

ASSESSING THE IMPACTS OF CITIZEN-LED POLICIES ON EMISSIONS, AIR QUALITY AND HEALTH

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Abstract

Air pollution is a global challenge, and especially urban areas are particularly affected by acute episodes. Traditional approaches used to mitigate air pollution primarily consider the technical aspects of the problem but not the role of citizen behaviour and day-to-day practices. ClairCity, a Horizon 2020 funded project, created an impact assessment framework considering the role of citizen behaviour to create future scenarios, aiming to improve urban environments and the wellbeing and health of its inhabitants. This framework was applied to six pilot cases: Bristol, Amsterdam, Ljubljana, Sosnowiec, Aveiro Region and Liguria Region, considering three-time horizons: 2025, 2035 and 2050. The scenarios approach includes the Business As Usual (BAU) scenario and a Final Unified Policy Scenarios (FUPS) established by citizens, decision-makers, local planners and stakeholders based on data collected through a citizen and stakeholder co-creation process. Therefore, this paper aims to present the ClairCity outcomes, analysing the quantified impacts of selected measures in terms of emissions, air quality, population exposure, and health.

Each case study has established a particular set of measures with different levels of ambition, therefore different levels of success were achieved towards the control and mitigation of their specific air pollution problems. The transport sector was the most addressed by the measures showing substantial improvements for NO₂, already with the BAU scenarios, and overall, even better results when applying the citizen-led FUPS scenarios. In some cases, due to a lack of ambition for the residential and commercial sector, the results were not sufficient to fulfil the WHO guidelines.

Overall, it was found in all cities that the co-created scenarios would lead to environmental improvements in terms of air quality and citizens' health compared to the baseline year of 2015. However, in some cases,

38 the health impacts were lower than air quality due to the implementation of the measures not affecting
39 the most densely populated areas. Benefits from the FUPS comparing to the BAU scenario were found to
40 be highest in Amsterdam and Bristol, with further NO₂ and PM₁₀ emission reductions around 10% to 16%
41 by 2025 and 19% to 28% by 2050, compared to BAU.

42 **Keywords:** Citizen engagement, impact assessment, urban emissions, air pollution reduction, health
43 benefits, European cities

44

45 1. Introduction

46 Air quality remains poor in various areas, and many European cities are still affected by severe air pollution
47 episodes, despite notable reductions in emissions and ambient concentrations over recent decades.
48 Urban areas are of particular concern due to higher population densities with 8 % and 77% (EEA, 2020),
49 in 2018, of the EU-28 urban population exposed to PM_{2.5} concentrations that exceed the EU Limit Value
50 established by the EU Directive 2008/50/EC (EU, 2008) and the stricter PM_{2.5} limits established by the
51 WHO Air Quality Guidelines (WHO, 2006), respectively. In fact, air pollution represents one of the biggest
52 environmental risks to health, responsible for around 400,000 premature deaths per year in the EEA-39
53 (excluding Turkey) as a result of exposure to PM_{2.5} (EEA, 2020; WHO, 2018).

54 In cities, the main problems are associated to NO₂, PM₁₀, and PM_{2.5} pollutants, mainly related to
55 transport and residential combustion sectors (EEA, 2020). Thunis et al. (2018) showed that cities could
56 have an essential role by taking actions to resolve air pollution problems. A lot of research has been done
57 to assess the impact of traffic management control strategies in urban areas (York Bigazzi and Rouleau,
58 2017) and even on background concentrations (Pisoni et al., 2019). Road transport technological
59 measures show an expected reduction of emissions below 20%, for some measures, while low emission
60 zones and pricings are expected to be more effective, reaching up to 50% of reductions (York Bigazzi and
61 Rouleau (2017)). These measures were expected to lead from 10% up to 25% of air quality improvements.
62 Matthias et al. (2020) concluded by applying traffic measures that in the future, NO_x emissions from
63 transport are expected to be highly reduced, while PM emissions show less reduction due to non-exhaust
64 particle emission, i.e., brake, tire, and street wear.

65 To tackle PM emissions in urban areas, it is essential to consider the residential heating sector, especially
66 due to the increased practice of household biomass burning as it is a cheaper alternative to the primary
67 energy sources (e.g., oil and natural gas) and as the emergence of solid fuel-burning for recreational or
68 atheistic purposes. Domestic wood combustion is a major source of ambient PM, mainly during winter,
69 accounting for 20–30% of local heating-season ambient PM_{2.5} levels, varying by location (WHO, 2015),
70 but not always perceived as a problem by citizens (Slingerland et al., 2020). As shown by Vicente and Alves
71 (2018), several technological improvements can be made to reduce residential biomass combustion PM
72 emissions. However, some of these technologies are not well-developed for domestic scale applications,
73 would increase costs and maintenance and may even raise safety issues. Therefore, national governments
74 and regional authorities should support voluntary woodstove and fireplace replacement/retrofit
75 programs to motivate households to replace older technologies with safer, more efficient, cleaner-
76 burning technologies. Even with the recent standardisation framework of requirements for domestic
77 heating systems set by the European Committee (Council Directive 2009/125/EC, 2009), the citizen
78 behaviour change is necessary to face this problem (Vicente and Alves, 2018).

79 Understanding how populations live and the societal factors that influence daily behaviours is the key to
80 reduce emissions and improve air quality (Fogg-Rogers et al., 2020) and therefore comprehend the

81 reasons for high levels of air pollution in cities is crucial for decision-making on urban air quality
82 management (EEA, 2018). Initiatives targeting public awareness and behavioural changes have led to
83 growing support and demand for measures to improve air quality (EEA, 2019). The ClairCity project,
84 funded under EU Horizon 2020, aimed to put citizens' behaviour and activities at the core of policymaking
85 in six European countries (ClairCity, 2020). The six pilot case study areas examined are Bristol (United
86 Kingdom), Amsterdam (Netherlands), Ljubljana (Slovenia), Sosnowiec (Poland), Aveiro Region (Portugal)
87 and Liguria Region (Italy). The ClairCity co-designed framework led to a creation of a policy package for
88 each case study, consisting of a set of policies designed by citizens, decision-makers, local planners and
89 stakeholders based on data collected through multi-stakeholder collaboration processes.

90 This paper tries to bring 'citizen-inclusive policy making' as an important focus point for future air quality
91 policy plans development to improve air quality and reach expected objectives. The main objective of this
92 paper is to quantify, understand and compare the impacts from citizen-led policy package, which account
93 for behavioural changes for the short and long term. The analysis focuses on emissions, air quality,
94 population exposure, and health for the six case studies. The paper is structured into four main sections:
95 Section 2 describes the methodology behind the BAU and FUPS scenarios, the methods and tools adapted
96 for the emission estimation, air quality modelling assessment, population exposure and health impact
97 assessment. Section 3 shows the results and discussion by applying both scenarios analysing reductions
98 achieved in terms of emission, air quality and population exposure, but also the improvements in terms
99 of health impacts. The main conclusions are presented in section 4.

100

101 2. Methodology

102 This section presents a summary of the engagement processes (section 2.1), then describes how the
103 measures were obtained to build the scenarios (section 2.2), and how they were interpreted to quantify
104 the variability in terms of emission (section 2.3), the impacts on air quality (section 2.4) and the respective
105 impacts on population exposure and health (section 2.5). The results from the quantification framework
106 will be further presented and discussed in section 3. A schematic representation of the ClairCity
107 methodology flow is presented in Figure S1 of the supplementary material, showing the connection
108 between the engagement process and the scenario co-creation. This work is focused on the impact
109 assessment step.

110 2.1 Engagement processes

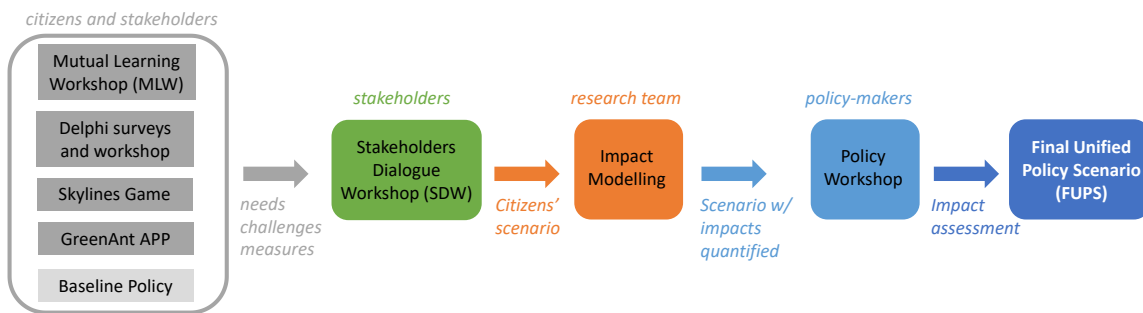
111 The engagement and co-creation process in ClairCity were performed in three key phases with several
112 activities which work towards achieving a final policy package, as schematically represented in Figure 1.
113 More details can be found in Artola and Slingerland (2019). This process has been adapted and applied
114 across all six case study areas and consists of:

- 115 1. Establishing the baseline situation for each city;
- 116 2. Citizen and Stakeholder Engagement & Co-creation of Scenarios;
- 117 3. Quantified Policy Package, Evaluation and Mutual Learning, Policy Recommendations;

