential	901,1	659,7	618,5	640,9	637,2	576,6
Services	420,3	231,0	170,1	165,0	134,9	78,0
Transport	407,4	361,7	311,6	290,9	262,0	128,8
Industry	472,2	269,3	201,5	176,8	152,2	115,0
Total	***2.201,1***	***1.521,8***	***1.301,6***	***1.273,7***	***1.186,4***	***898,5***

Table 3-6: Bristol Scenario 1 Carbon Footprint by Sector: index (2015=100).

Year	2015	2020	2025	2030	2035	2050
		Carbon dioxide equivalent on life cycle (CO_{2eq})				
Residential	100	73	68	70	70	64
Services	100	54	39	38	31	18
Transport	100	98	95	89	79	38
Industry	100	56	42	37	32	24
Total	***100***	***70***	***62***	***60***	***56***	***42***

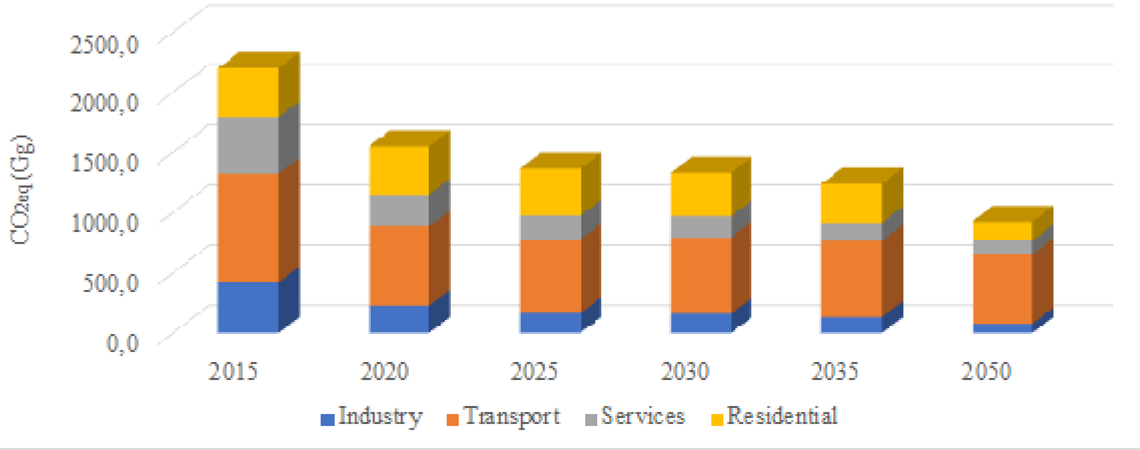


Figure 3-34: Bristol Scenario 1 Carbon Footprint by sector (Gg CO_2 equivalent on Life Cycle).

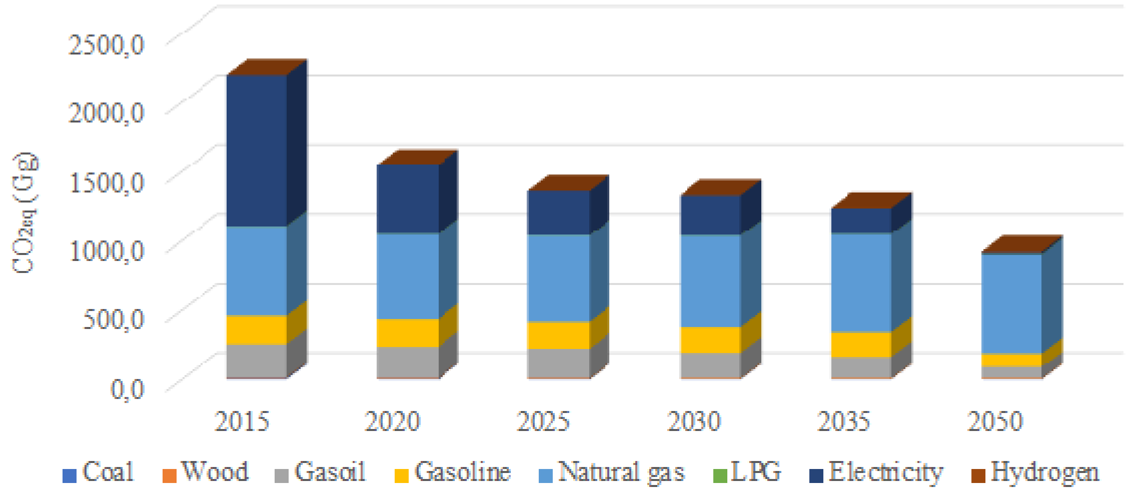


Figure 3-35: Bristol Scenario 1 Carbon Footprint by fuel (Gg CO_2 equivalent on Life Cycle).

In Table 3-7 Carbon Footprint by sector is reported for Bristol Scenario 2 expressed as CO_2, CO_2 equivalent and CO_2 equivalent on Life Cycle. In

Table 3-8 CO_2 equivalent on Life Cycle reductions on 2015 are reported.

Table 3-7: Bristol Scenario 2 Carbon Footprint by Sector (Gg).

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide (CO_2)						
Residential	767,4	556,6	519,6	537,9	533,2	479,8
Services	364,8	199,8	146,6	141,9	115,5	65,8
Transport	339,6	301,7	260,0	242,0	216,8	103,5
Industry	409,4	232,2	173,2	151,9	130,3	97,7
Total	***1881,2***	***1290,3***	***1099,5***	***1073,8***	***995,8***	***746,8***
Carbon dioxide equivalent (CO_{2eq})						
Residential	771,5	559,9	522,8	541,0	536,1	482,6
Services	365,9	200,3	146,9	142,2	115,7	65,8
Transport	340,5	302,6	260,7	242,7	217,4	103,7
Industry	410,5	232,7	173,6	152,2	130,5	97,8
Total	***1.888,3***	***1.295,5***	***1.104,0***	***1.078,1***	***999,7***	***749,9***
Carbon dioxide equivalent on life cycle (CO_{2eq})						
Residential	901,1	659,7	618,5	640,9	637,2	576,6
Services	420,3	231,0	170,1	165,0	134,9	78,0
Transport	407,4	361,7	161,0	290,9	262,0	128,8
Industry	471,9	269,3	201,5	176,8	152,2	115,0
Total	***2200,7***	***1521,8***	***1151,0***	***1273,7***	***1186,4***	***898,5***

Table 3-8: Bristol Scenario 2 Carbon Footprint by Sector: index (2015=100).

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide equivalent on life cycle (CO_{2eq})						
Residential	100	73	69	71	71	64
Services	100	55	40	39	32	19
Transport	100	89	76	71	64	32
Industry	100	57	43	37	32	24
Total	***100***	***69***	***59***	***58***	***54***	***41***

For the Scenario 2, Carbon Footprint, expressed as CO_2 equivalent on Life Cycle, is reported in Figure 3-36 by sector and in Figure 3-37 by fuel.

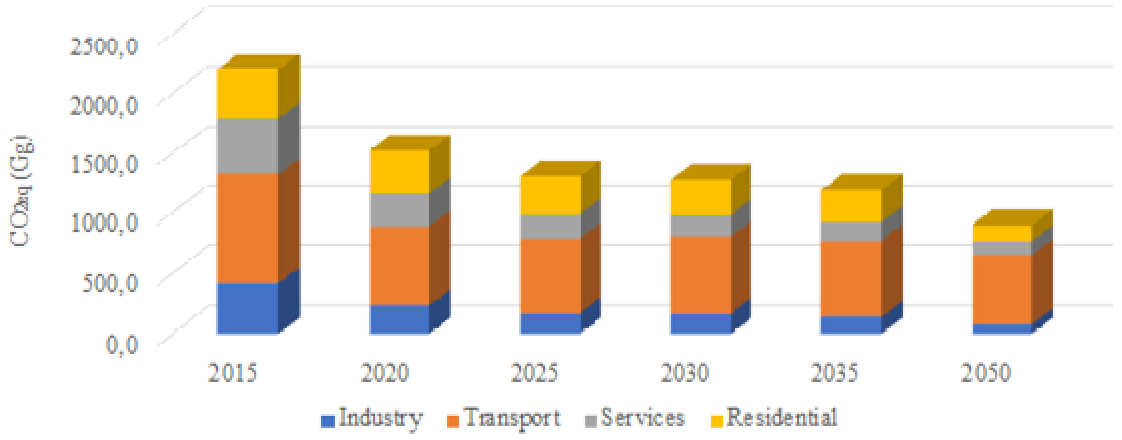


Figure 3-36: Bristol Scenario 2 Carbon Footprint by sector (Gg CO_2 equivalent on Life Cycle).

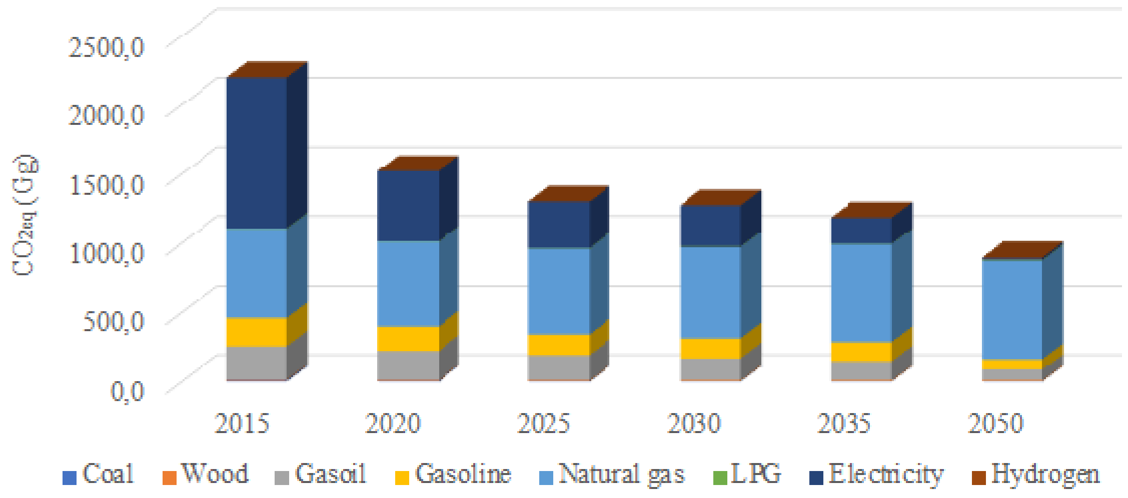


Figure 3-37: Bristol Scenario 2 Carbon Footprint by fuel (Gg CO_2 equivalent on Life Cycle).

In Table 3-9 Carbon Footprint by sector is reported for Bristol Scenario 3 expressed as CO_2, CO_2 equivalent and CO_2 equivalent on Life Cycle. In

Table 3-10 CO_2 equivalent on Life Cycle reductions on 2015 are reported.

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

Table 3-9: Bristol Scenario 3 Carbon Footprint by Sector (Gg).

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide (CO_2)						
Residential	767,4	481,5	365,7	347,1	302,0	200,9
Services	364,8	187,0	122,8	113,9	85,0	31,3
Transport	339,6	262,6	167,8	132,7	94,8	38,2
Industry	409,4	229,7	169,4	148,9	128,5	97,5
Total	***1881,2***	***1160,8***	***825,7***	***742,5***	***610,3***	***367,9***
Carbon dioxide equivalent (CO_{2eq})						
Residential	771,5	484,4	367,8	349,1	303,7	202,2
Services	365,9	187,5	123,1	114,1	85,2	31,3
Transport	340,5	263,3	168,2	133,0	95,1	38,3
Industry	410,5	230,2	169,8	149,2	128,7	97,6
Total	***1888,3***	***1165,4***	***828,9***	***745,4***	***612,6***	***369,3***
Carbon dioxide equivalent on life cycle (CO_{2eq})						
Residential	901,1	569,7	433,6	411,8	359,7	241,6
Services	420,3	216,0	142,0	131,8	98,7	37,1
Transport	407,4	315,4	202,9	161,3	116,6	50,0
Industry	472,2	266,5	197,1	173,4	150,2	114,7
Total	***2201,1***	***1367,5***	***975,6***	***878,3***	***725,2***	***443,3***

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

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide equivalent on life cycle (CO_{2eq})						
Residential	100	63	48	46	40	27
Services	100	51	34	31	23	9
Transport	100	77	50	40	29	12
Industry	100	56	42	37	32	24
Total	***100***	***62***	***44***	***40***	***33***	***20***

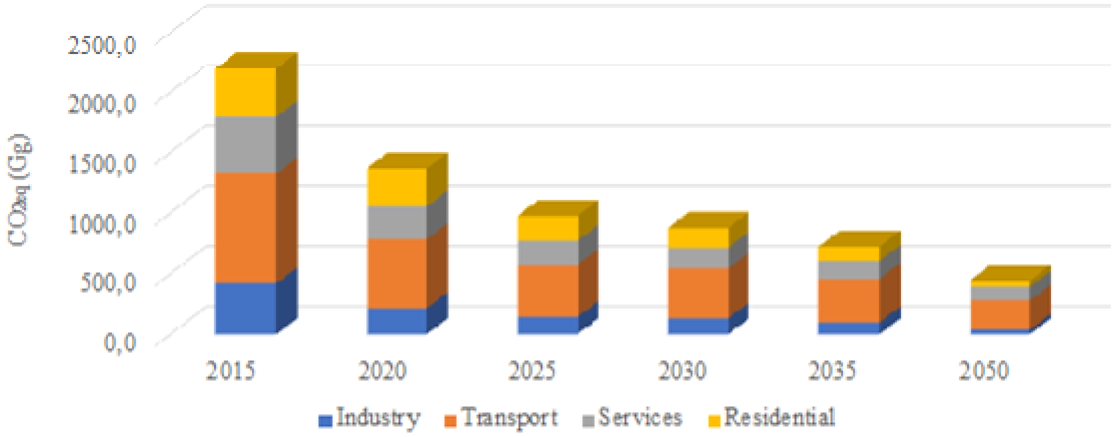


Figure 3-38: Bristol Scenario 3 Carbon Footprint by sector (Gg CO_2 equivalent on Life Cycle).

