2050 Climate-friendly Mobility in Cities

Project Summary

Municipality of Bydgoszcz

Municipality of Plymouth

Municipality of Thessaloniki

Municipality of Leipzig

Potsdam Institute for Climate Impact Research (PIK)

Delft University of Technology (TUD; Project leader)

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2050 Climate-friendly mobility in cities (2050 CliMobCity)

Project Summary

This Project Summary gives an overview of the work process and results of the project's so-called Demonstration, the centre of the project's interregional learning. In the demonstration each partner city explored the impacts of long term mobility and land use measure packages and of powertrain and energy scenarios for mobility and CO_2e emissions in the city.

Important background documents for the Summary are the Appendix-Bydgoszcz-Report, Appendix-Plymouth-Report, Appendix-Thessaloniki-Report, Appendix-Leipzig-Report and the Appendix-PIK-Report.

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About the project leadership

The project leadership of the project 2050 CliMobCity is hosted by the department **Transport and Planning** in the faculty **Civil Engineering and Geosciences (CEG)** of the Delft University of Technology (Netherlands).

In the process of this department becoming the project's host the interest of Niels van Oort (associate professor and head of the Public Transport Lab) and of Serge Hoogendoorn (professor and director of the department Transport and Planning) in the project's subject was a decisive factor.

While Ekki Kreutzberger (initiator of the project and senior researcher at different faculties of the Delft University of Technology for many years, senior planner at the Mobility department of the municipality The Hague for many years, and now guest at the department of Transport and Planning) coordinated the project, Arjan van Binsbergen (associate professor at the department Transport and Planning) was found interested in co-conducting research, management and communication work in the project together with Ekki.

The financial management was carried out by Alwin Wink in the first half and Aart Hemker in the second half of the project, respectively a former or current employee at the Innovation Impact Centre of the Delft University of Technology.

Involved departments of the municipalities and of other project partners

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Content

1 INTRODUCTION: 2050 CliMobCity – project goals and general approach

1.1 Why this project? (EK, AvB)

2050 CliMobCity is about climate mitigation in the field of urban mobility, hence about reducing CO_2e (Carbon Dioxide Equivalents)[1] emitted by cars, trucks, public transport and other motorised vehicles in the city. Many cities have ambitious climate goals aiming for substantial reductions of CO_2e emissions like achieving climate neutrality in 2050 or earlier.[2] Many of the same cities, however, are uncertain about **how the mobility should change in order to reduce CO_2e emissions to the levels of their aims**, also against the background of exogenous technical and socio-economic developments. As the spatial setting of a city affects the sustainability of mobility the question includes: **how must the urban structure change to achieve climate-friendly mobility?** These questions were found relevant by what became the project partners: the **municipalities Bydgoszcz, Leipzig, Plymouth and Thessaloniki** and the knowledge organisations **Potsdam Institute for Climate Impact Research (PIK)** and the **Delft University of Technology (TUD)**, the latter being the initiator of the project and the project leader. The project started in 1 August 2019 and will end 31 July 2023.

The “2050” in the project name is to emphasize that the project focusses on the **long term**, on measure **packages** and on the **big picture**, not on individual measures and not on the short term. “2050” is indicative for a typical horizon of climate mitigation policies and does not mean that the exploration of policies by the partner cities in the project needs to focus on that specific year. The cities themselves decide which time horizon they aim for. Also, for ease of formulation, this report will often use the term CliMobCity instead of 2050 CliMobCity, for instance to distinguish a more ambitious measure package from a current strategic package.

1.2 Interregional learning (EK, AvB)

The centre of Interreg Europe projects is **interregional learning**. The interregionally learning actors in this project are the four municipalities, Bydgoszcz, Plymouth, Thessaloniki and Leipzig. The subject of interregional learning is to how to make mobility in cities sufficiently climate-friendly.

More precisely, the interregional learning refers to **three learning issues**. The project focusses on strategic planning and the question what the content of municipal long-term transport and spatial measure packages could be to achieve the municipal climate aims. The identification of such measure packages is the first and central learning issue of the project.

The themes electric mobility and large scale charging, and information and communication systems supporting climate-friendly mobility represent the two other specific learning issues. The corresponding measures are part of the measure package(s) to be identified in learning issue 1.

The partner cities have, prior to the project, manifested themselves in one or more of these three learning fields. The project idea was to have all cities transfer knowledge and experience wherever they can, while letting them learn in all three fields.

1.3 Outputs of the interregional learning (EK, AvB)

The findings and (intermediate) conclusions of all learning results in the project’s main outputs, namely Action Plans in the definition of Interreg Europe, one per partner city, and the Project Report. Each Action Plan contains two or more short-term actions that aim to contribute to the long term

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[1] Also referred to as Green House Gases (GHG).

[2] At the same times, cities are aware of the fact that other challenges are at stake as well: accessibility and attractiveness of the cities must be safeguarded, as well as liveability – and consequently – also space utilisation.

strategy for sustainable mobility and are to be implemented during the fourth project year.[3] Typical actions of the cities were simple infrastructure measures like the implementation of charging infrastructure or mobility hubs, awareness raising actions, or first steps for future more climate-friendly strategic planning and the development of tools in this field. The implementation of the actions is described in a separate document, the Action plans Monitoring report.