118 In Phase 1, data on city characteristics, demographics, air quality and climate change situation, as well as
119 historical and current policy and citizen engagement landscape, were collected to quantify the baseline
120 air pollutants emissions and concentrations, public health impacts, and current policies. Phase 2 focused
121 on engaging citizens and key stakeholders in order to: understand citizens' current behaviours, practices,
122 and activities; enabling citizens and stakeholders to co-create and provide information about desired
123 future behaviours and future policies; and raising awareness of the environmental challenges and their

124 solutions. For this purpose, in addition to the Skylines Game and the GreenAnt App, 2-round Delphi
 125 surveys and a Delphi workshop were carried out with citizens to get their views and opinions on their
 126 city/region needs, challenges and barriers. The engagement process was crucial for the project goals. The
 127 results from these activities were surmised towards achieving consensus and processed into qualitative
 128 ‘citizen scenarios’. These were subsequently discussed in workshops with stakeholders – Mutual Learning
 129 Workshops and Stakeholders Dialogue Workshops (SDW), and with policymakers - Policy Workshops
 130 (PW), regarding opportunities, barriers and limitations to their implementation, as well as their
 131 prioritisation and planning. The SDW originated scenarios with different levels of ambition, which were
 132 later quantified and presented as an input for the PW to help participants choose between the level of
 133 ambition of each measure and to be further integrated into phase 3. The impact assessment between
 134 different stages, as shown in figure S1 of the supplementary material, is an essential step in the
 135 framework. This allows to provide quantified guidelines to assist the debate but also identify possible
 136 limitations which improve the quality of further debates and results.

137 Phase 3 gathered the evidence and lessons learned from Phase 1 and Phase 2 to reach a quantification of
 138 the FUPS in each city. The inclusion of citizens and stakeholders’ suggestions into decision making was
 139 evaluated using cutting-edge modelling to understand the impacts on emissions, air quality and health,
 140 compared to a policy baseline scenario, as described in the following section 2.2. Then, this assessment
 141 returned to policymakers, citizens and influential organisations in each city and region. The policy and
 142 political feasibility of the scenarios were discussed together with policymakers in the PW to draw a
 143 consensual package of measures – Policy Package –that defined the FUPS for each city/region.



144
 145 **Figure 1-Schematic representation of the engagement process to obtain the Final Unified Policy Scenario (FUPS) for each**
 146 **city/region.**

147
 148 **2.2 Scenarios development**

149 The scenarios developed in the scope of the ClairCity project were co-designed following a framework
 150 that can be separated into two different groups: (1) the Business-As-Usual (BAU) scenarios, which aims to
 151 capture the continuation of city policy assuming no additional measures are taken, reflecting the normal
 152 trend without any behavioural changes, or any policy, neither interventions beyond the measures already
 153 established; and (2) the Final Unified Policy Scenarios (FUPS), which translates the vision and expectations
 154 of local citizens, stakeholders and policymakers based on data collected through ClairCity engagement
 155 processes. The data collected through the engagement process from the ClairCity framework estimated
 156 the impact of future scenarios considering 3-time horizons: 2025, 2035 and 2050, and was used to support
 157 and inform the development of city policy packages. The scenarios were compared, considering the
 158 impact on the baseline year (2015).

159 As previously mentioned, BAU scenarios take into consideration national and city-level measures already
160 defined. Overall, for the six case studies, the scenarios were designed using the projections of greenhouse
161 gas emissions and energy demand from the 7th national communication to United Nations Framework
162 Convention on Climate Change (UNFCCC); from the national measures projections in the frame of the
163 National Emission Ceiling Directive (NECD); and when applicable, other specific case study related
164 measures, as for example, the ban of coal power plants by the Dutch government in 2018, or the
165 permanent shutdown of the Genoa coal thermal power plant in 2016 (Rodrigues et al., 2020).

166 The final policies included in the FUPS for each case study are presented in Table S1 of the supplementary
167 material.

168 Overall, for the developed FUPS (see section 2.1), there was no set of measures to fit all cases equally
169 since each city/region has different priority measures and views on how far they can go implementing
170 those measures. A common ground found across all cities is the focus on the transport sector, whether
171 these are public transport policies, policies targeting private vehicles or policies to foster active travel. All
172 the cities proposed ambitious policies to discourage car use. Regarding the energy sector, Bristol,
173 Amsterdam, Sosnowiec and the Liguria Region were quite ambitious, while Ljubljana and Aveiro were less
174 so. When assigning ambition levels for each policy, generally, the reasons for opting for a low ambition
175 level were the cost of implementation of the measures and an unrealistic timeframe proposed in the high
176 ambition level (Artola and Slingerland, 2019). For example, cleaner public transport was given low
177 ambition in all cases.

178 Bristol is the only city with an equality policy, namely "spread economic opportunities across the city".
179 Most energy policies are found in Amsterdam, while in Ljubljana deliberately no energy policies were
180 generated, which reflects the dominance of transport policies in the public debate. Sosnowiec was the
181 only case which proposed two measures that can be considered adaptation measures to air pollution,
182 namely: "Free public transport on days with a high level of air pollution by 2020", and "Ban diesel cars
183 from the city centre on days with poor levels of air pollution by 2050". Liguria region considered high
184 priority shifting private vehicles to electric, and it is partly being facilitated through financial incentives.
185 Active travel policies mostly regard cycling, with only Aveiro proposing a specific measure to foster
186 walking. Four out of the six case studies (Bristol, Amsterdam, Ljubljana and Liguria) discussed measures
187 around "environmental zones". Furthermore, the set of policy measures of Sosnowiec and Aveiro included
188 industry (technological) measures, which do not require behaviour change of citizens.

189

190 2.3 Emissions estimation

191 The ClairCity impact assessment framework included the development of an emission inventory
192 considering the most relevant emission sectors in urban areas, such as the road transport sector, the
193 residential, commercial and institutional sector (IRCI), and the industrial sector. Additionally, the shipping
194 sector was quantified for the baseline for Amsterdam and the Liguria Region. The BAU scenarios for the
195 shipping sector were only quantified for the Liguria Region, where the International Maritime
196 Organization Tier 2 and cold ironing implementation measures account for reductions of NO_x emissions
197 of 15.5% in 2025 and 24.1% in 2050.

198 The methodology for the scenarios' emissions quantification process for each sector will be described
199 next. The baseline framework also follows the quantification methodology for all case studies described
200 in Rodrigues et al. (2020).

201

202 2.3.1 Transport

203 The transport sector was the most addressed sector by measures of the FUPS, therefore the scenarios
204 accounted for several variations in terms of the vehicle fleet composition and modal choice changes for
205 the future.

206 A mode choice model (Purwanto et al., 2017) was used to predict the modal shift (and the mileage change)
207 caused by various policy decisions or scenario targets. The model predicts the percentage chances of a
208 traveller choosing a given transport mode, based on a given socioeconomic background (income, car
209 ownership, age, gender, etc.), who travels for a given reason (work, education, shopping, etc.), between
210 two points. It then forecasts transport demand and vehicle fleet size, calculating change not only in the
211 percentage of trips over various modes but also the change in total mileage per mode. Predicting how
212 mode choices would be influenced by different assumptions made for each measure/scenario allows
213 estimating energy and emission values, which are related to the vehicle kilometres.

214 While the FUPS scenarios account for all the behavioural change idealised by citizens and stakeholders,
215 BAU scenarios assumed no change in the modal split, accounting only for the predicted fleet evolution as
216 stated by McKinsey & Company (2012). For each scenario, the final emissions were then estimated based
217 on the new modal splits and the resulting mileage changes for the various years. So, the emissions were
218 calculated by following the common COPERT V methodology (<https://www.emisia.com>) by applying the
219 EU standard vehicle emission factors to the new traffic volumes.

220 Although different approaches and assumptions had to be made for each case study, all the cities
221 proposed one or multiple measures focusing on four main groups: restrictions of private vehicles, an
222 improvement in terms of public transportation, improvements to promote active travel, and
223 encouragement for electric vehicles (EV).

224 The restrictions of private vehicles account for several aspects regarding private transportation. In a lot of
225 cities, the restriction pointed to a ban on most polluting vehicles which resulted in policies ranging from
226 banning the most polluting vehicles (old Euro standard diesel) in low emission zones to completely
227 banning cars with an internal combustion engine. These kinds of measures were all modelled by changing
228 the survival rates and the growth rates in the fleet models. For example, if a city decides to introduce a
229 stepwise ban on diesel cars, so that, e.g., by 2030 only Euro 6 diesel cars are allowed on the roads, then
230 this is modelled by making sure that all Euro 5 or worse diesel vehicles were scrapped out of the fleet by
231 the end of 2029 (for example scrapping all Euro 3 by the end of 2025 and Euro 4 by the end of 2027 as a
232 lead up to put smaller pressure on the new sales that still need to fill the suddenly larger demand-gap).
233 Such scrapping schemes are very easy to model by setting the survival rates for all to be fully scrapped
234 vintages to 0.