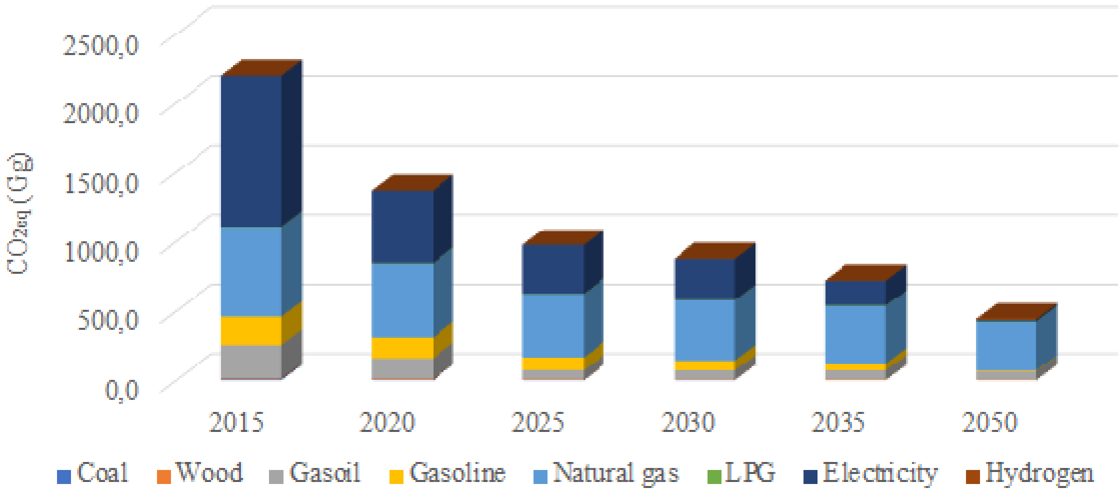


Figure 3-39: Bristol Scenario 3 Carbon Footprint by fuel (Gg CO_2 equivalent on Life Cycle).

3.4.4 Unified Policy Scenario

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

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

Table 3-11: Bristol Unified Policy Scenario Carbon Footprint by Sector (Gg).

Year	2015	2020	2025	2030	2035	2050
Carbon dioxide (CO_2)						
Residential	767,4	453,8	321,1	241,8	138,3	4,7
Services	364,8	184,9	120,3	101,8	63,8	3,8
Transport	339,6	329,7	310,2	209,4	97,8	35,4
Industry	409,4	232,2	173,2	151,9	130,3	97,7
Total	***1881,2***	***1200,6***	***924,9***	***704,9***	***430,2***	***141,6***
Carbon dioxide equivalent (CO_{2eq})						
Residential	771,5	456,6	323,3	243,8	140,1	5,9
Services	365,9	185,4	120,6	102,1	64,0	3,8
Transport	340,5	330,6	311,1	210,0	98,1	35,5
Industry	410,5	232,7	173,6	152,2	130,5	97,8
Total	***1888,3***	***1205,4***	***928,6***	***708,0***	***432,6***	***143,1***
Carbon dioxide equivalent on life cycle (CO_{2eq})						
Residential	901,1	536,6	380,4	286,5	165,1	8,4
Services	420,3	213,4	138,8	117,2	73,4	4,4
Transport	407,4	395,6	372,8	252,9	120,6	47,1
Industry	472,2	269,3	201,5	176,8	152,2	115,0
Total	***2201,1***	***1414,9***	***1093,5***	***833,4***	***511,3***	***174,9***

Table 3-12: Bristol 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	60	42	32	18	1
Services	100	51	33	28	17	1
Transport	100	97	91	62	30	12
Industry	100	57	43	37	32	24
Total	***100***	***64***	***50***	***38***	***23***	***8***

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

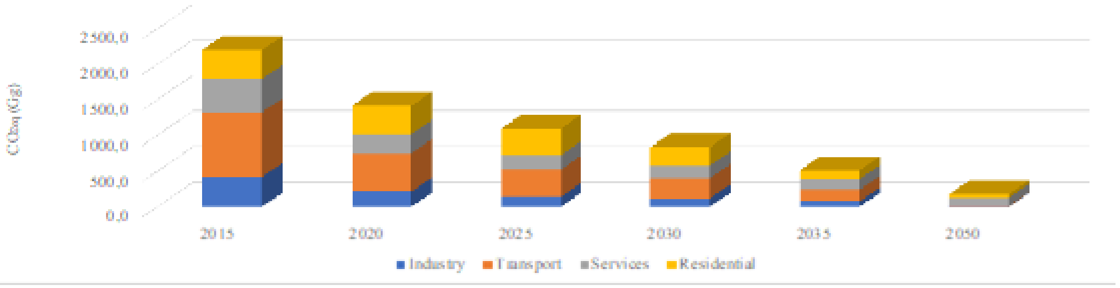


Figure 3-40: Bristol Unified Policy Scenario Carbon Footprint by sector (Gg CO_2 equivalent on Life Cycle).

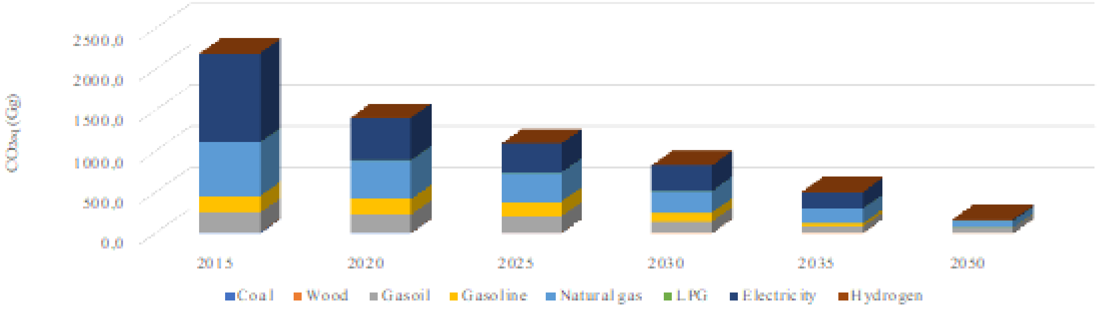


Figure 3-41: Bristol Unified Policy Scenario Carbon Footprint by fuel (Gg CO_2 equivalent on Life Cycle).

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

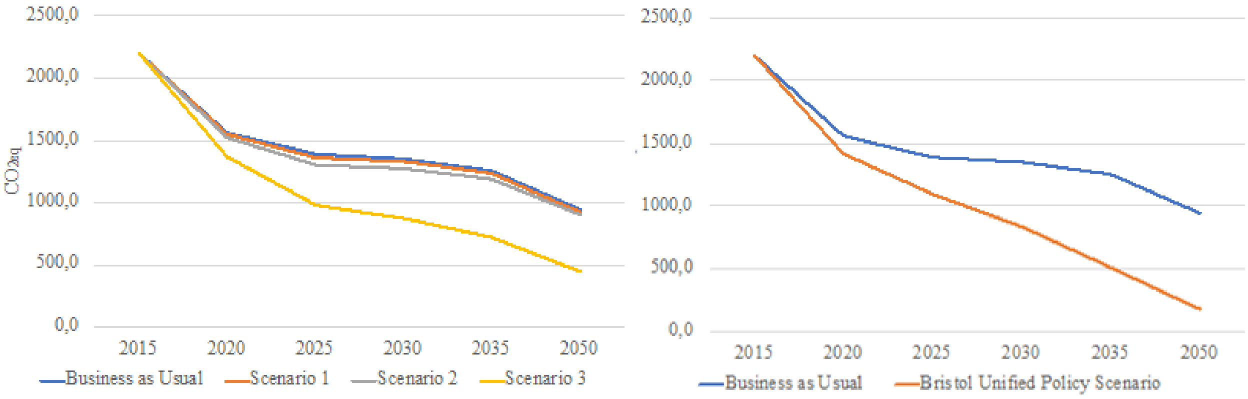


Figure 3-42: Bristol Carbon Footprint (Mg CO_2 equivalent on Life Cycle) by SDW scenario (left) and final unified scenario (right).

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

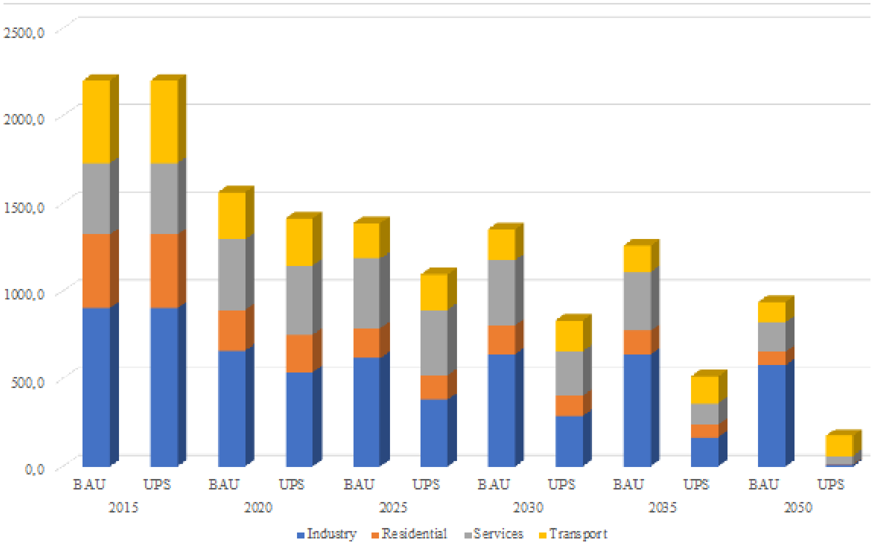


Figure 3-43: Bristol Carbon Footprint BAU and UPS comparison by sector (Mg CO_2 equivalent on Life Cycle).

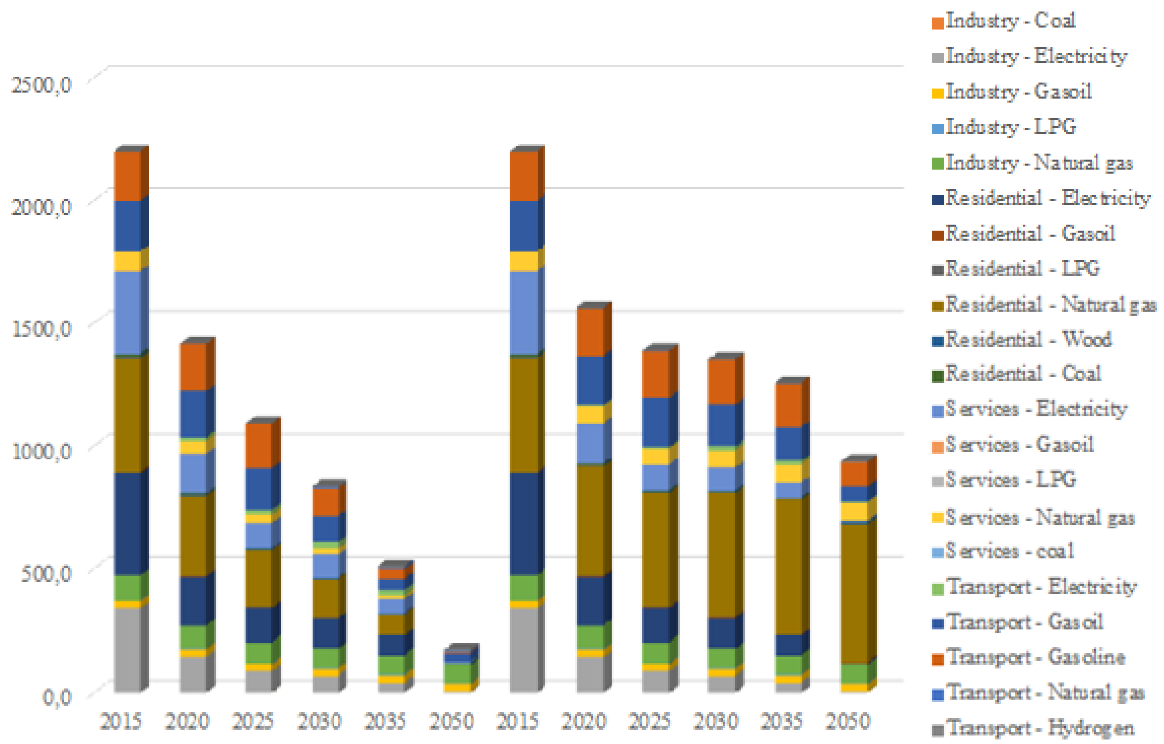


Figure 3-44: Bristol Carbon Footprint BAU and UPS comparison by sector and fuel (Mg CO_2 equivalent on Life Cycle).

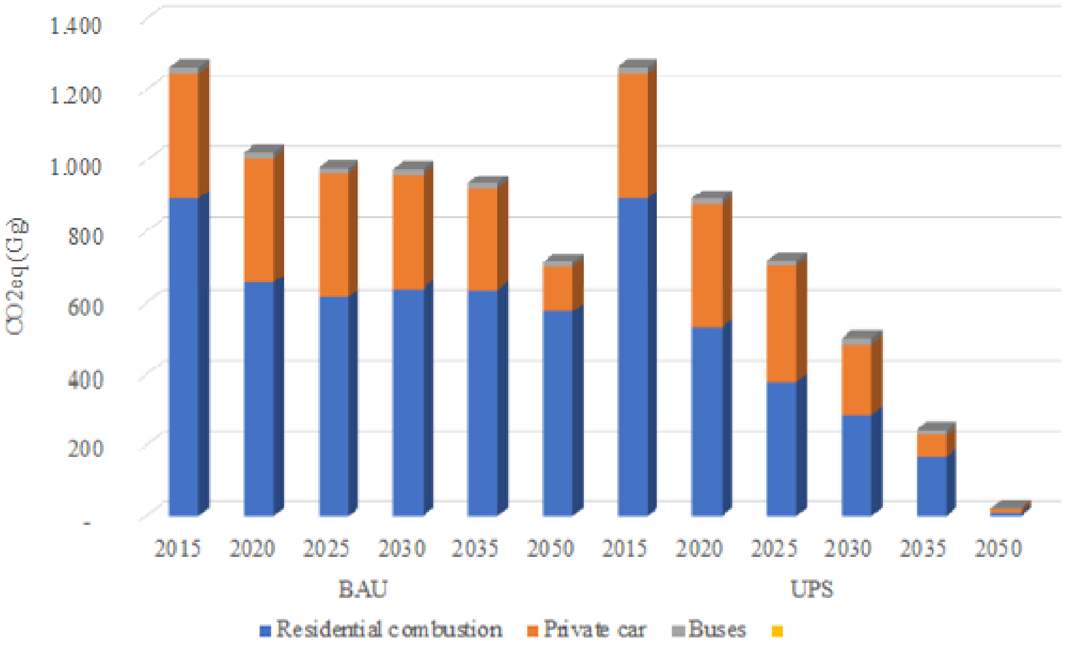


Figure 3-45: Bristol Carbon Footprint generated by citizens' activities in BAU and UPS scenario (Mg CO2 equivalent on Life Cycle).

3.5 Air quality impacts

3.5.1 Assessment of air quality at mesoscale: baseline year

The meteorological characterization in the Bristol, at the mesoscale, was based on the analysis of the spatial average of the following variables: temperature, precipitation and wind speed and direction. The mean air temperatures and accumulated temperature, for each month, are presented in Figure 3-46.

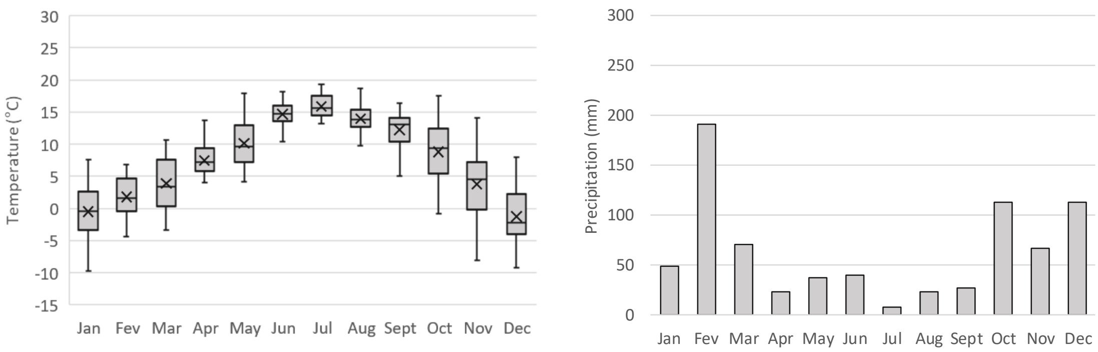


Figure 3-46: (Left) Box and whisker plot of temperature by month; boxes indicate the lower and upper quartile; horizontal line in each box represents the median temperature; the mean temperature for each month is indicated by a x; vertical lines extending from each box represent the minimum and maximum temperature recorded for that month. (Right) Column graph of total precipitation by month.

According to Figure 3-46, in Bristol, the minimum mean temperatures are obtained in December and January, with -1.3°C and 0.5°C, respectively. The month where the highest mean temperature is recorded is July, with 15.8°C, followed by June, with 14.5°C. Regarding precipitation, the months with the highest accumulated precipitation go from October to March (with values up to 190mm), while the driest month is July with 8 mm. During almost the whole year, the wind blows predominantly from the 3rd quadrant (SW), with a wind speed between 2 and 10 $m.s^{-1}$.

The air quality characterization in Bristol, at mesoscale, was based on spatial maps of concentrations and on a source contribution analysis. The spatial analysis was done for the average concentrations of NO_2, PM10 and PM2.5 for the following periods: (i) annual; (ii) a typical winter month (February); and (iii) a typical summer month (August) (Figure 3-47).

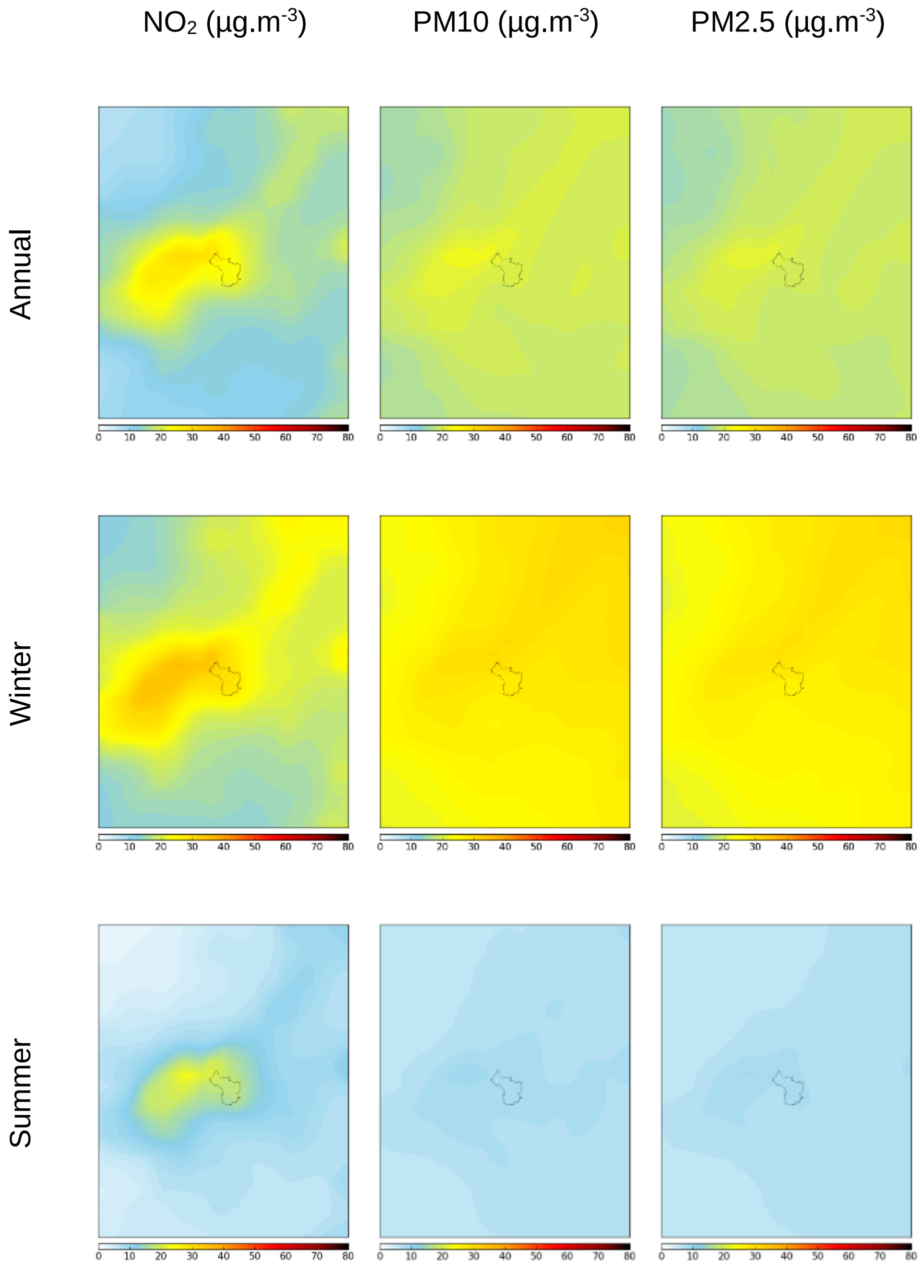


Figure 3-47: Spatial distribution of NO_2, PM10 and PM2.5 concentrations, for the different periods analysed (annual, winter and summer) in Bristol.

Results presented in Figure 3-47 show similar spatial patterns for the different periods and air pollutants analysed. The spatial pattern of both air pollutants concentration follows the predominant wind direction. For both NO_2 and PM, the higher concentration values were obtained in the area west of Bristol, in South Wales. This area is the location of Cardiff, the largest city in Wales, and the eleventh-largest city in the UK; but also the location of one of the biggest coal-fired power plants in the UK. These two factors may be the source of higher concentrations of PM and NO_2 in this area. These results are in accordance with studies conducted in UK (Brookes et al. 2011). Regarding the analysis of seasonal concentration fields, results show that, for all pollutants, the maximum values are found in winter, while the minimum values are recorded in summer. For NO_2, the highest concentration values, for annual, winter and summer periods are 33 µg.m^{-3}, 43 µg.m^{-3} and 23 µg.m^{-3}, respectively. For PM10, the maximum concentration values are close to 23 µg.m^{-3}, for the annual average, 32 µg.m^{-3} in winter and 15 µg.m^{-3} in summer. For PM2.5, the highest concentration values are 22 µg.m^{-3}, 31 µg.m^{-3} and 9 µg.m^{-3} for annual, winter and summer periods, respectively.

The source contribution analysis was provided to estimate the contribution to the modelled NO_2, PM10 and PM2.5 concentrations, from transboundary transport (TBD) and from specific source groups previously defined – residential and commercial combustion (RES), industrial combustion and processes (IND), road transport (TRP) and all the remaining sources (OTH). The results were analysed in terms of the relative contribution of those groups to the NO_2, PM10 and PM2.5 concentration simulated for the urban area of Bristol 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 Bristol for the three periods previously defined, are analysed in Figure 3-48.

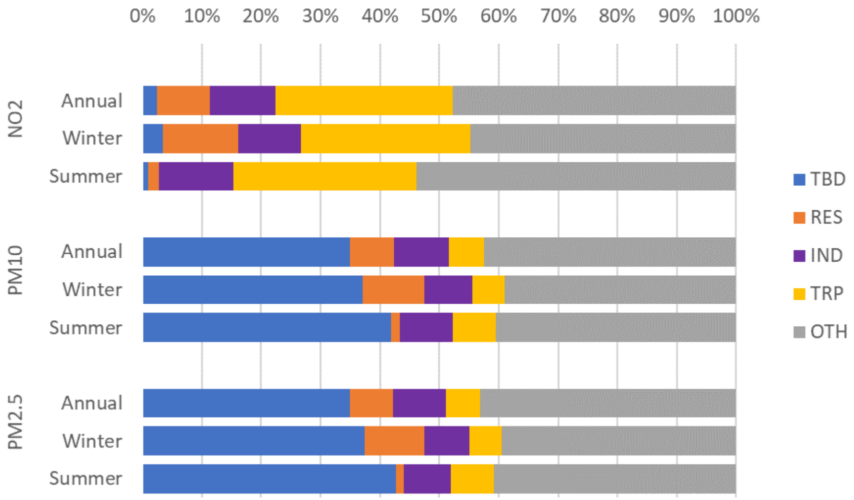


Figure 3-48: Annual, winter and summer averages contribution for each source group for NO_2, PM10 and PM2.5 concentrations, for Bristol urban area; (TBD- transboundary transport, RES - residential and commercial combustion, IND - industrial combustion and processes, TRP - road transport and OTH - all the remaining sources).

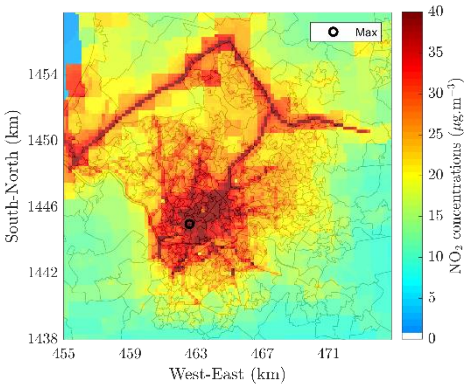
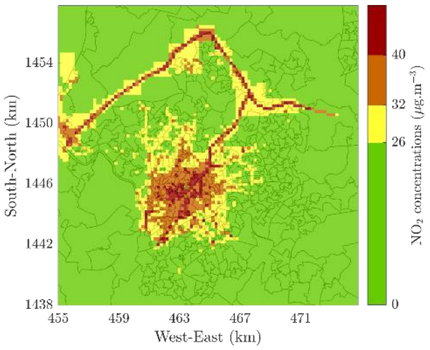
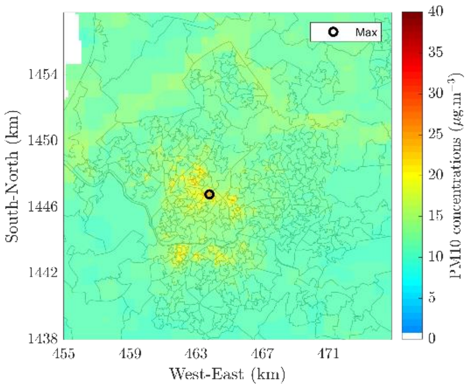
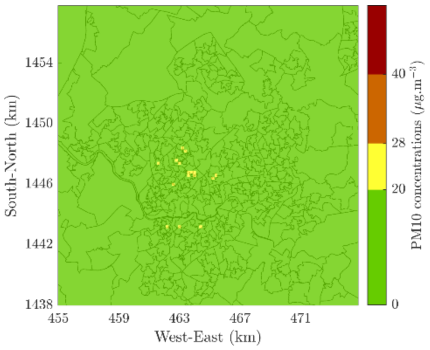
The average annual contributions of each source group reveal that, for NO_2, the largest contribution is from TRP, followed by IND and RES, with RES being higher in the annual and winter periods and IND remaining constant in the three analysed periods

For PM10, the annual average contributions of each source group reveal that one of the major contributions is from TBD (35%), highlighting the importance of transboundary transport for the PM10 pollution in the study region. This background/transboundary effect is even more notorious in the summer period, with values of 42%. Source contribution results also point to a great influence of the contribution of different human activities, such as residential combustion and traffic emissions, to the PM10 levels, with the residential combustion being higher in the winter period and the traffic 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.

3.5.2 Assessment of air quality at urban scale: baseline year

Figure 3-49 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 from DEFRA and the adjustment factor. For each pollutant two color scheme are presented, a) the standard ClairCity color scheme and b) a customized color scheme based on the EC assessment thresholds, which the EC directive EU/50/2008 establishes for each pollutant an upper and a lower assessment threshold. For NO_2 the lower assessment threshold (LAT) is 26 and the upper assessment threshold (UAT) is 32.For PM_{10} the LAT value is 20 and the UAT value is 28, and for $PM_{2.5}$ the LAT value is 12 and the UAT value is 17.

	a) Standard colour scheme	b) EC assessment thresholds
NO_2 concentrations		
PM_{10} concentrations		

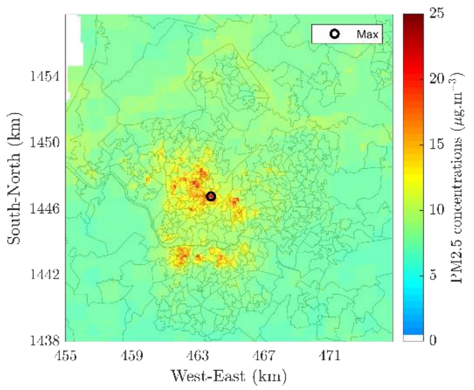
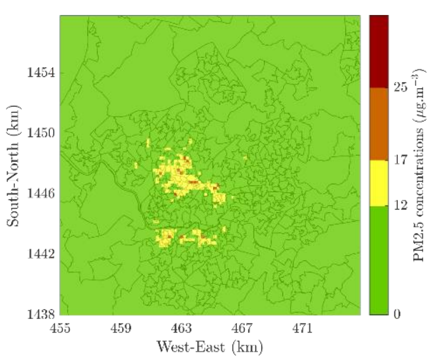
$PM_{2.5}$ concentrations		

Figure 3-49: Annual average of the NO_2, PM_{10} and $PM_{2.5}$ concentrations, including the background concentrations and the adjustment factor. a) using a standard color scheme, and b) using a customized color scheme based on the EC assessment thresholds

The maximum value of the annual NO_2 concentrations in 2015 is equal to 91.2 µg.m^{-3} and is located within the urban area over de M32 motorway (as indicated on the map). The main sector contributing to that maximum value is the road transport, with a contribution of 74.7, followed by the residential and commercial sector with a contribution of 23.1%, and the industrial sector with a contribution of 2.2%. These contributions are obtained from the source apportionment analysis. The average value of the NO_2 concentrations over the entire domain is equal to and the source apportionment analysis indicates that transport is contributing with 52.9%, industrial sector with 7.1% and the residential and commercial sector with 40.0% to the simulated concentrations.

The maximum value of the annual PM_{10} concentrations in 2015 is equal to 25.1 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 1.6% from transport sector, 0.1% from the industrial and 98.3% from the residential and commercial sector. The average value over all the domain is equal to 12.0 µg.m^{-3}. For PM_{10} concentrations average over all the domain a source apportionment analysis allowed to determine the contribution of each sector, which indicates transport is contributing with 11.3%, industrial sector with 1% and the residential and commercial sector with 87.7%.