235 Cheaper and more efficient public transportation was seen as a common goal between all cities/regions.
236 The idea behind these measures is to induce a modal shift by reducing the use of private vehicles and
237 enhancing the use of public transportation. The improvement of the overall network organisation, as a
238 result of higher frequencies and more fluid routes (e.g., with the introduction of more bus lanes), leads to
239 a strong decrease in waiting and travel times. Furthermore, overcoming the identified problems with the
240 public transportation network is evident to be a suitable alternative to private vehicles, and so, it will lead
241 to a bigger modal shift in the future. Combining a reduction of private vehicles, the improvement of the
242 network and a greener public fleet shows a significant impact on emission reduction.

243 To promote active travel, the measures focused mainly on bike lanes and pedestrian routes. The
244 construction of bike lanes or pedestrian routes was seen as an incentive for active travel since it improves

245 the safety of the users, a highly valuable factor in decision making. The attractiveness of better
246 infrastructures in the future, combined with the willingness by the citizens to change, leads to
247 assumptions for the growth of walking/bike trips share. The identified levels of ambition from the citizens
248 for active travel were significantly different between case studies, therefore the growth assumptions by
249 measure for each scenario was heavily influenced by this factor.

250 The encouragement of electric vehicles covered different aspects, e.g., financial incentives, replacement
251 of fleets, charging facilities, and others. For example, in the Liguria Region, one measure consisted of
252 replacing 50% of vehicles circulating in urban areas with electric automobiles and motorcycles (including
253 sharing) by 2050 and installing an adequate number of recharging stations. The assumption focused on
254 updating the EV sales share progressively to achieve the 50% fleet share by 2050. Overall, the assumption
255 for the scenarios focuses on a fleet evolution, from incentives (as subsidies, advertisement, environmental
256 considerations) that will boost the uptake of vehicles with electric and hybrid powertrains.

257

258 2.3.2 Industrial, Residential, Commercial & Institutional (IRCI)

259 The IRCI emissions were estimated for the future years for every single territorial unit LSOA (Bristol), buurt
260 (Amsterdam), naselje (Ljubljana), gminas (Sosnowiec), freguesia (Aveiro region), and census section
261 (Liguria region)) for a specific activity starting from the emissions from the baseline year. These
262 estimations use specific projections factors (drivers) of activity level due to activity measures and specific
263 drivers for emission factors related to emission control measures and, if any, additional emissions are
264 foreseen for a selected new activity. Drivers for activity levels and emission factors can be related to
265 multiple activities. For example, the demographic driver can be used to forecast emissions for the
266 residential sector related to fuel consumption.

267 Regarding policy measures for the IRCI sector, Bristol and Amsterdam were the most ambitious case
268 studies. For Bristol, the measures focused on increasing the production and usage of renewable energy,
269 raise awareness between property developers regarding air pollution and climate change, improve the
270 energy efficiency of housing, and further measures were designed based on the Bristol strategy for carbon
271 neutrality by 2050. For Amsterdam, the measures aimed at gas-free policies by 2040, with no fossil fuel
272 for 100% of buildings and residual use of gas allocated to biogas (45%) and green gas (55%). While
273 Sosnowiec aimed for a partial ban of coal on the Residential and Commercial sector. Ljubljana, Liguria
274 Region and Aveiro Region didn't include measures concerning the residential and commercial sector to
275 go further than established by the BAU scenarios.

276 The planned strategies by the governments accounted for in the BAU scenarios had big impacts on the
277 industrial sources in different case studies. For example, in Amsterdam due to the coal ban, the production
278 of electricity with coal as fuel is prohibited from 2030 onwards. Therefore, the two oldest power plants
279 will stop electricity production by the end of 2024 through coal. In consequence, the BAU scenario
280 accounts for the closure of a power plant by 2025. In Liguria Region, the BAU scenario accounts for the
281 shutdown of the Genoa Power Plant in 2016 (Rodrigues et al., 2020).

282 The cities/region to present FUPS scenarios to go further than the BAU scenarios for the industrial sector
283 were Sosnowiec and the Aveiro Region. The Aveiro region presented measures to reduce PM industrial
284 emissions by 15% in 2025, and Sosnowiec defined a measure to reduce industrial emissions by 25% in
285 2025. One important assumption considered is without any policy to limit or to prohibit the most polluting
286 fuels, no change was foreseen in the share of use of the different fuels.

287

288 2.4 Air quality modelling assessment

289 To assess the impact of the scenarios on air quality, a hybrid method composed by a numerical approach
290 – using the URBAIR – URBan AIR model (Borrego et al., 2016; Dias et al., 2018) and a weighting approach,
291 was applied.

292 First, the air quality simulations were performed for the entire year of 2015 on an hourly basis considering
293 the meteorological conditions for each hour and emission variability, following the quantification
294 methodology described further in Rodrigues et al. (2020) and Rafael et al. (2021). The URBAIR is a second-
295 generation Gaussian model that has been widely applied to assess air quality at urban scale (Borrego et
296 al., 2016; Dias et al., 2018). The assessment of air quality was focused on NO₂, PM₁₀ and PM_{2.5}
297 concentrations. The different emission sectors – transport, IRCl, industrial, and shipping (for Amsterdam
298 and the Liguria Region) - were simulated separately in order to have their individual contribution (source-
299 apportionment approach). The air quality simulations were performed for the computational domain over
300 the urban area of each city/ region with a horizontal resolution of 200 m x 200 m, except for the Aveiro
301 Region, which was run with a horizontal resolution of 400 m x 400 m. The computational domains of each
302 city/ region differ in Bristol, Ljubljana, and Sosnowiec domains dimensions are 20 km x 20 km, Amsterdam
303 domain is 25 km x 20 km, Liguria domain is 25 km x 15 km, and Aveiro domain is 40 km x 55 km.

304 Second, the annual percentual reductions of each emission sector were applied to the annual air quality
305 outputs per sector for each scenario and time-horizon for the six cities/regions.

306 It should be noted that this hybrid method can be adopted since the focus of the study are annual metrics.
307 As showed by Thunis et al. (2015), linear simplifications could have different impacts depending on the
308 time scales considered. In particular, when focusing on long-term averages (annual averages), can exhibit
309 very low level of non-linearities depending on the pollutant and location, and so, the secondary formation
310 through chemical reactions can be neglected when the annual mean concentrations are calculated. This
311 simplification guarantees both spatial and temporal distribution of air pollutants concentrations, proving
312 to be less time demanding and requires less computational resources. Despite that, this hybrid method
313 has uncertainties associated, which will be discussed further in section 3.5.

314 For each case study, air quality spatial and temporal maps were produced, and different analyses were
315 conducted considering the EU regulated limit values for these specific pollutants and the stricter but
316 voluntary WHO guidelines that are established for PM₁₀ and PM_{2.5}.

317 2.5 Population exposure and health impact assessment

318 The population potentially exposed to NO₂, PM₁₀ and PM_{2.5} concentrations above the EU legal limit
319 values (EU, 2008) and the WHO guidelines (WHO, 2006) was estimated for all the case studies. The
320 population exposure was estimated considering an annual average of air quality concentrations and
321 population data (CBS, 2015; INE, 2011; Istat, 2011; ONS, 2015; Statistics Poland, 2011; SURS, 2011)
322 distributed by each computational grid cell.

323 To estimate the health benefits related to each of the individual air pollution reduction scenarios, the
324 following health impact indicators were calculated individually for PM_{2.5}, PM₁₀ and NO₂ concentrations:

- 325 i) Reduction in mortality is expressed as the reduction in premature deaths.
- 326 ii) Reduction in years of life lost (YLL).

327 These mortality health outcomes were estimated based on the methodology described in Soares et al.
328 (2019). To calculate premature deaths and YLL, population density and demographic data per country,
329 age, and sex was combined with gridded concentrations provided by the air quality estimations from

330 section 2.3 and concentration-response functions. The concentration-response functions follow the
 331 recommendations from the HRAPIE project (WHO, 2013): for PM2.5, all-cause (natural) mortality is
 332 considered in ages above 30, for all concentration levels, assuming an increase in the risk of mortality of
 333 6.2% for a 10 $\mu\text{g.m}^{-3}$ increase of PM2.5; for PM10, all-cause (natural) mortality is considered in ages above
 334 30, for all concentration levels, assuming an increase in the risk of mortality of 4.0% for a 10 $\mu\text{g.m}^{-3}$
 335 increase of PM10; and for NO₂, all-cause (natural) mortality is considered in ages above 30, for
 336 concentrations above 20 $\mu\text{g.m}^{-3}$, assuming an increase in the risk of mortality of 5.5% for a 10 $\mu\text{g.m}^{-3}$
 337 increase of NO₂.