The maximum value of the annual $PM_{2.5}$ concentrations in 2015 is equal to 22.3 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 0.9% from transport sector, 0.1% from the industrial and 99.0% from the residential and commercial sector. The average value over all the domain is equal to 8.2 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 6.8%, industrial sector with 1.1% and the residential and commercial sector with 92.1%.

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 3-50 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.

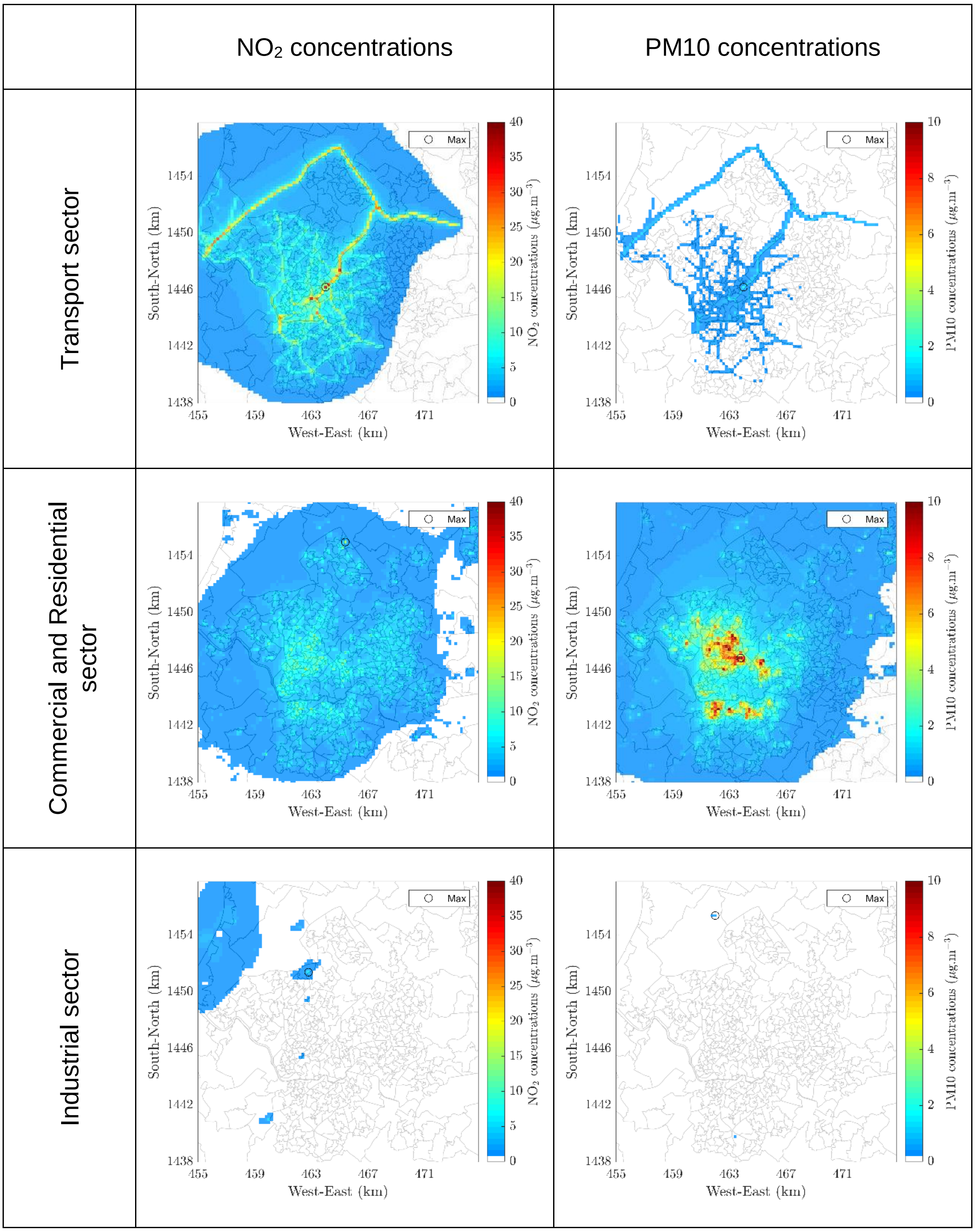


Figure 3-50: Air quality maps for NO_2 and PM adjusted concentrations by sector without the added background.

For the emission sectors considered, the emissions of particulate matter are assumed to be the same except for the transport sector, therefore, for industrial and commercial and residential sector the $PM_{2.5}$ concentrations maps will be the same as PM_{10} concentration maps. For transport, the emission are different due to different $PM_{10}/PM_{2.5}$ contribution from exhaust and non-exhaust emissions, as explained before at the transport methodology (Section 1.1). In terms of concentrations, for the transport sector the spatial distribution is roughly the same although smaller concentration of $PM_{2.5}$ are simulated. For transport, the maximum value simulated for PM_{10} is 1.6 µg.m^{-3} and for $PM_{2.5}$ is 0.9 µg.m^{-3}.

The final air quality results are then compared with the measuring data. Table 3-13 presents the comparison between the measurements and the simulated concentrations (with the background concentrations and the adjustment factor) for all the continuous monitoring sites.

Table 3-13: Comparison between the measurements and the simulated NO_2 concentrations (with the background concentrations and the adjustment factor).

	NO_2 concentrations	
Measurement site	Measurement	Simulated
Brislington Depot	31.2	30.3
Parson Street School	44.2	32.2
Wells Road	39.3	30.4
St. Pauls	25.8	40.9
Fishponds Road	39.7	30.4

The final simulated concentrations present a good agreement with the measurements.

Table 3-14 shows the contribution of each sector to the simulated NO_2 concentration values for the location of each monitoring station. For this pollutant, the major contribution to those locations comes from the transport but there is also a significant contribution from the commercial and residential sector.

Table 3-14: Contribution of each sector to the simulated NO_2 concentration values for each measuring location.

	NO_2 contribution by sector (%)		
Measurement site	Transport	Industrial	Commercial and residential
Brislington Depot	66	1.5	32.5
Parson Street School	60.4	1.9	37.7
Wells Road	81.5	1.1	17.4

St. Pauls	58.7	2.1	39.2
Fishponds Road	66.2	1.6	32.2

As previously explained, the adjustment factor is calculated by a linear regression between the measurements and the simulation concentrations. Since for PM_{10} and $PM_{2.5}$, for the year of 2015, only measured data from the urban background monitoring station from St. Pauls was available, the measured and simulated value is the same. For PM_{10} the measured/simulated value for that point is 14.9 and for $PM_{2.5}$ is 10.9.

Table 3-15 shows the contribution of each sector to the simulated PM_{10} and $PM_{2.5}$ concentration for the location of the monitoring station. For particulate matter, the major contribution comes from the commercial and residential sector but there is also a relevant contribution from the transport sector. This contribution fits well in the classification of the air quality station.

Table 3-15: Contribution of each sector to the simulated PM_{10} and $PM_{2.5}$ concentration values for the measuring location.

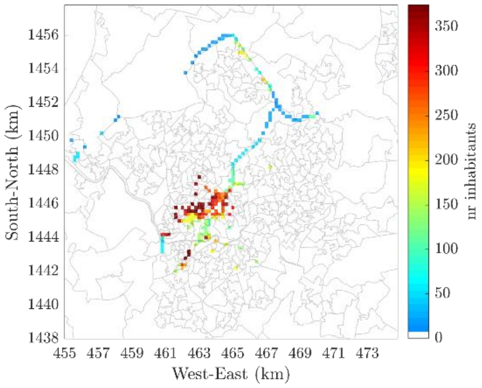
Measurement site	PM10 contribution by sector (%)			PM2.5 contribution by sector (%)		
	Transport	Industrial	Commercial and residential	Transport	Industrial	Commercial and residential
St. Pauls	12.3	0.3	87.4	7.4	0.4	92.2

3.5.3 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 3-51 shows the population exposure to NO_2, PM_{10} and $PM_{2.5}$ baseline concentration values.

	EU annual limit value	WHO guideline value

<table>
<tr>
<td>NO_2 concentrations</td>
<td colspan="2">
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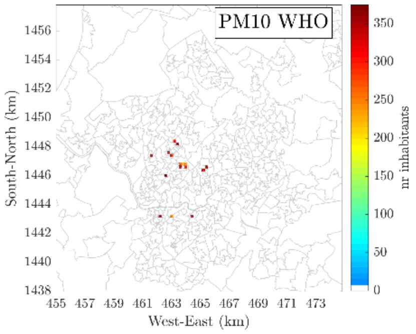
<tr>
<td>PM_{10} concentrations</td>
<td>There are no exceedances to the EU limits</td>
<td>
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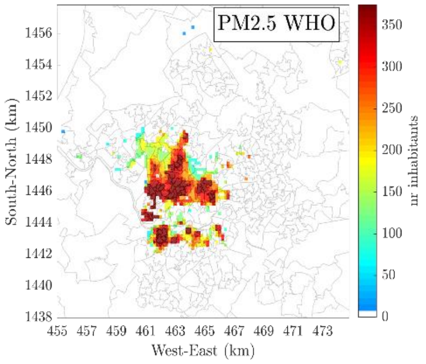
<tr>
<td>$PM_{2.5}$ concentrations</td>
<td>There are no exceedances to the EU limits</td>
<td>
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Figure 3-51: Population potentially exposed to values above the EU limits and WHO guideline values for NO_2, PM_{10} and $PM_{2.5}$ baseline concentrations.

For NO_2 the limits established by the EU and the WHO are equivalent, being 40 µg.m^{-3} for the annual mean. In Bristol, the NO_2 annual limits are exceeded in 231 cells corresponding to 5% of the total population within the urban area potentially exposed to those concentrations.

As for particulate matter, the limits diverge between both standards, with WHO showing stricter limits. PM_{10} values under the EU annual mean limits are 40 µg.m^{-3} and under WHO guidelines are 20 µg.m^{-3}, for $PM_{2.5}$ the EU established for the annual mean limit value of 25 µg.m^{-3} and for the WHO limits it's established at 10 µg.m^{-3}. For PM_{10} and $PM_{2.5}$ concentration maps for the baseline point out no exceedances to the EU legal limit values, although for the WHO guidelines the annual concentrations indicate exceedances to the limit values. For PM_{10}, 16 cells are exceeding the guideline value, which represents 1% of the population within the simulation area potentially affected. For $PM_{2.5}$, 655 cells are exceeding the guideline value, denoting that 25% of the population within the simulation area are potentially exposed to those concentrations.

3.5.4 Assessment of air quality impacts at urban scale

3.5.4.1 BAU scenarios

The substantial reductions of NOx emissions in the BAU scenario will lead to significant reductions of the NO_2 concentrations. Figure 3-52 presents the NO_2 annual averaged concentrations considering the impacts of BAU scenario in 2025 and 2050. The maximum annual averaged NO2 concentrations will be equal to 38.5 µg.m^{-3} in 2025 and to 22.2 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 57.8% and 75.7%, when compared to the baseline.

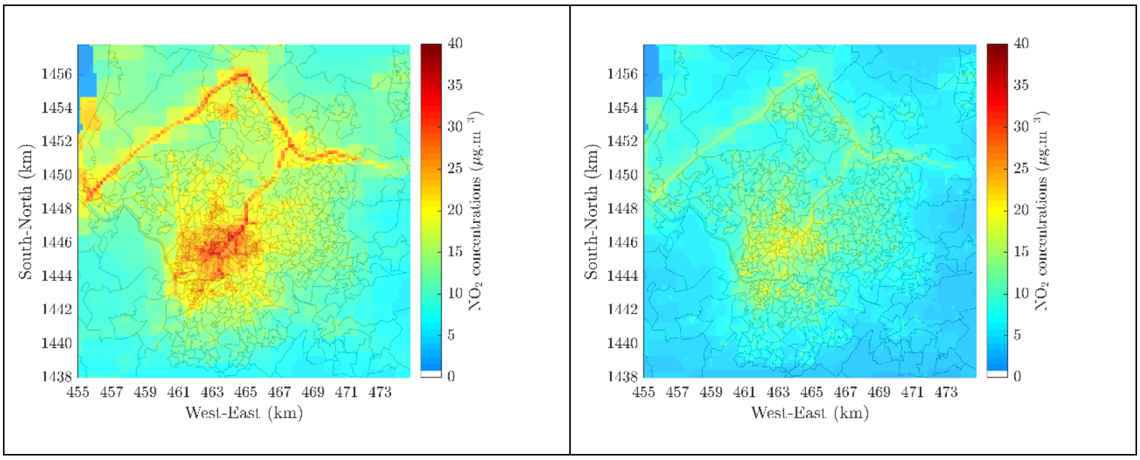


Figure 3-52: NO_2 annual average concentrations in the BAU scenario a) in 2025 and b) in 2050.

Figure 3-53 presents the differences of the NO_2 concentrations between the baseline year and the BAU scenarios in 2025 and 2050. These differences are absolute concentrations obtained from the relationship $NO_{2\ \text{baseline year}} - NO_{2\ \text{scenarios}}$ in µg.m^{-3}. The BAU scenario will lead to a maximum reduction of 62.3 µg.m^{-3} of the NO_2 concentrations in 2025, corresponding to a reduction of 68.7%, while the spatial average over the entire the domain will reduce 6.2 µg.m^{-3} of NO_2 concentrations, which corresponds to a reduction of 31%. In 2050 the BAU scenario will lead to a maximum reduction of the NO_2 concentrations of 74.4 µg.m^{-3} which corresponds to a reduction of 81.6%, while the average over the entire domain will reduce 11.8 µg.m^{-3} (60.6%).

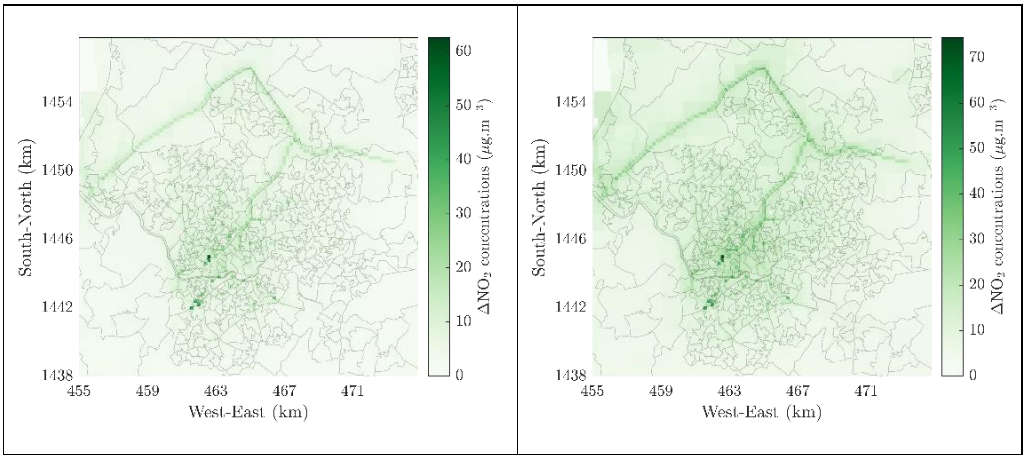


Figure 3-53: Differences of the NO_2 annual averaged concentrations in the BAU scenario a) in 2025 and b) in 2050.

Table 3-16 summarizes the overall impacts of BAU scenarios on air quality and population exposure. The population within the urban area of Bristol potentially exposed to NO_2 concentrations will diminish from 5.4% in the baseline year to no inhabitants in risk of exposure with the implementation of the BAU scenarios. Therefore, the simulation results indicate compliance with the EU limits already with the BAU scenario in 2025.

Table 3-16: Summary of results including the annual averages of NO_2 concentrations, together with the number of exceedances to the EU legal limit value, the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit, and the corresponding % of population.

	Min.	Max.	Aver.	Exc.	Inhabit.	Pop.
2015	1.9	91.2	19.5	231	36169	5.4%
BAU 2025	1.2	38.5	13.3	0	0	0
BAU 2035	1.2	27.4	10.4	0	0	0
BAU 2050	1.2	22.2	7.7	0	0	0

The substantial reductions of NOx emissions in the BAU scenario will lead to significant reductions of the NO_2 concentrations. Figure 3-52 presents the NO_2 annual averaged concentrations considering the impacts of BAU scenario in 2025 and 2050. The maximum annual averaged NO2 concentrations will be equal to 38.5 $\mu g.m^{-3}$ in 2025 and to 22.2 $\mu g.m^{-3}$ in 2050, corresponding to an overall reduction of the maximum concentration of 57.8% and 75.7%, when compared to the baseline.

The reductions of PM emissions in the BAU scenario will also lead to reductions of the PM concentrations. Figure 3-54 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 24.0 µg.m^{-3} in 2025 and to 23.0 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 4.6% and 8.5%, when compared to the baseline.

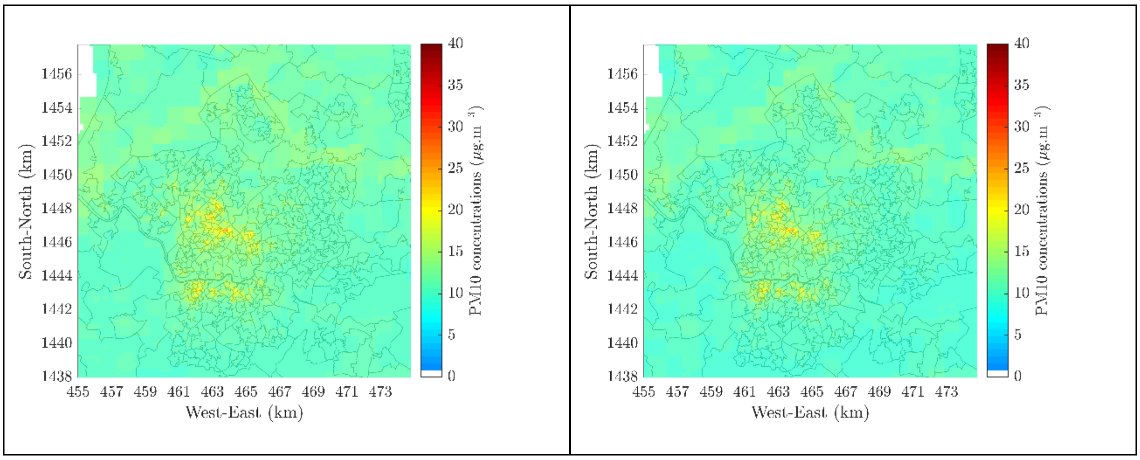


Figure 3-54: PM10 annual average concentrations in the BAU scenario a) in 2025 and b) in 2050.

Figure 3-55 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 1.6 µg.m^{-3} of the PM_{10} concentrations in 2025, corresponding to a reduction of 14.4%, while the spatial average over the entire the domain will reduce 0.5 µg.m^{-3} of PM_{10} concentrations, which corresponds to a reduction of 4.6%. In 2050 the BAU scenario will lead to a maximum reduction of the PM10 concentrations of 17.5 µg.m^{-3} which corresponds to a reduction of 2.6%, while the average over the entire domain will reduce 10.3 µg.m^{-3} (1.2%).

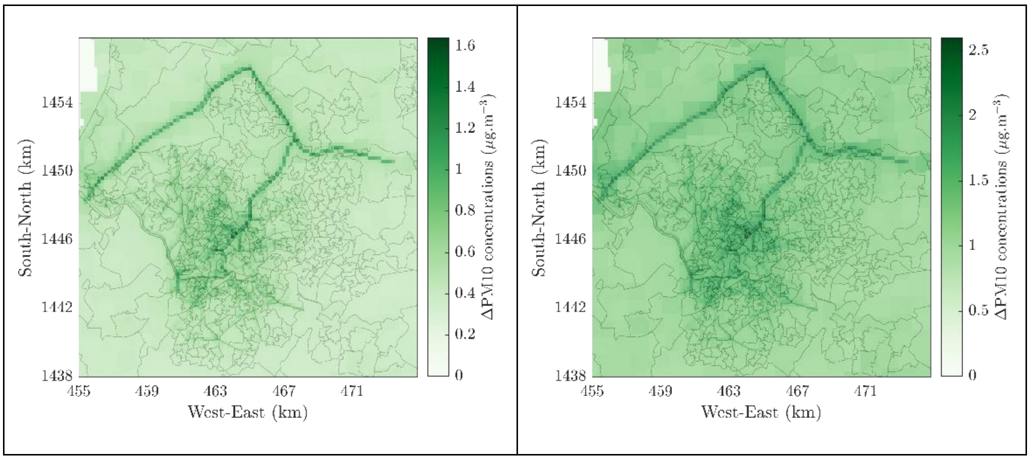


Figure 3-55: Differences of the PM_{10} annual averaged concentrations in the BAU scenario a) in 2025 and b) in 2050.

Table 3-17 summarizes the overall impacts of BAU scenarios on PM10 concentrations and population exposure to those concentrations. The population within the urban area of Bristol potentially exposed to PM10 concentrations considering the WHO guideline values will diminish from 0.8% in the baseline year to 0.2% in 2050 with the implementation of the BAU scenarios. The simulation results indicate compliance with the EU limits already in 2015.

Table 3-17: Summary of results including the annual averages of PM$_{10}$ 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. WHO	Inhabit.	Pop.
2015	0.3	25.1	12.0	16	5528	0.8%
BAU 2025	0.2	24.0	11.4	8	2781	0.4%
BAU 2035	0.2	23.5	11.2	5	1731	0.3%
BAU 2050	0.2	23.0	10.7	3	948	0.2%

Figure 3-56 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 21.1 µg.m^{-3} in 2025 and to 20.0 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 5.3% and 10.5%, when compared to the baseline.

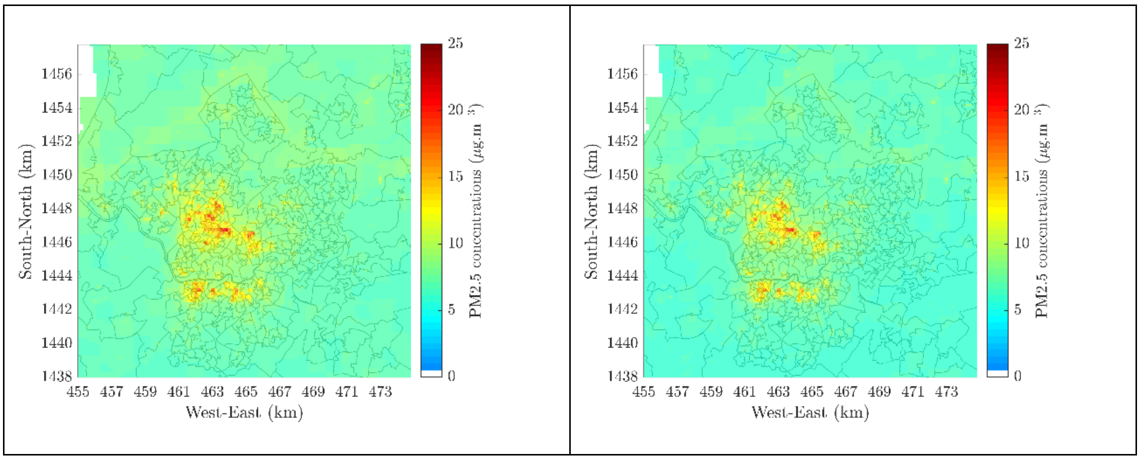


Figure 3-56: PM2.5 annual average concentrations in the BAU scenario a) in 2025 and b) in 2050.

Figure 3-57 presents the differences of the PM$_{2.5}$ concentrations between the baseline year and the BAU scenarios in 2025 and 2050. The BAU scenario will lead to a maximum reduction of 1.2 µg.m^{-3} of the PM$_{2.5}$ concentrations in 2025, corresponding to a reduction of 10.6%, while the spatial average over the entire the domain will reduce 0.6 µg.m^{-3} of PM$_{10}$ concentrations, which corresponds to a reduction of 7.1%. In 2050 the BAU scenario will lead to a maximum reduction of the PM2.5 concentrations of 2.3 µg.m^{-3} which corresponds to a reduction of 21.3%, while the average over the entire domain will reduce 1. µg.m^{-3} (17.2%).

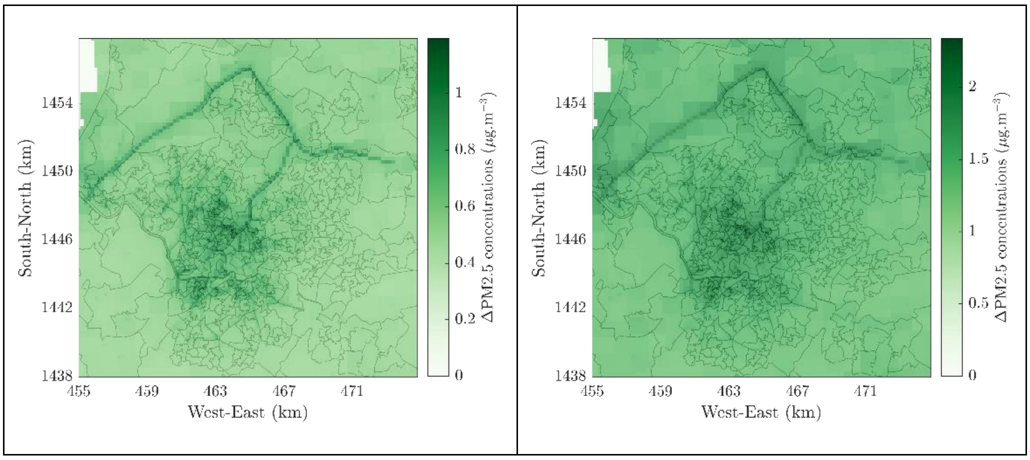


Figure 3-57: Differences of the $PM_{2.5}$ annual averaged concentrations in the BAU scenario a) in 2025 and b) in 2050.

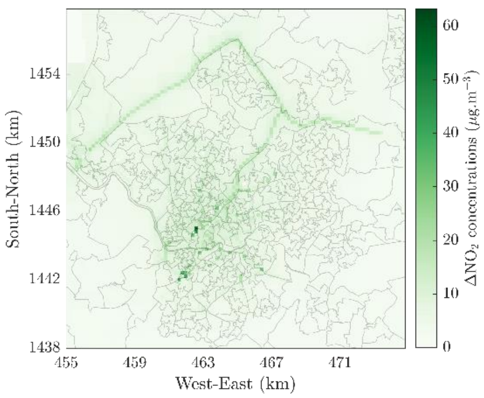
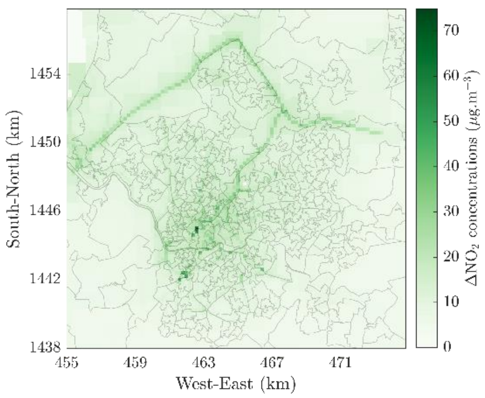
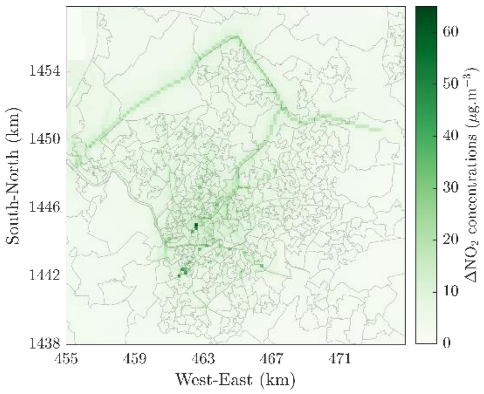
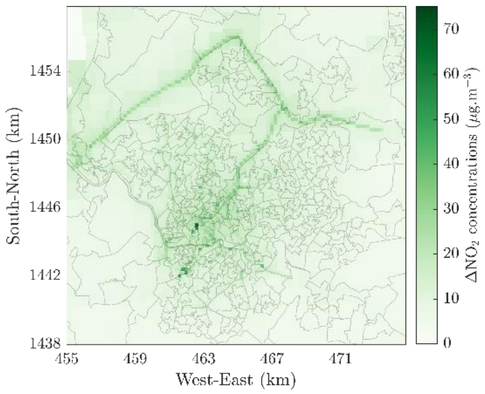
Table 3-18 summarizes the overall impacts of BAU scenarios on PM2.5 concentrations and population exposure to those concentrations. The population within the urban area of Bristol potentially exposed to PM2.5 concentrations considering the WHO guideline values will diminish from 25.4% in the baseline year to 11.8% in 2050 with the implementation of the BAU scenarios. The simulation results indicate compliance with the EU limits already in 2015.

Table 3-18: Summary of results including the annual averages of $PM_{2.5}$ 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. WHO	Inhabit.	Pop.
2015	0.3	22.3	8.2	655	171680	25.4%
BAU 2025	0.2	21.1	7.6	406	119980	17.8%
BAU 2035	0.2	20.5	7.3	338	103960	15.4%
BAU 2050	0.2	20.0	6.8	249	79881	11.8%

3.5.4.2 SDW scenarios

The three proposed scenarios from the SDW will distinctly impact the air quality over the urban area of Bristol. Figure 3-58 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 37.0 µg.m^{-3} to 21 µg.m^{-3} between 2025 and 2050 with the implementation of the proposed scenario 1 (the scenarios with the lowest ambition level), while with the implementation of the proposed scenario 3 (with the highest ambition level) the maximum NO_2 concentrations will range from 28.4 µg.m^{-3} to 13.8 µg.m^{-3}. Figure 3-58 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.