338

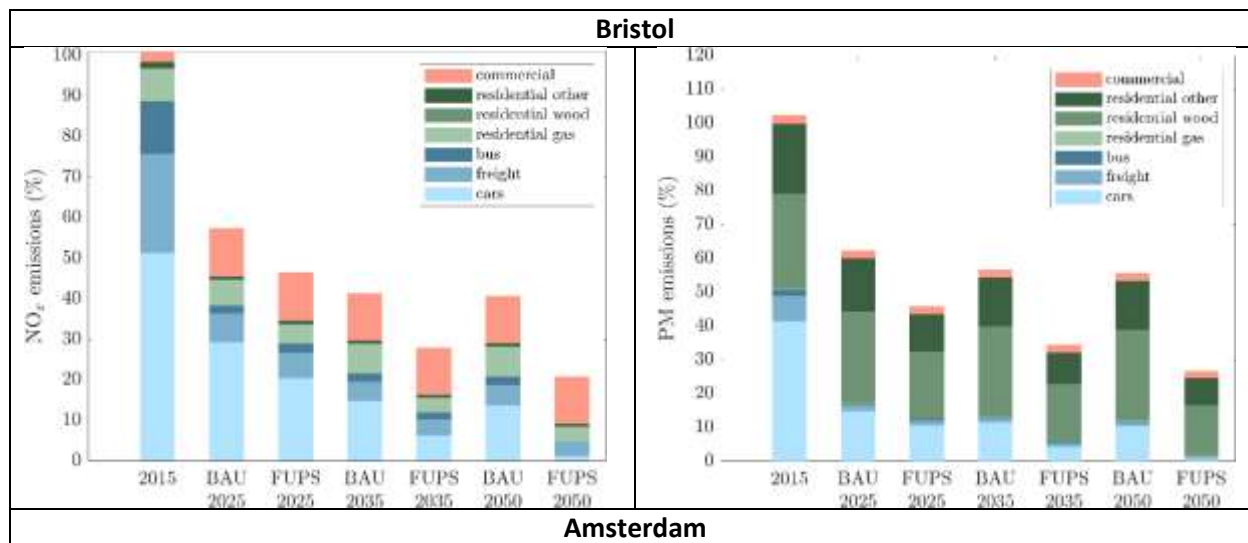
339 3. Results and discussion

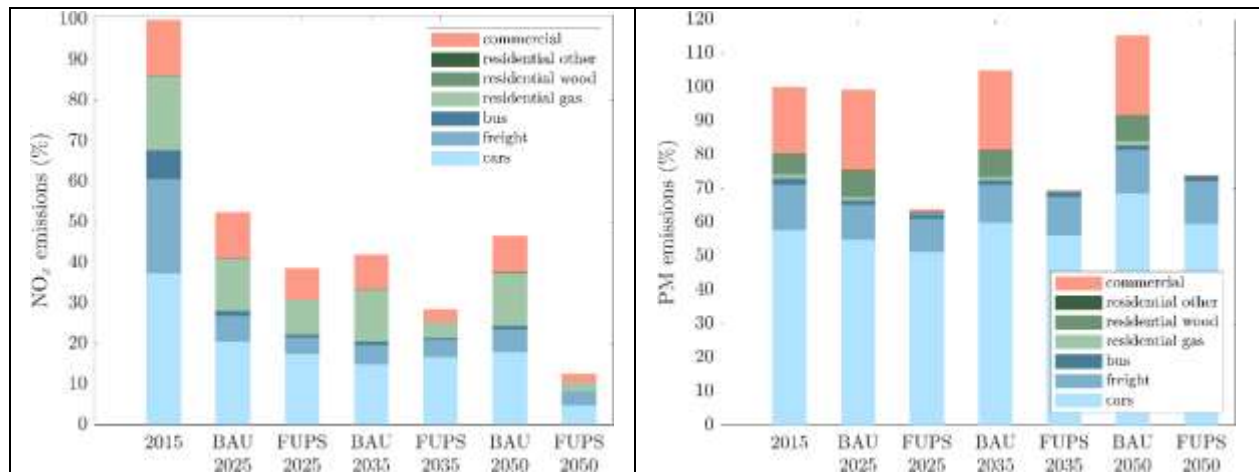
340 This section discusses the potential impacts of implementing the measures comparing to the baseline year
 341 in terms of emissions (section 3.1), air quality (section 3.2), population exposure (section 3.3), and health
 342 impacts (section 3.4).

343 3.1 Emissions

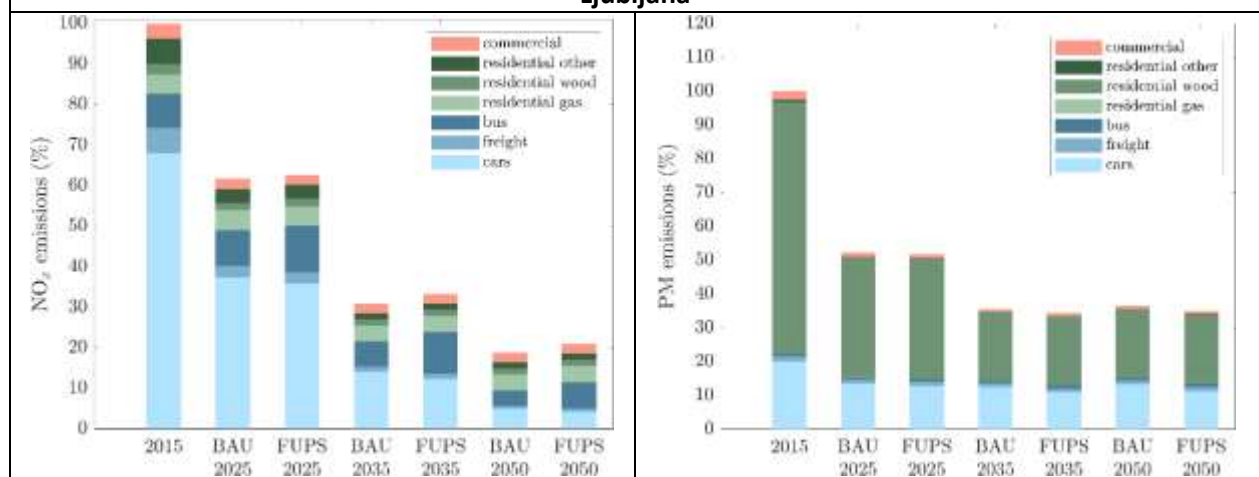
344 Figure 2 shows the emission reductions for the transport, residential and commercial sector, for NO_x and
 345 PM, compared to the baseline for both BAU and FUPS scenarios for all the cities/regions.