	2025	2050
S1		
S2		

S3

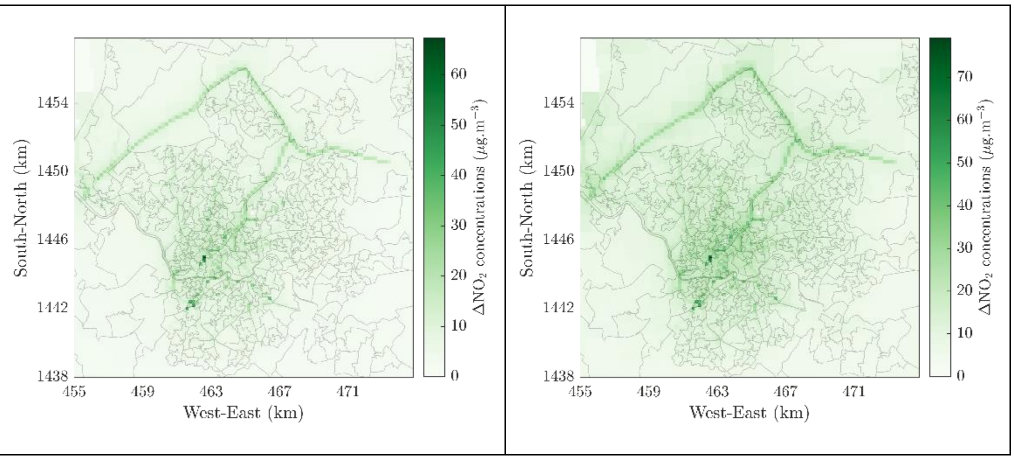


Figure 3-58: Differences of the NO_2 annual averaged concentrations in the SDW scenarios a) in 2025 and b) in 2050.

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 no risk of population exposure to those concentrations already in 2025, in comparison with 5.4% of the population within the Bristol urban area, which are potentially exposed to NO_2 concentrations above the EU annual legal limit value.

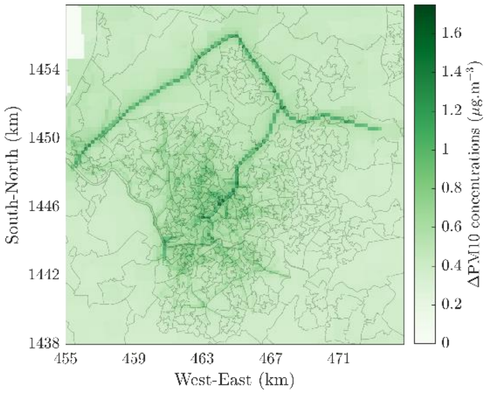
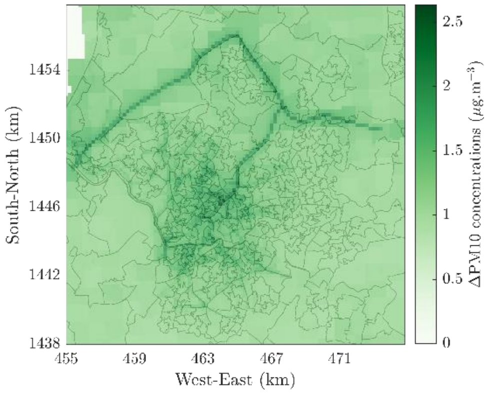
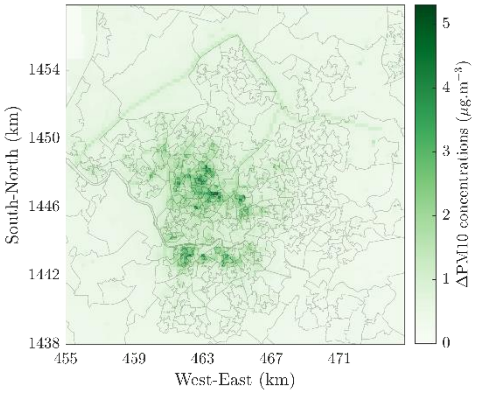
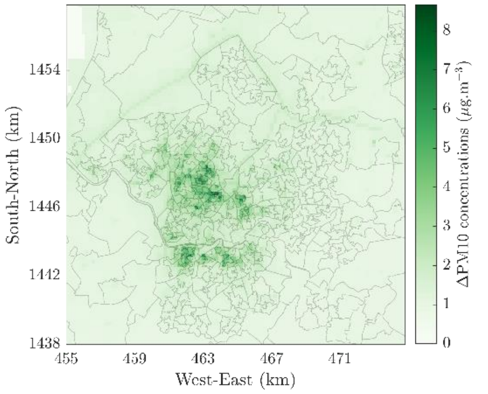
The proposed scenario 1 will lead to an overall reduction of 31.5% over the entire computational domain in 2025, and of 60.9% in 2050. While the proposed scenario 2 will lead to a reduction of 32.8% in 2025, and of 61.1% in 2050. The proposed scenario 3 will lead to a reduction of 36.1% and 67.3% in 2025 and 2050.

Table 3-19: Summary of the SDW impacts including the annual averages of NO_2 concentrations, together with the number of exceedances to the EU legal limit value, the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit, and the corresponding % of population.

	Min.	Max.	Aver.	Exc.	Inhabit.	Pop.
2015	1.9	91.2	19.5	231	36169	5.4%
S1 2025	1.2	37.0	13.2	0	0	0
S1 2035	1.1	26.1	10.3	0	0	0
S1 2050	1.1	21.1	7.6	0	0	0
S2 2025	1.1	32.5	12.9	0	0	0
S2 2035	1.1	25.7	10.3	0	0	0

S2 2050	1.1	21.0	7.5	0	0	0
S3 2025	0.9	28.4	12.2	0	0	0
S3 2035	0.9	20.6	9.2	0	0	0
S3 2050	0.8	13.8	6.2	0	0	0

The overall measures impacting the transport sector will also promote important reductions of PM10 concentrations over the city centre and over the main roads and motorways as indicated in Figure 3-59. The differences contour maps of the annual PM10 concentrations point out a maximum concentration ranging from 24.0 µg.m^{-3} to 23.0 µg.m^{-3} between 2025 and 2050 with the implementation of the proposed scenario 1, while the proposed scenario 3 will lead to a maximum concentration of PM10 concentrations from 19.8 µg.m^{-3} to 16.4 µg.m^{-3}.

	2025	2050
S1		
S2		

S3

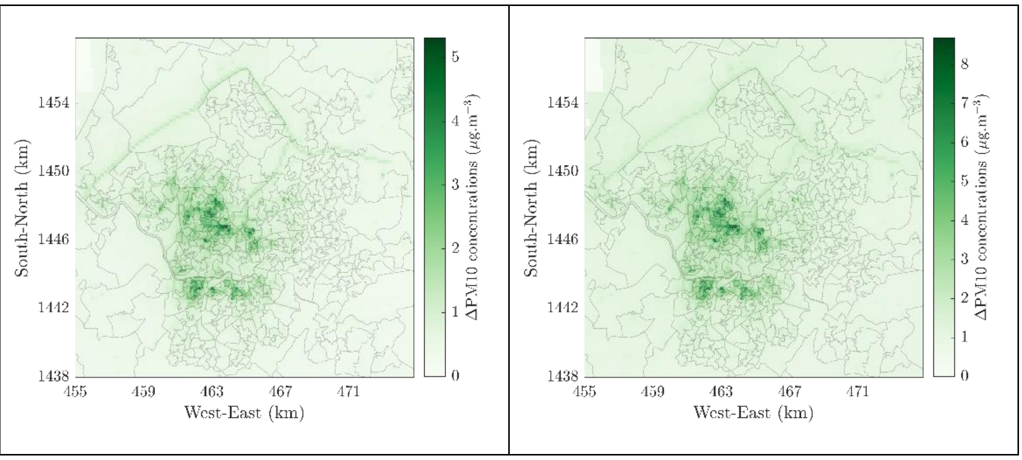


Figure 3-59: Differences of the PM_{10} annual averaged concentrations in the SDW scenario a) in 2025 and b) in 2050.

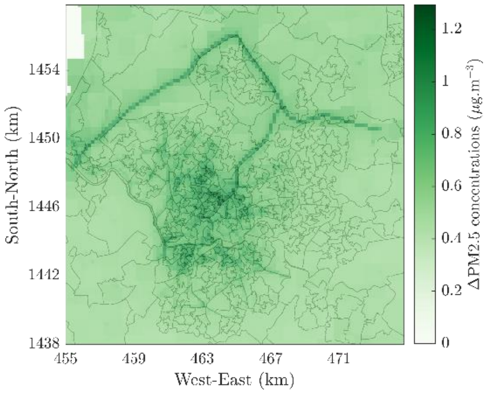
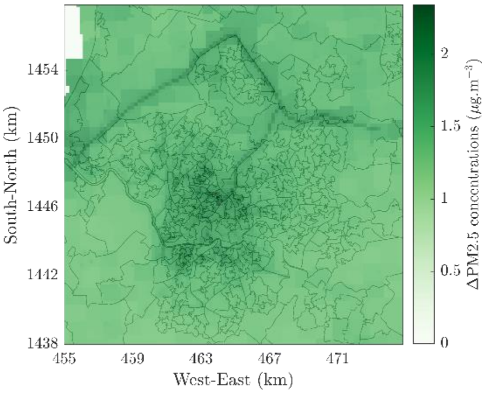
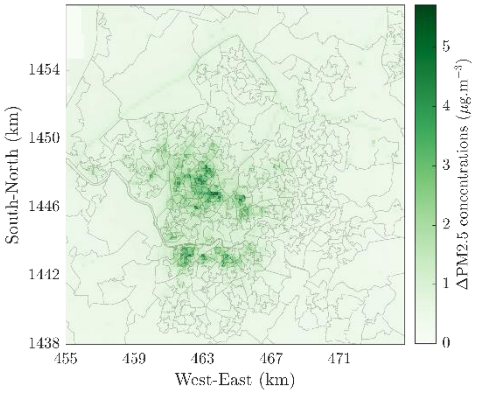
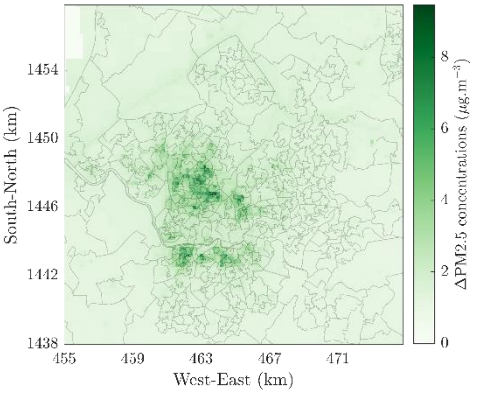
Table 3-20 presents an overview of the overall impact of the SDW scenarios on the PM_{10} concentrations. The proposed scenario 1 will lead to an overall reduction of 4.6% over the entire computational domain in 2025, and of 10.4% in 2050. While the proposed scenario 2 will lead to a reduction of 6.7% in 2025, and of 13.6% in 2050. The proposed scenario 3 will lead to a reduction of 6.7% and 13.7% in 2025 and 2050. The results indicate no risk of population exposure to PM10 concentrations to the EU annual limit value already in the baseline year. However, there are some risks of population exposure over the urban area of Bristol to the stricter limits recommended by the WHO in the baseline year and with the proposed scenario 1.

Table 3-20: Summary of results including the annual averages of PM_{10} concentrations, together with the number of exceedances to the WHO 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.	Inhabit.	Pop.
2015	0.3	25.1	12.0	16	5528	0.8%
S1 2025	0.2	24.0	11.4	8	2781	0.4%
S1 2035	0.2	23.5	11.2	5	1731	0.3%
S1 2050	0.2	23.0	10.7	3	948	0.2%
S2 2025	0.2	19.8	11.2	0	0	0
S2 2035	0.1	18.3	10.9	0	0	0

S2 2050	0.1	16.5	10.4	0	0	0
S3 2025	0.2	19.8	11.2	0	0	0
S3 2035	0.1	18.2	10.9	0	0	0
S3 2050	0.1	16.4	10.4	0	0	0

Figure 3-60 shows the contour maps with the differences between the proposed scenarios and the baseline of the annual PM2.5 concentrations. These contour maps point out a maximum concentration ranging from 21.1 µg.m^{-3} to 20.0 µg.m^{-3} between 2025 and 2050 with the implementation of the proposed scenario 1, while the proposed scenario 3 will lead to a maximum concentration of PM2.5 concentrations ranging from 16.6 µg.m^{-3} to 12.8 µg.m^{-3}.

	2025	2050
S1		
S2		

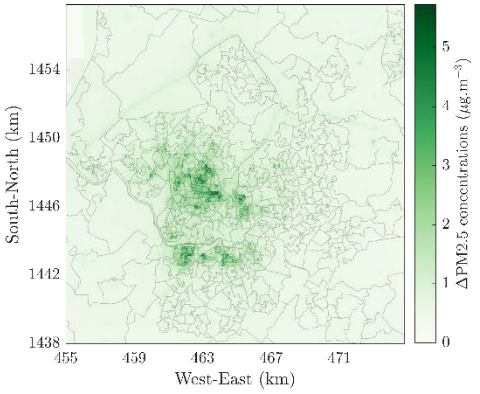
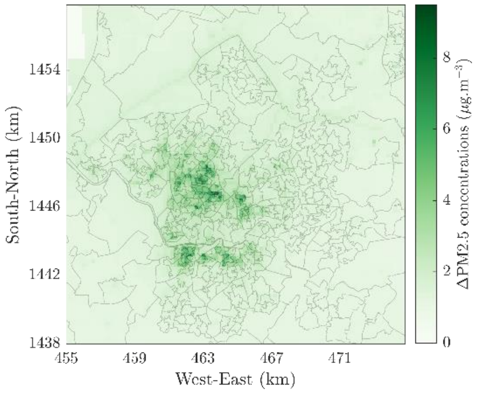
S3		

Figure 3-60: Differences of the $PM_{2.5}$ annual averaged concentrations in the FUPS scenario a) in 2025 and b) in 2050.

Table 3-21 presents an overview of the overall impact of the SDW scenarios on the $PM_{2.5}$ concentrations. The proposed scenario 1 will lead to an overall reduction of 7.2% over the entire computational domain in 2025, and of 17.2% in 2050. While the proposed scenario 2 will lead to a reduction of 10.2% in 2025, and of 22.0% in 2050. The proposed scenario 3 will lead to a reduction of 10.2% and 22.1% in 2025 and 2050. The results indicate no risk of population exposure to $PM_{2.5}$ concentrations to the EU annual limit value already in the baseline year. However, there are some risks of population exposure over the urban area of Bristol to the stricter limits recommended by the WHO in the baseline year and even with all the proposed scenario from the SDW.

Table 3-21: Summary of results including the annual averages of $PM_{2.5}$ concentrations, together with the number of exceedances to the WHO guideline value, the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit, and the corresponding % of population.