346

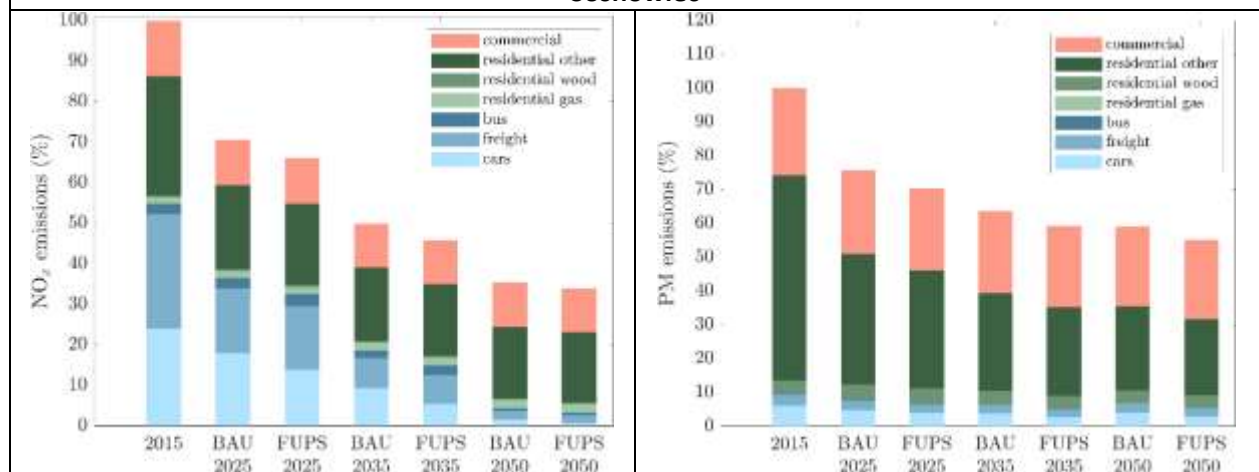




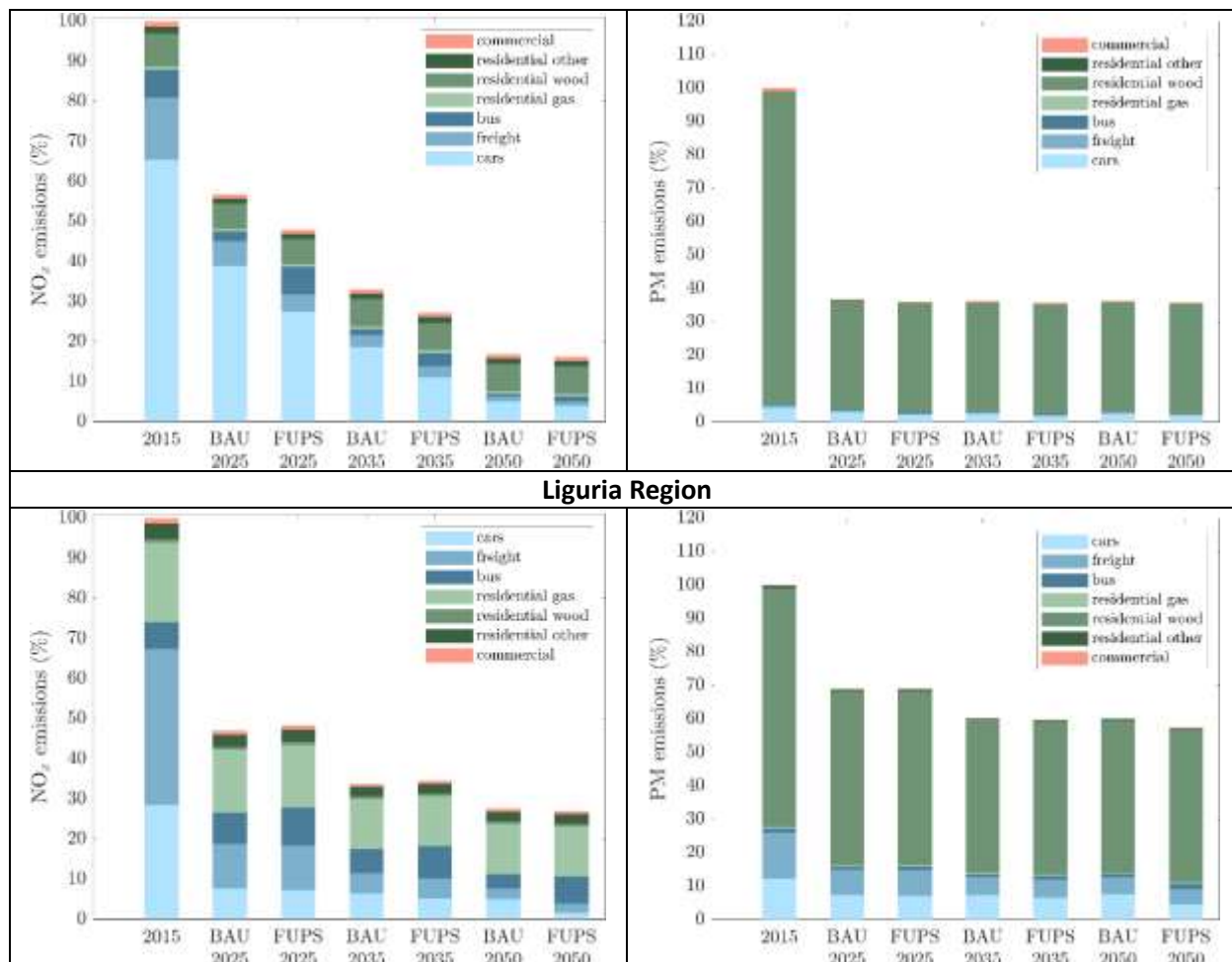
Ljubljana



Sosnowiec



Aveiro Region



347 Figure 2- Scenario emissions for NOx and PM as a percentage of the baseline emissions after applying the emission reduction
 348 measures

349 For Bristol, the FUPS scenario is successful in further decreasing the emissions from transport beyond the
 350 reductions already in the BAU. Transport NOx emissions are reduced to about 10% in 2035 compared to
 351 2015 in the FUPS scenario, while the BAU emissions in that year are still 19% of the 2015 emissions. For
 352 the FUPS scenario, transport emissions are reduced to 5% for NOx and 3% for PM in 2050 compared to
 353 2015. A side-effect of the FUPS scenario is that it increases the importance of emissions from other
 354 sources that are not affected by the policy measures. For example, while PM emissions of residential
 355 sources overall are decreasing, their slower emission reduction pace compared to transport is making
 356 residential sources the dominant sources of PM emissions over time, from about 47% in 2015 to 85% in
 357 2050.

358 For Amsterdam, the NOx emissions are highly reduced in both scenarios but going further with FUPS. The
 359 difference between both scenarios is explained mainly due to gas-free measures for the residential sector
 360 and the transport restriction measures presented by the FUPS scenarios. The PM emissions in the city
 361 centre would increase in the BAU scenario as a result of higher emissions from cars (due to the non-
 362 exhaust emissions of transport, i.e., the brake and tyre wear and tear), but would strongly decrease in the
 363 FUPS as a result of the ban of wood burning from residential and commercial sources included as a
 364 measure.

365 For Ljubljana, the BAU scenario would reduce NO_x emissions to about 62% of 2015 levels in 2025 and
366 about 19% of the base year value in 2050. The FUPS scenario includes no measures related to the IRCI
367 sector, so the changes, when compared to the BAU, are only observed in the transport sector. The FUPS
368 scenario measures as modelled lead to a slight increase of NO_x emissions compared to BAU, mainly
369 because the selected measures contribute to a modal shift from private cars to buses, however none
370 promote the replacement of the public transport fleets with electric vehicles. Therefore, when comparing
371 FUPS to BAU, slight increases can be seen in 2025 and even higher in 2035 due to an increase of public
372 transport of 10% by 2027. The PM emissions show a strong decrease in the BAU with a great reduction of
373 residential solid fuel consumption but would not go further in the FUPS due to the lack of specific
374 measures targeting these emissions.

375 For Sosnowiec, the FUPS scenario adds an additional decrease in emissions (e.g., around 5% in the short
376 term and less in the longer term) beyond the reductions in the BAU. For the NO_x emissions, the decrease
377 is mainly due to decreasing transport emissions, through measures pushing citizens away from car use
378 towards active travel and public transport (being cleaner compared to the BAU due to additional
379 investments in zero-emission buses). A similar downward trend is observed for PM emissions. The main
380 driver for the reduction is linked to heating in the residential sector. Already in the BAU, a gradual
381 improvement is expected, leading to stronger reductions with the FUPS scenarios due to more ambitious
382 measures for the replacement of residential heating sources. The FUPS will generate an additional
383 decrease in PM emissions compared to the BAU. However, a decrease in PM emissions from transport will
384 continue to have a limited impact on the overall emissions.

385 For the Aveiro Region, the NO_x emissions exhibit a significative trend of reduction in both scenarios, with
386 the FUPS scenario allowing a slight extra reduction comparing to BAU. Reductions in both scenarios result
387 mainly from decreasing transport emissions. In the FUPS, due to the encouragement of a modal choice, a
388 stronger reduction in emissions from cars and an increase in bus emissions were observed, with a net
389 emission reduction. However, by 2050, emission reductions from BAU and FUPS will be almost the same.
390 For PM, the emission reductions are limited for both scenarios, mainly observed for residential solid fuel
391 consumption. The measures in FUPS have a similar effect to BAU due to the lack of specific measures in
392 FUPS targeting, for example, residential heating. Given the low contribution of transport to PM emissions,
393 the emission savings from transport in the FUPS compared to BAU are negligible in the overall result.

394 For the Liguria Region, the NO_x emissions show a clear trend of reduction over the three time-horizons.
395 The FUPS scenario leads to a limited decrease in emissions beyond the reductions already in the BAU for
396 most sectors. Moreover, the decrease of passenger car NO_x emission is offset by a rebound of emissions
397 from buses. This is because FUPS measures increase the use of buses by citizens but present no measures
398 concerning the improvement of public transport emissions. So, buses emissions are expected to increase
399 in the FUPS scenario. In 2050, the total emissions in the BAU scenario and the FUPS will be almost the
400 same. A similar trend is observed for PM emissions, without the rebound from bus emissions. This
401 decrease in PM emissions is mainly a result of a decrease in residential emissions linked to heating. The
402 FUPS does lead to a slight additional reduction of PM emissions compared to the BAU (2.6%), mainly due
403 to reductions in transport emissions. Given the low contribution of transport to PM emissions, the
404 emission savings from transport in the FUPS compared to BAU are very small.

405

406 3.2 Air quality outcomes

407 To better understand the impact of the emission reductions described in subsection 3.1 on air quality, the
408 number of computational cells with annual exceedances to the EU limits and WHO guidelines by case

409 study for each scenario is present in Table 1. For NO₂ the limit values established by the EU and the ones
 410 recommended by WHO are equivalent, being 40 µg.m⁻³ for the annual mean. As for particulate matter,
 411 the limits diverge between both standards, with WHO showing stricter limits. PM10 values under the EU
 412 annual mean limits are 40 µg.m⁻³ and under WHO guidelines are 20 µg.m⁻³, for PM2.5 the EU established
 413 a limit value of 25 µg.m⁻³ for the annual mean and the WHO recommends 10 µg.m⁻³.

414 Table 1 shows that mainly PM2.5 is still and will be, even by 2050, a big concern in the cities, especially
 415 for Ljubljana, Sosnowiec and the Liguria Region.