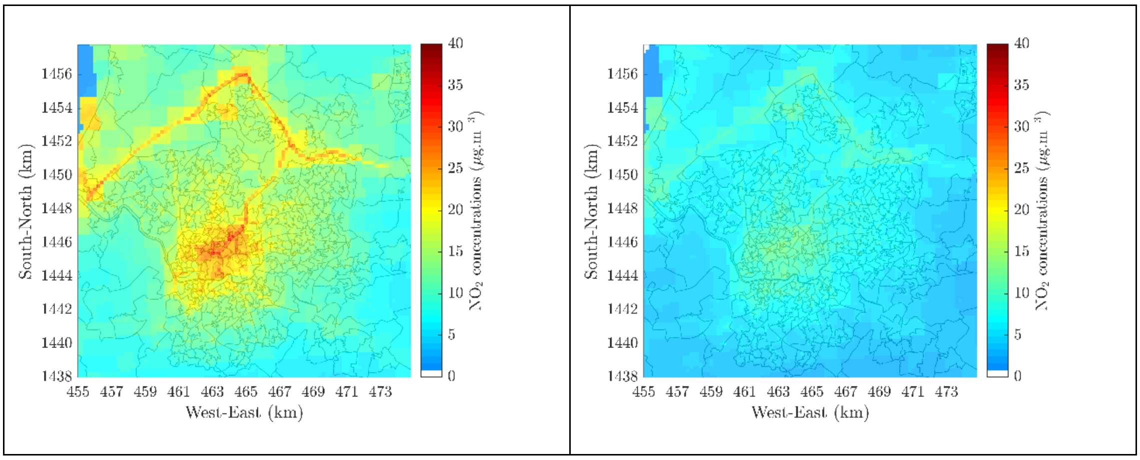
	Min.	Max.	Aver.	Exc.	Inhabit.	Pop.
2015	0.3	22.3	8.2	655	171680	25.4%
S1 2025	0.2	21.1	7.6	403	119260	17.6%
S1 2035	0.2	20.5	7.3	337	103790	15.4%
S1 2050	0.2	20.0	6.8	248	79479	11.8%
S2 2025	0.2	16.6	7.4	190	63669	9.4%
S2 2035	0.1	14.8	7.0	101	36117	5.3%

S2 2050	0.1	12.8	6.4	22	7779	1.2%
S3 2025	0.2	16.6	7.4	190	63669	9.4%
S3 2035	0.1	14.8	7.0	99	35300	5.2%
S3 2050	0.1	12.8	6.4	21	7439	1.1%

3.5.4.3 FUPS scenarios

The substantial reductions of NOx emissions in the FUPS scenario will lead to significant reductions of the NO_2 concentrations. Figure 3-61 presents the NO_2 annual averaged concentrations considering the impacts of FUPS scenario in 2025 and 2050. The maximum annual averaged NO_2 concentrations will be equal to 33.4 µg.m^{-3} in 2025 and to 13.4 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 63.4% and 85.2%, when compared to the baseline.

Figure 3-61: NO_2 annual average concentrations in the FUPS scenario a) in 2025 and b) in 2050.



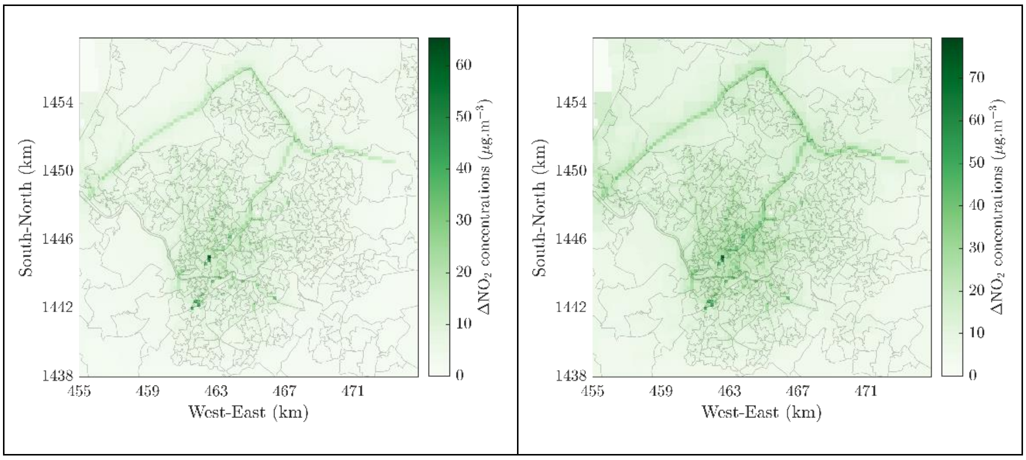


Figure 3-62: Differences of the NO_2 annual averaged concentrations in the FUPS scenario a) in 2025 and b) in 2050.

Table 3-22 shows the summary of the overall impact of the FUPS scenario on the NO_2 concentrations, indicating no risk of population exposure to those concentrations already in 2025.

The FUPS scenario will lead to an overall reduction of 34.7% over the entire computational domain in 2025, and of 67.7% in 2050.

Table 3-22: Summary of the FUPS impacts including the annual averages of NO_2 concentrations, together with the number of exceedances to the EU legal limit value, the number of inhabitants within the urban area potentially exposed to concentrations exceeding this limit, and the corresponding % of population.

	Min.	Max.	Aver.	Exc.	Inhabit.	Pop.
2015	1.9	91.2	19.5	231	36169	5.4%
FUPS 2025	1.0	33.4	12.5	0	0	0
FUPS 2035	0.8	20.8	9.1	0	0	0
FUPS 2050	0.8	13.4	6.1	0	0	0

Figure 3-63 and Figure 3-64 presents the impact of the FUPS scenario on PM10 concentrations. The contour maps with the differences of the annual PM10 concentrations point out a maximum concentration ranging from 19.8 µg.m^{-3} to 16.4 µg.m^{-3} between 2025 and 2050 with the implementation of the FUPS scenario.

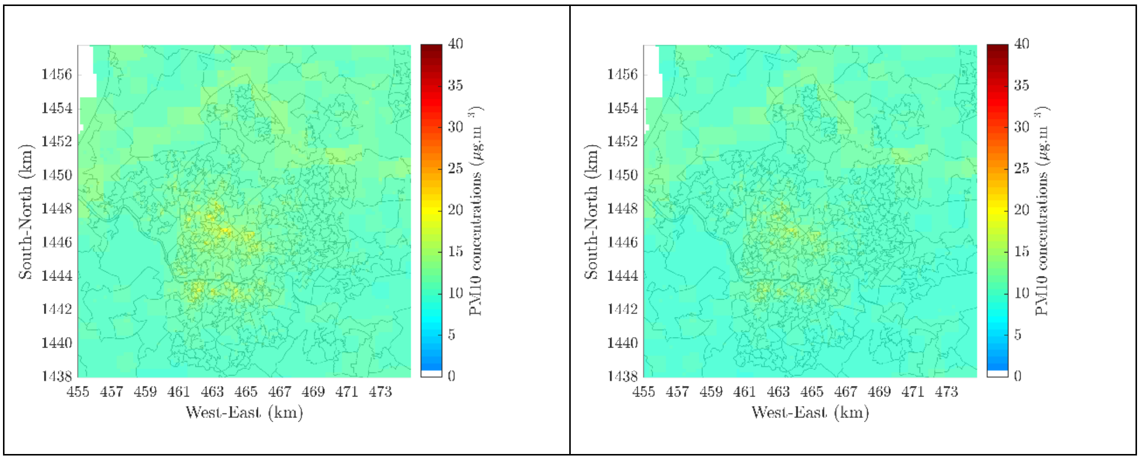


Figure 3-63: PM10 annual average concentrations in the FUPS scenario a) in 2025 and b) in 2050.

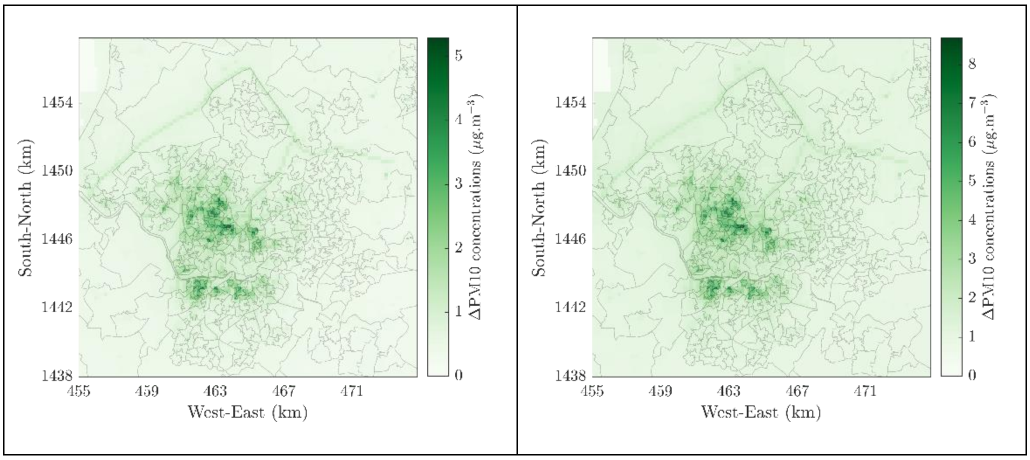


Figure 3-64: Differences of the PM$_{10}$ annual averaged concentrations in the FUPS scenario a) in 2025 and b) in 2050.

Table 3-23 summarizes the overall impact of the FUPS scenario on the PM10 concentrations. This scenario will lead to an overall reduction of 6.7% over the entire computational domain in 2025, and of 13.7% in 2050. The results indicate no risk of population exposure to PM$_{10}$ concentrations above the EU annual limit value already, as well as to the stricter limits recommended by the WHO with the FUPS already in 2025.

Table 3-23: Summary of results including the annual averages of PM_{10} 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. WHO	Inhabit.	Pop.
2015	0.3	25.1	12.0	16	5528	0.8%
FUPS 2025	0.2	19.8	11.2	0	0	0
FUPS 2035	0.1	18.3	10.9	0	0	0
FUPS 2050	0.1	16.4	10.4	0	0	0

Figure 3-65 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 16.6 µg.m^{-3} in 2025 and to 12.8 µg.m^{-3} in 2050, corresponding to an overall reduction of the maximum concentration of 25.6% and 42.6%, when compared to the baseline.

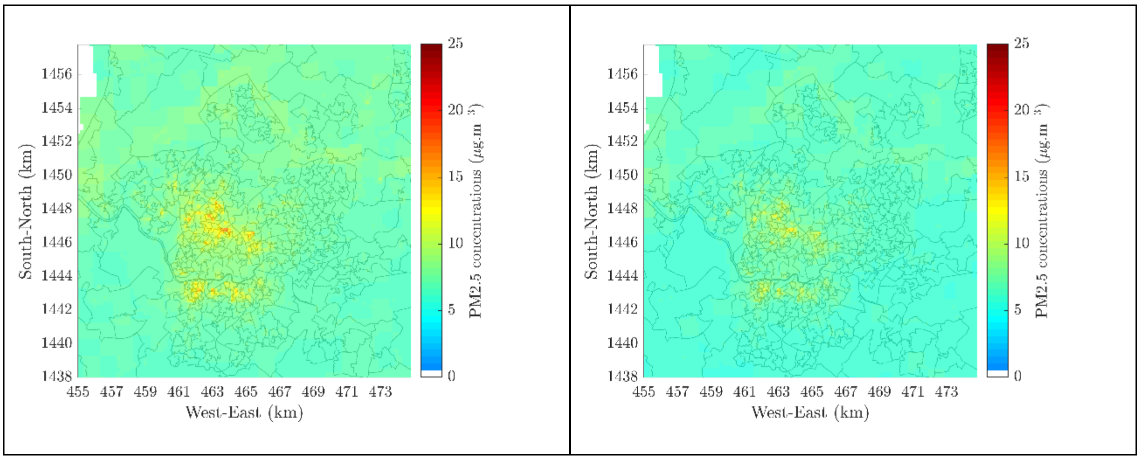


Figure 3-65: PM2.5 annual average concentrations in the FUPS scenario a) in 2025 and b) in 2050.

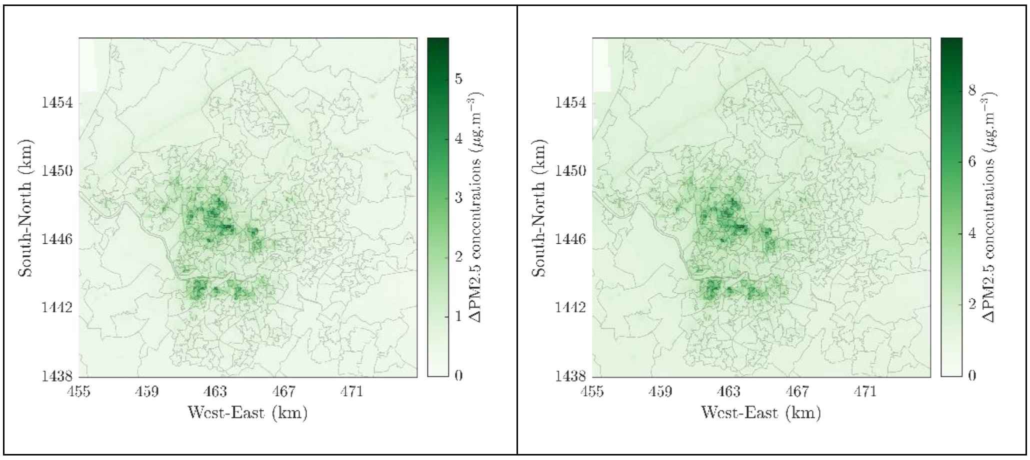


Figure 3-66: Differences of the $PM_{2.5}$ annual averaged concentrations in the FUPS scenario a) in 2025 and b) in 2050.

Table 3-24 presents the overall impact of the FUPS scenario on the $PM_{2.5}$ concentrations. The FUPS scenario will lead to an overall reduction of 10.1% over the entire computational domain in 2025, and of 22.1% in 2050. The results indicate no risk of population exposure to $PM_{2.5}$ concentrations above the EU annual limit value already in the baseline year. However, there are some risks of population exposure over the urban area of Bristol to the stricter limits recommended by the WHO in the baseline year and even with all the FUPS scenario, with 9.5% of the population within the urban area of Bristol potentially exposed to those levels in 2025, and reducing to 1% of the population in 2050.

Table 3-24: Summary of results including the annual averages of $PM_{2.5}$ 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.