416

417 **Table 1- Number of computational cells (cells with 0.04km², except for the Aveiro Region with cells of 0.16km²) with annual**
 418 **exceedances to the EU limits and, in parenthesis, to the WHO guidelines by case study and scenario**

	Bristol	Amsterdam	Ljubljana	Sosnowiec	Aveiro Region	Liguria Region
	EU/ (WHO)	EU/ (WHO)	EU/ (WHO)	EU/ (WHO)	EU/ (WHO)	EU/ (WHO)
NO₂						
2015	231	214	170	915	11	97
BAU25	5	3	34	493	-	7
FUPS25	1	-	45	459	-	7
BAU35	-	-	-	252	-	3
FUPS35	-	-	-	214	-	3
BAU50	-	2	-	180	-	2
FUPS50	-	-	-	171	-	2
PM10						
2015	- (16)	- (179)	- (2)	46 (3800)	- (-)	3 (924)
BAU25	- (8)	- (37)	- (-)	16 (2670)	- (-)	1 (656)
FUPS25	- (-)	- (35)	- (-)	14 (2505)	- (-)	1 (661)
BAU35	- (5)	- (35)	- (-)	5 (1740)	- (-)	- (541)
FUPS35	- (-)	- (35)	- (-)	5 (1547)	- (-)	- (536)
BAU50	- (3)	- (35)	- (-)	4 (1385)	- (-)	- (553)
FUPS50	- (-)	- (35)	- (-)	3 (1245)	- (-)	- (514)
PM2.5						
2015	- (655)	- (3609)	- (3792)	372 (5755)	- (1997)	5 (2637)
BAU25	- (406)	- (2261)	- (3792)	170 (5755)	- (279)	3 (2637)
FUPS25	- (192)	- (55)	- (3792)	155 (5755)	- (234)	3 (2637)
BAU35	- (338)	- (1616)	- (3792)	69 (5755)	- (250)	1 (2637)
FUPS35	- (100)	- (11)	- (3792)	65 (5755)	- (61)	1 (2637)
BAU50	- (249)	- (1394)	- (3792)	47 (5755)	- (267)	1 (2637)
FUPS50	- (21)	- (13)	- (3792)	45 (5755)	- (71)	1 (2637)

419

420 For NO₂, in 2015 all the cities/regions presented some exceedances problems in some areas of the
 421 domain. By 2025, significant reductions are showing a big impact of the measures from both scenarios,
 422 resolving the NO₂ issues for the majority of the case studies. By 2050, Sosnowiec, although with a big
 423 reduction of the number of cells with exceedances (a reduction around 81% from 2015), is the only case
 424 study that still presents some major exceedances to NO₂. The potential problems in Sosnowiec by 2050
 425 are caused mainly by the residential sector, which indicates a necessity for more ambitious measures for
 426 that sector.

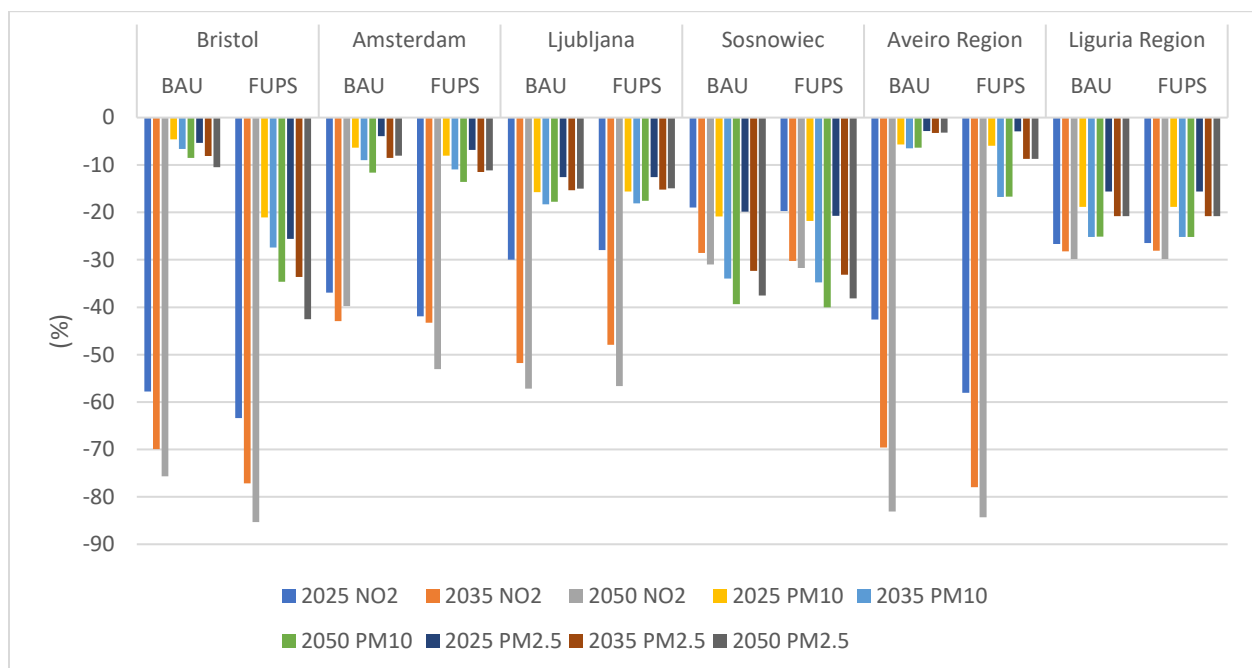
427 For PM10 and PM2.5, when looking at the EU legal limit concentrations for the baseline, only Sosnowiec
 428 shows exceedances of particulate matter and the Liguria Region with a located problem in a reduced area
 429 (3 cells for PM10 and 5 cells for PM2.5 that are exceeding the EU annual limits) of the domain. The
 430 application of the scenarios improves the PM10 concentrations significantly, showing no exceedances by

431 2035 in the Liguria Region, and by 2050 with FUPS scenarios, only 3 cells are exceeding the EU limits in
 432 Sosnowiec. On the other hand, when applying the stricter WHO guidelines limit, Table 2 shows that mainly
 433 PM2.5 is still and will be, even by 2050, a big concern in the cities, especially for Ljubljana, Sosnowiec and
 434 the Liguria Region.

435 Figure 3 shows the percentage of reduction of the maximum concentration value for the annual average
 436 compared to 2015 of NO₂, PM10 and PM2.5 for each case study when applying BAU and FUPS scenarios
 437 for the three-time horizons (2025, 2035, and 2050).

438 Overall, the reductions of the maximum value range between 19% and 85% for NO₂, 5% and 40% for
 439 PM10, and between 3% and 43% for PM2.5, showing generally bigger reductions for the FUPS comparing
 440 to BAU scenarios.

441



442

443 **Figure 3- Reduction (in %) for each scenario (2025, 2035, 2050) of the maximum annual average concentration in the domain**
 444 **of NO₂, PM10 and PM2.5 in each case study.**

445 By looking at the reductions is possible to identify the cities/regions with the most ambitious/efficient
 446 measures. For example, Bristol FUPSs shows a significant improvement when compared to the BAU
 447 scenario, being even more evident when looking at PM. While the Aveiro Region shows huge reductions
 448 for NO₂, when looking at PM10 and PM2.5, it is one of the least ambitious, as previously explained, by
 449 presenting no measures for the residential and commercial sector for the FUPS scenario. Sosnowiec and
 450 the Liguria Region show the highest reductions of the maximum value for PM10 and PM2.5 concentrations
 451 while exhibiting a low reduction in terms of NO₂.

452

453 3.3 Population exposure

454 Directly related to air quality outcomes is the population exposure. Table 2 shows the percentage of
 455 population potentially exposed to the annual NO₂, PM10 and PM2.5 concentrations considering the EU

456 limits and WHO guidelines (in parentheses) for each scenario. The status of population exposure is
 457 distinguishable in the 6 cities and regions under study.

458 A general reduction of the population potentially exposed was obtained in the BAU scenario when
 459 compared with the baseline, with an average reduction of 6%, 8% and 9% for the three time-horizons
 460 (2025, 2035 and 2050), respectively. This improvement is explained by the overall reduction of PM10,
 461 PM2.5 and NO₂ concentrations due to the reduction in transport and residential combustion emissions,
 462 as discussed in section 3.1 Emissions . For the BAU scenarios, Sosnowiec will still be the city that has the
 463 highest rate of population potentially exposed to PM10, PM2.5 and NO₂ concentrations. The percentage
 464 of exposure ranges between 44.9% (BAU 2025) and 28.3% (BAU 2050) for NO₂; for PM10 and PM2.5 the
 465 percentage of exposure is higher than 2%, reaching 100% for PM2.5 regarding the WHO standard. For the
 466 remaining cities and regions, the population exposed to high levels of NO₂, PM10 and PM2.5
 467 concentrations are less than 1% for BAU 2025, BAU 2035 and BAU 2050 when the EU annual limit values
 468 are considered. For the PM10 WHO target, the Liguria Region showed a high rate of population exposure,
 469 varying between 63.5% (BAU 2025) and 55.3% (BAU 2050). As observed in the baseline, PM2.5 will still be
 470 the most critical pollutant in the BAUs, for all the cities and regions except Aveiro Region, having more
 471 than 10% of the population exposed to PM2.5 concentrations above 20 µg.m⁻³.

472 FUPS also showed a trend of reduction of the population exposure, with significant reductions for Bristol
 473 and Amsterdam when compared to BAUs. In FUPS scenarios, Sosnowiec, Ljubljana and the Liguria Region
 474 showed no major reductions in the percentage of population exposure compared to BAUs. This outcome
 475 is explained by the low ambition of the overall measures regarding transport and energy, not going further
 476 than the established in BAUs. On the other hand, for the remaining cases – Bristol, Amsterdam and Aveiro
 477 Region, FUPS showed a substantial reduction compared to BAU for the three time-horizons, and by 2050
 478 less than 1% of the population will be exposed to the EU and WHO annual standards for PM2.5 and PM10.