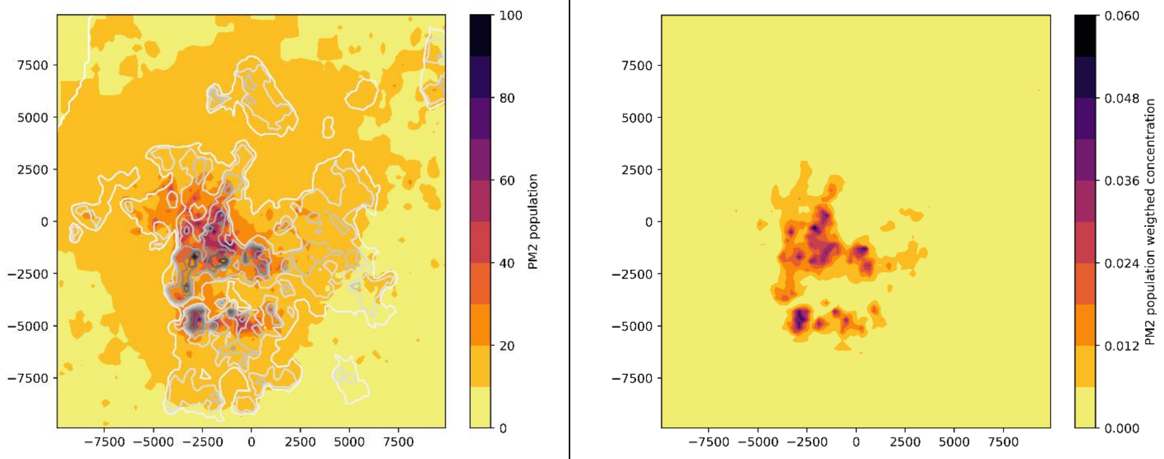
	Min.	Max.	Aver.	Exc. WHO	Inhabit.	Pop.
2015	0.3	22.3	8.2	655	171680	25.4%
FUPS 2025	0.2	16.6	7.4	192	64241	9.5%
FUPS 2035	0.1	14.8	7.0	100	35755	5.3%
FUPS 2050	0.1	12.8	6.4	21	7439	1.1%

3.6 Health impacts

3.6.1 Baseline

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

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 577, 290, 439 premature deaths, and 6170, 3102, and 4696 years of life potentially lost attributed to $PM_{2.5}$, PM_{10}, and NO_2 pollution levels in Bristol in 2015, respectively.



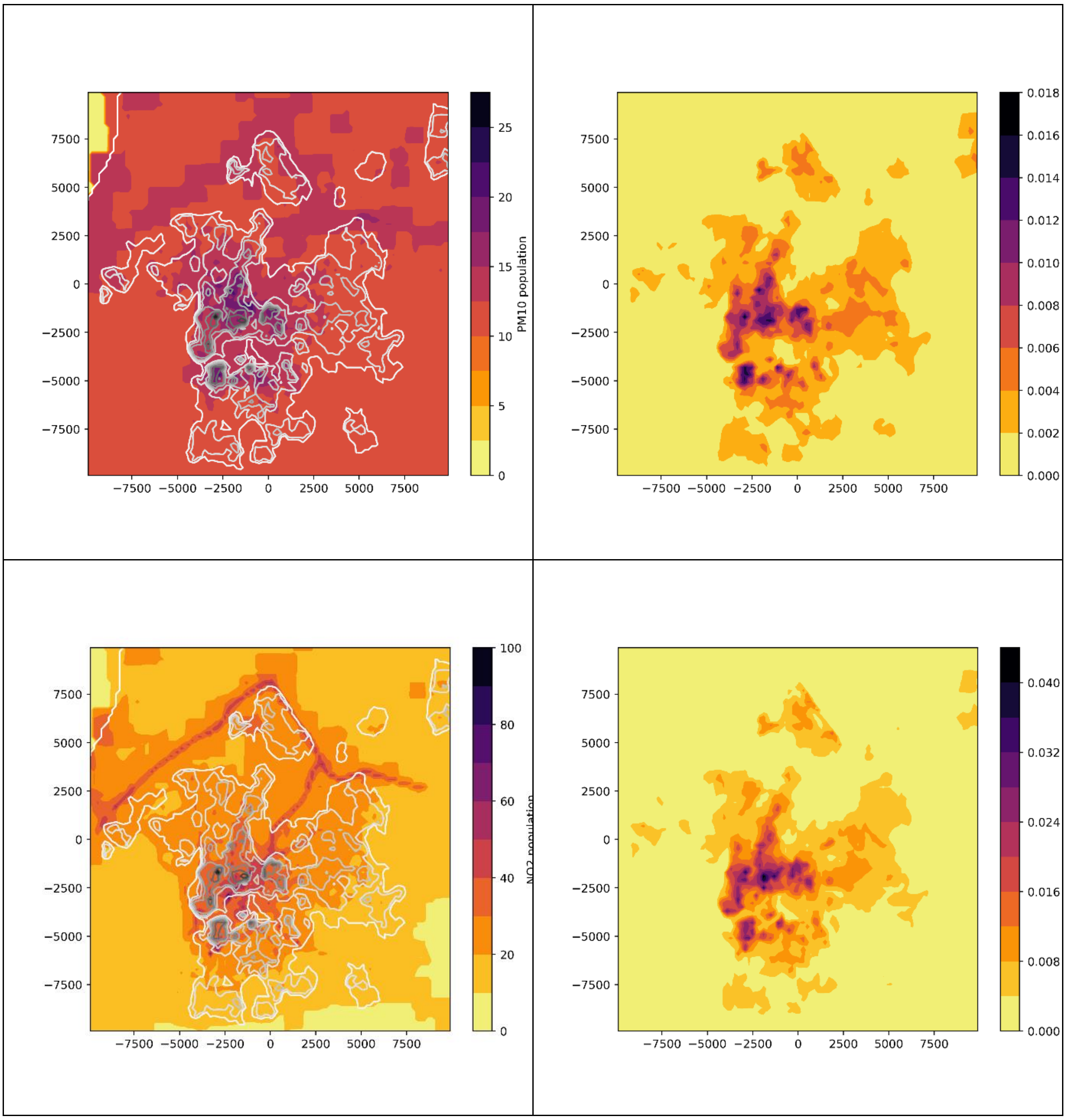


Figure 1-67: concentration maps overlaid with population density contours (left), population weighted concentration maps (right) for PM2.5 (top), PM10 (centre), and NO2 (bottom) based on the baseline emission scenario (2015).

3.6.2 BAU and UPS

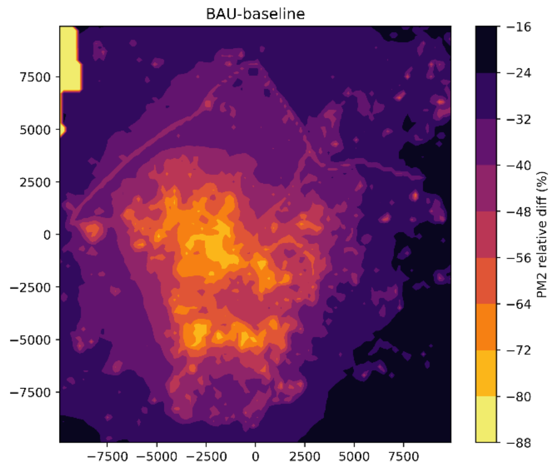
The analysis of the health impact benefits of implementing emission control measures can be quantified by benchmarking the health indicators estimated based on the BAU and UPS emission scenarios. The results in relative terms (%) are described in the table below. Note that independently of the indicators,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

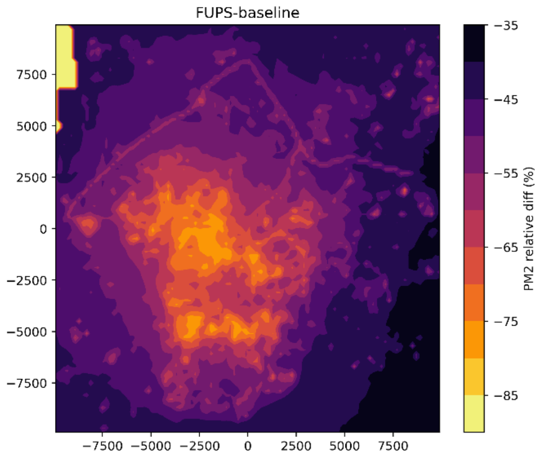
Table 1-25: Health impact benefits of implementing emission control measures for Bristol (%).

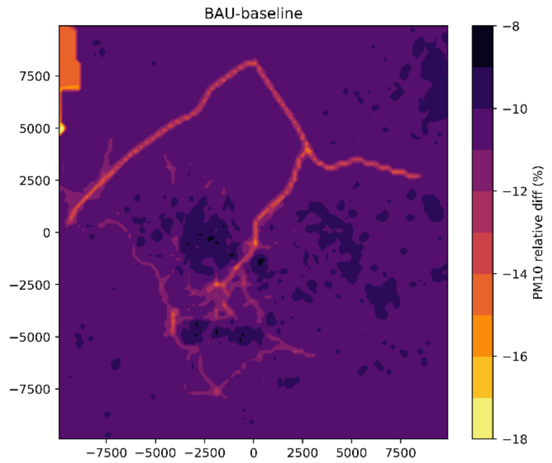
	PM2.5			PM10			NO2		
	2025	2035	2050	2025	2035	2050	2025	2035	2050
BAU	-49	-49	-49	-8	-9	-9	-21	-26	-27
UPS	-54	-55	-59	-17	-19	-28	-42	-49	-53

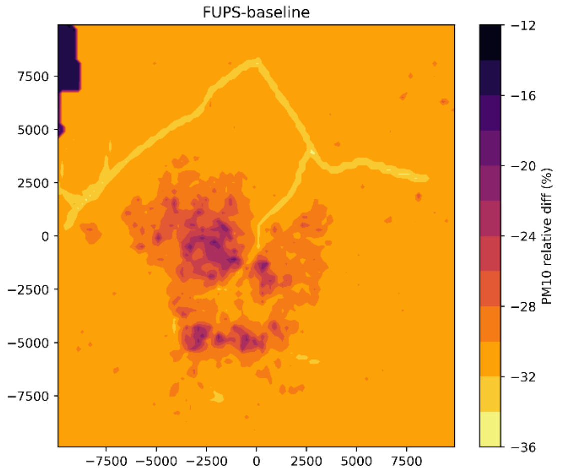
The results show that both future emission scenarios will contribute to the improvement on human health, reducing the health impact indicators for all air pollutants. UPS scenario seems to be the most efficient on reducing the numbers on premature deaths and years of life lost. According to these results, both future scenarios will be more efficient on reducing the impact of $PM_{2.5}$ on human health and less on $PM_{10;}$ none will show large reduction when comparing 2025 and 2050.

The mapping of the air quality impact benefits of implementing emission control measures is a good proxy to support the analysis on the impact of the emission scenario. The maps for the year 2050 are shown in Figure 1-68 shows the comparison between future and current emission scenario. Note that the maps have different scales and they show the reduction, thus the higher the negative values, the larger the reduction is. For particulate matter, the figures show very different patterns for concentration levels reduction. For PM2.5, the centre of Bristol shows the highest reduction on concentration levels, and for PM10. the maps show that the highest reduction is over the most trafficked roads and less significant reduction occurs where the population density is higher. This difference explains the PM2.5 emission reduction measures being more effective on the reduction on the health indicators than PM10. Thought NO_2 concentration levels have a larger reduction in the city centre, there are a couple of hotspots where the reduction is not as high, reducing the overall positive impact of the future emission scenarios.


BAU-baseline
7500
5000
2500
0
−2500
−5000
−7500
−7500 −5000 −2500 0 2500 5000 7500
−16
−24
−32
−40
−48
−56
−64
−72
−80
−88
PM2 relative diff (%)


FUPS-baseline
7500
5000
2500
0
−2500
−5000
−7500
−7500 −5000 −2500 0 2500 5000 7500
−35
−45
−55
−65
−75
−85
PM2 relative diff (%)


BAU-baseline
7500
5000
2500
0
−2500
−5000
−7500
−7500 −5000 −2500 0 2500 5000 7500
−8
−10
−12
−14
−16
−18
PM10 relative diff (%)


FUPS-baseline
7500
5000
2500
0
−2500
−5000
−7500
−7500 −5000 −2500 0 2500 5000 7500
−12
−16
−20
−24
−28
−32
−36
PM10 relative diff (%)

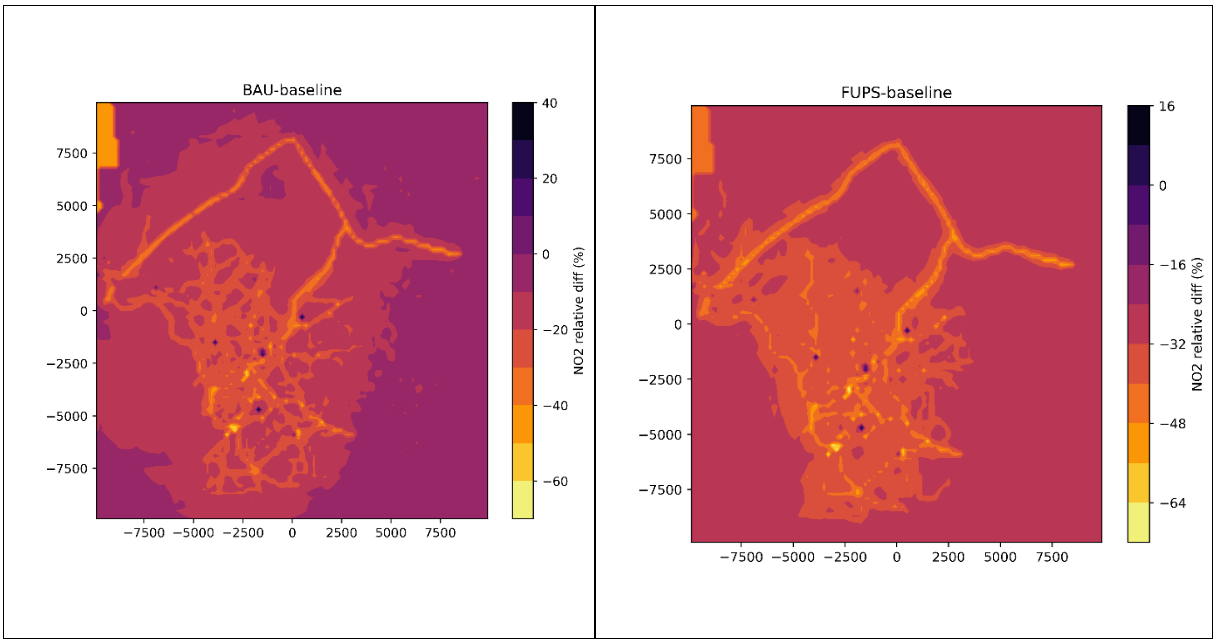


Figure 1-68: Air quality impact benefits of implementing emission control measures in 2050 for Bristol. BAU vs baseline on the left and UPS vs baseline on the right for PM2.5 (top), PM10 (centre), and NO_2 (bottom).

4 Conclusions

This report presents the overall results on the impact assessment approach to consider the impacts on emissions (air pollution and carbon), air quality concentrations, exposure and health of the ClairCity baseline and future scenarios for Bristol. 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/d5-5-assessment-of-impacts-first-city. 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.