479

480 **Table 2- Population potentially exposed (expressed in percentage) to the annual NO₂, PM10 and PM2.5 concentrations**
 481 **considering the EU limits and WHO guidelines (in parentheses) for each scenario in the 6 cities/regions.**

	Bristol	Amsterdam	Ljubljana	Sosnowiec	Aveiro Region	Liguria Region
% of population potentially exposed to NO ₂						
Baseline	5	3	5	59	1	8
BAU 25	-	-	80	45	-	25
FUPS 25	-	-	80	44	-	<1
BAU 35	-	-	-	34	-	-
FUPS 35	-	-	-	31	-	5
BAU 50	-	-	-	28	-	-
FUPS 50	-	-	-	28	-	-
% of population potentially exposed to PM10						
Baseline	- (<1)	- (2)	- (-)	13 (95)	- (-)	<1 (78)
BAU 25	- (<1)	- (<1)	- (-)	6 (89)	- (-)	- (64)
FUPS 25	- (-)	- (<1)	- (-)	5 (88)	- (-)	- (64)
BAU 35	- (<1)	- (<1)	- (-)	3 (80)	- (-)	- (54)
FUPS 35	- (-)	- (<1)	- (-)	3 (78)	- (-)	- (54)
BAU 50	- (<1)	- (<1)	- (-)	2 (75)	- (-)	- (55)
FUPS 50	- (-)	- (<1)	- (-)	2 (73)	- (-)	- (53)
% of population potentially exposed to PM2.5						
Baseline	- (25)	- (71)	- (100)	13 (100)	- (49)	<1 (100)
BAU 25	- (18)	- (59)	- (100)	29 (100)	- (9)	- (100)

FUPS 25	- (10)	- (<1)	- (100)	28 (100)	- (7)	- (100)
BAU 35	- (15)	- (50)	- (100)	16 (100)	- (8)	- (100)
FUPS 35	- (5)	- (<1)	- (100)	16 (100)	- (1)	- (100)
BAU 50	- (12)	- (47)	- (100)	13 (100)	- (8)	- (100)
FUPS 50	- (1)	- (<1)	- (100)	13 (100)	- (2)	- (100)

482

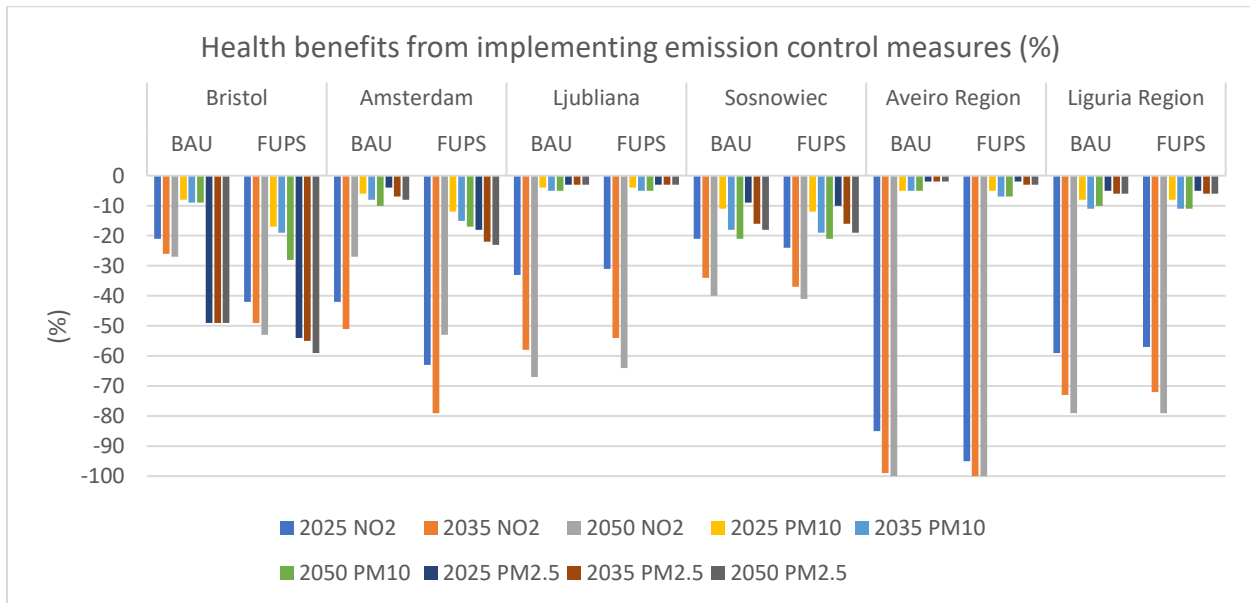
483 3.4 Health impact

484 Health impacts were estimated for the baseline and the future emission scenarios. The health impact
 485 assessment for the baseline, with the number of premature deaths (PD) and life-years lost (YLL), is
 486 presented in Table 3. The health benefits from implementing emission control measures for PM2.5, PM10
 487 and NO₂ in 2025, 2035 and 2050 are presented in Figure 4. The benefit is estimated by benchmarking the
 488 future health outcome values with the values estimated for 2015.

489 **Table 3-Health outcomes related with exposure to PM2.5, PM10, and NO₂ concentration levels in 2015 (baseline).**

Baseline		PM2.5	PM10	NO ₂		PM2.5	PM10	NO ₂	
Bristol (pop. 675908)	PD	577	290	439	Liguria Region (pop. 566483)	PD	590	506	418
	YLL	6170	3102	4696		YLL	5014	4294	3549
	YLL/1e5 inhabitants	913	459	695		YLL/1e5 inhabitants	885	758	626
Amsterdam (pop. 838153)	PD	568	557	697	Ljubljana (pop. 314691)	PD	255	185	219
	YLL	5933	5821	7277		YLL	2687	1950	2306
	YLL/1e5 inhabitants	708	695	868		YLL/1e5 inhabitants	854	620	733
Aveiro Region (pop. 347589)	PD	194	154	63	Sosnowiec (pop. 624542)	PD	879	664	1194
	YLL	2235	1766	720		YLL	12552	9479	17039
	YLL/1e5 inhabitants	643	508	207		YLL/1e5 inhabitants	2010	1518	2728

490



491

492 **Figure 4-Health benefits from implementing emission control measures in 2020, 2035 and 2050.**

493

494 For Bristol, it shows that the FUPS scenario significantly improves human health compared to the current
495 situation and the BAU scenario. For the baseline year, the number of premature deaths as a result of
496 PM_{2.5}, PM₁₀ and NO₂ is 404, 336 and 429, respectively. The BAU scenario reduces these numbers by 87%,
497 17% and 26% in 2050 respectively, but the FUPS scenario results in far larger reductions: 94%, 79% and
498 52%. The reduction in the number of premature deaths is higher than the average concentration
499 reduction when comparing the baseline and future emission scenarios. This discrepancy confirms that the
500 reduction occurs more in areas with a high population.

501 For Amsterdam, the FUPS scenario significantly improves human health compared to the current situation
502 and the BAU scenario. The health benefit of implementing citizen measures in the FUPS is considerable.
503 In 2015, the number of premature deaths as a result of PM_{2.5}, PM₁₀ and NO₂ is 568, 557, and 697,
504 respectively. In 2050, the BAU scenario reduces these numbers by 8%, 10% and 46%, respectively, but the
505 FUPS scenario results in larger reductions: 23% for PM_{2.5}, 17% for PM₁₀, and 84% for NO₂. The FUPS
506 scenario is therefore effective in reducing the long-term health effects of NO₂ as well as PM
507 concentrations. The health benefit from the emissions reduction is in line with the concentration levels
508 reduction predicted for Amsterdam. However, the reduction in the number of premature deaths and the
509 numbers of years of life lost is far more than the average concentration levels reduction. This is explained
510 by the emission reduction measures targeting the more densely populated areas, thus benefiting the
511 population health.

512 For Ljubljana, the health improvements derived from PM₁₀ and PM_{2.5} concentration reductions are the
513 same for both scenarios, showing only a slight difference for NO₂. The health benefit from implementing
514 the control measures behind the future emission scenarios is considerable. For the baseline year, the
515 number of premature deaths as a result of PM_{2.5}, PM₁₀ and NO₂ is 169, 185 and 219, respectively. The
516 scenarios, in 2050, respectively, reduce these numbers by 3%, 5% and 67% (64% for the FUPS). The health
517 benefit from the reduction of emissions is in line with the reduction of concentration levels predicted for
518 Ljubljana.

519 For Sosnowiec, the FUPS scenarios significantly improve human health compared to the current situation,
520 however, offers only a moderate improvement over the BAU. The health benefits from implementing the
521 control measures behind the future emission scenarios (BAU and FUPS) are considerable for NO₂ but not
522 as significant for neither PM₁₀ nor PM_{2.5}. For the baseline year, the number of premature deaths as a
523 result of PM_{2.5}, PM₁₀ and NO₂ is 879, 664 and 1 194, respectively. The BAU scenario reduces these
524 numbers by 18% (19% for the FUPS), 21% and 40% (41% for the FUPS) by 2050 respectively.

525 For the Aveiro Region, both FUPS and BAU scenarios lead to moderate improvements in human health
526 when considering exposure to PM concentrations, but substantially improves human health when
527 considering exposure to NO₂ concentrations. For the baseline year, the number of premature deaths as a
528 result of PM_{2.5}, PM₁₀ and NO₂ is 194, 154, and 63, respectively. The health benefit from implementing
529 the control measures behind the future emission scenarios (BAU and FUPS) is considerable for NO₂ but
530 moderate for particulate matter. In 2050, the BAU scenario will reduce premature deaths as a result of
531 PM_{2.5}, PM₁₀ and NO₂ by 2% (3% for the FUPS), 5% (7% for the FUPS) and 100% in 2050 respectively,
532 when compared to the baseline.

533 For the Liguria Region, the positive impact on human health prompted by the FUPS and the BAU scenario
534 is virtually the same. The health benefit from implementing the control measures behind the future

535 emission scenarios (BAU and FUPS) is considerable for NO₂ but not as significant for neither PM10 nor
536 PM2.5. For the baseline year, the number of premature deaths as a result of PM2.5, PM10 and NO₂ were
537 590, 506, and 418, respectively. By 2050, the BAU scenario will reduce these premature deaths by 6%,
538 10% (11% for the FUPS), and 79%, respectively. The health benefits from the emissions reduction in terms
539 of the number of premature deaths and the number of years of life lost are lower than average
540 concentration levels reduction.

541 3.5 Lessons learned and recommendations

542 For future application of the proposed methodology, it is necessary to consider the existence of limitations
543 and a set of recommendations are advised.

544 When looking at the social aspect, public engagement is a critical step for the success of the results but
545 also a big source of uncertainty. To fully realise the goal of citizen-led air pollution reduction in cities,
546 researchers and policymakers need to work hard to ensure that the engagement is reflective of city
547 demographics by including different age and socioeconomic groups. Engagement activities should be
548 designed accordingly to the target audience, since the more enjoyable the engagement activities are, the
549 more people gain understanding about the issues and show more willingness to change and improve their
550 behaviour.

551 During the engagement process, it was evident that citizens were not always keen on policies that require
552 investment or a significant change of behaviour, while for policymakers, the main barriers were the
553 investment costs and the implementation deadlines. Therefore, it is important to set a guidance in the
554 discussion to find common ground between both parties, allowing to filter out unreasonable policies.
555 However, in the case of very high environmental ambitions, such as in Amsterdam, it was also found that
556 there might still be a substantial gap between what policymakers wish and the specific contribution that
557 citizens are willing to make by changing behaviour.

558 For future replications of this methodology, it is important at first to examine what are citizens' most
559 desired policies to be applied in the future, setting different ambition levels for each measure, and analyse
560 into what extent these coincide with existing policies. Second, presenting the citizen scenarios to
561 policymakers with different ambition levels so policymakers can discuss implementation barriers and
562 enabling factors and then choose the more feasible ones. At last, it is important to identify policy options
563 that do seem to have relatively little popular support or that are subject to public debate. Consider if the
564 implementation of such options should be pursued and, if so, what should be done to increase support
565 for them (Slingerland and Artola, 2020).

566 The co-creation of the scenarios should always follow an iterative process by returning the quantification
567 results back to those involved, to calibrate the vision of citizens, stakeholders, and policymakers, as
568 opposed to a unilateral process of involvement. In the framework of this work, a debate was held between
569 citizens and stakeholders (the Stakeholder Dialogue Workshop) during the scenarios building process, to
570 discuss the results of the Delphi and Mutual Learning Workshop evidence and co-create scenarios. The
571 scenarios generated in the SDW were quantified and then returned to the local citizens/stakeholders to
572 discuss at a Policy Workshop and to agree a single Final Unified Policy Scenario. Performing an impact
573 assessment between steps of the co-creation process, allowed to provide quantified evidence to guide
574 the debate between the different players. This may also help to point out possible gaps or less effective
575 measures to improve air quality, which should be known to an effective air quality management.

576 The impact analysis of the scenarios in terms of emission, concentrations, health impacts and costs are
577 highly relevant to quantify the importance of the measures and to support decision making. It is relevant

578 to mention that the whole process, from behaviour quantification to the air quality and health assessment
579 presents uncertainties associated. The modelling framework, as presented before, proved to be an
580 efficient way to support the choice of citizens and stakeholders in the participatory process of the ClairCity
581 project. However, several uncertainties are associated to it. The emission inventories usually represent
582 one of the largest sources of uncertainty in the air quality modelling chain (Russell and Dennis, 2000).
583 Then, for the air quality approach inherent uncertainties are linked to the air quality models, through
584 difficulties in representing all the atmospheric processes which are depending on the spatial and temporal
585 scale. Moreover, the health impact quantification shows uncertainties due to a lack of specific
586 epidemiological data for each study site.

587 In order to handle these uncertainties, the assessment and communication of uncertainties should play a
588 key role in the discussion of the results. This was carefully addressed during the whole ClairCity
589 framework, even though they were not quantified for each step. Uncertainties were addressed for the
590 baseline year when estimating emissions, by comparing the results with national and European emission
591 inventories; when simulating air quality, through a process of model calibration, verification and
592 validation, by comparing with available air quality measurements; when assessing health indicators,
593 through a benchmark with the annual estimates for premature deaths and years of lost life reported by
594 the European Environment Agency. These uncertainties were communicated to citizens, stakeholders,
595 decision- and policymakers during the engagement and co-creation activities. The outcomes of these
596 debates, depending on the level of expertise of the attendees in those activities, allowed the modelers to
597 double-check their input data, simulations and results, contributing to their improvement.

598

599 4. Conclusions

600 This work focuses on the quantification of impacts on emissions, air quality and human health for the
601 ClairCity future scenarios. ClairCity scenarios were established following a co-creation approach consisting
602 of 3 main vectors: i) establish the baseline, ii) engage citizens, stakeholders and local policymakers, iii)
603 deliver the Policy Package. The assessment of the existing problems for the baseline in each city/region
604 marked the first phase of the scenario's framework. Then, along the process, a set of measures and
605 policies with different levels of ambition were proposed to policymakers. These measures came from
606 citizens and stakeholder's consultation. In general, policymakers found the measures realistic which
607 indicates some common ground between citizens' visions for their future city and what policymakers
608 consider implementable. Any eventual disagreement lied mostly on timeframe and ambition level, e.g.
609 citizens typically wanted more ambitious measures and faster implementations.

610 Bristol and Amsterdam stand out by having ambitious local policies that go beyond the legal obligations
611 on a national and EU level. The ambition set for the final scenario is significantly higher than the BAU
612 targets. On other hand, the remaining 4 cities/ regions tend to impose the same level of ambition in the
613 final scenario as in the already established BAU policies. Furthermore, both Bristol and Amsterdam were
614 the ClairCity pilots with higher concern and ambition regarding reducing residential emissions, which is a
615 sector of great concern in other cities.

616 Concerning the residential practices, Ljubljana, Aveiro and Liguria had no measures affecting this sector
617 on their Policy Packages. Consequently, the reductions on PM emissions and concentrations are similar
618 both in BAU and FUPS scenarios, and thus there are no benefits from the FUPS. This means that either
619 from now to 2050, citizens, stakeholders, and local policymakers will need to work harder towards more
620 ambitious policies and targets to solve their air quality issues. Additionally, in Sosnowiec, despite the

621 measure aiming to ban coal for residential heating accounted on their Policy Package, this seems to be
622 insufficient to address their PM pollution problems.

623 The population will benefit the most in terms of NO₂ exposure for all the cities. The benefit in terms of
624 population exposed to particulate matter varies a lot across the study areas, with only Bristol and
625 Amsterdam showing substantial differences between fine and coarse particulate matter. Three areas
626 target the pollutants with the highest health impact on their population: Amsterdam (NO₂), Bristol and
627 Sosnowiec (PM_{2.5}); Aveiro Region and Liguria Region are mostly targeting the pollutant with the least
628 health impact (NO₂). This limited health benefit from emission control measures is either due to low
629 emission reductions or the measures being implemented in low populated areas.

630 Overall, the main findings of this paper highlight a decreasing trend of NO₂, PM₁₀ and PM_{2.5} up to 2050
631 considering the implementation of the already established BAU scenario. These achievements will be
632 possible due to a set of policies technologically-centred. On the other hand, future policy scenarios
633 centred on citizens visions, followed by stakeholders and policymakers calibration may have a crucial
634 impact towards clean air in European cities. However, this requires further ambition from those players.
635 In addition, the implementation of the recommendations from ClairCity will lead to better support, more
636 effective and more cost-effective air quality policies from now until 2050. Within the six pilot cities,
637 ClairCity has quantified how EU Air Quality Directives targets can be achieved through low-cost high-gain
638 behaviour changes, bringing significant benefits through several different health outcome pathways, and
639 demonstrate how this is adaptable across any city.

640 The scope of this work was to quantify the impacts of defined scenarios as a whole, so for further
641 investigation, it would be extremely relevant to quantify each measure, and to link each one to a specific
642 emission reduction.

643

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651

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