The Project Report consists of:

- the Project Summary which you are now reading. It gives a streamlined overview of the work and results of the contributions of all project partners, focussing on the cities' so-called demonstrations (explained in Section 1.6).
- four city reports, one per partner city and written by the cities.
- the report on the analysis of CO_2e emissions of PIK.

The city reports and the PIK report are appendices to the Summary Report. We refer to them as the Appendix-Bydgoszcz-Report, Appendix-Plymouth-Report, Appendix-Thessaloniki-Report, Appendix-Leipzig-Report and the Appendix-PIK-Report.
Such structuring allows to describe the project results in a consistent way without limiting the freedom of project partners to describe their demonstration results and methodology in ways they consider to be beneficial for their own learning processes and that of the other cities and of other readers.

Action Plans are important, as Interreg Europe aims to improve society by means of its projects, and as the actions represent a first set of such improvements in real life.[4] The Project Report is important, as it contributes to strategy development and measures and actions that are not limited to what can be implemented in one year.

1.4 Which CO_2e reduction? (EK, AvB, FR)

Global warming is caused by CO_2e emitted to the air, consisting of CO_2 and other greenhouse gases like methane. CO_2e emissions of mobility are mainly made up of CO_2. Still, throughout the report we refer to the term CO_2e, as non-CO_2 gases in mobility emissions do exist and as the emission factors used for analyses also refer to CO_2e. In a small part of the last chapter of this Project Summary, dealing with the so-called carbon budgets, we exceptionally distinguish the terms CO_2 and non-CO_2 gases, as carbon budgets refer to these gases separately.

The **CO_2e emissions analysed** in this project relate to the **use** of motorised vehicles in the municipal area of each partner city, including the emissions from **producing fuels or electricity**. More precisely speaking, the analysis focusses on all the emissions caused by motorised vehicles running in the envisaged partner city, starting from the emissions coming from the production of fuels or electric energy (well-to-tank emissions; WTT) and also describing the in-vehicle energy conversion (tank-to-wheel; TTW, where for BEVs 'tank' stands for battery), so in total the 'well to wheel' emissions (WTW) of energy used.
The CO_2e emissions of the use of vehicles include emissions deriving from supportive operations, like the repositioning of shared dockless bicycles or scooters by means of trucks.

The CO_2e analyses follow the **geographical approach**. This is that all mobility in the city, whoever travels, is the object of explorations. The opposite would be the functional approach which focusses on the mobility of all residents of the city, wherever they travel. The geographical approach, in line with many mobility emission studies, entails that for trips from, to and through a city, only the journey part taking place in the municipal area is included in the description of average travel

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3 This is from 1 August 2022 to 31 July 2023. The implementation is monitored by the project, and the monitoring is reported to Interreg Europe.

4 Including to influence the policy instruments envisaged by each Interreg Europe project.

distances and CO_2e emissions. In this project we apply the geographical approach insofar travel is conceded, but related WTT emissions are also included if they were produced outside the envisaged municipality, which often is the case.

An important impact of the geographical approach is that the mobility in the envisaged city does not only depend on the (mobility) policies of that city, but is also the result of the policies of neighbour municipalities, the region and other decision-makers.[5]

In the analysis the focus is on **total CO_2e emissions** and not emissions per capita, as the more recent climate aims of the partner cities most often also refer to total emissions. The consequence is that a certain reduction needs to be achieved, no matter how the population or economy in the city develop. This report nevertheless occasionally also presents the emissions per capita, as some partner cities were interested in these.

Having the **use of vehicles** and production of fuel and electricity being the object of CO_2e analysis is widespread, however not the only option. Numerous studies conduct life cycle analyses (LCAs), analysing not only the CO_2e emissions of vehicle use and fuel production, but also of **vehicle production, maintenance and recycling, optionally even infrastructure production, maintenance and recycling**. Use oriented analyses are simpler than LCAs and have the advantage that they more consequently stick to the geographical approach, as the emissions from vehicle production and recycling seldomly take place in the envisaged municipality. On the other side, skipping the vehicle production emissions etc. to some extent implies that the value added by some types of measures in terms of CO_2e reduction doesn't come into picture. One example: when people join the community of shared car users, the total number of cars (shared and privately owned cars) will often decline, hence there is less CO_2e emission from producing etc. cars.[6] This benefit is not visible when limiting the CO_2e analysis to the use of vehicles.
It is relevant to notify that the results of ranking alternative travel modes in terms of CO_2e emissions (e.g. a bicycle emits less CO_2e per passenger-kms than an electric bicycle than the scooter than … the private car) is similar in the use-oriented and the LCA-based CO_2e analysis, as long as one is dealing with **private** vehicles. For **shared** vehicles like the shared (e-) car, shared (e-) scooter, shared (e-) bicycle, the results of ranking turn out to be quite different in use analyses in comparison to lifecycle analyses. A main reason is that shared vehicles have shorter live spans than private ones.[7]

Shared vehicles and mobility hubs facilitating shared mobility are part of the measure packages of the partner cities in the project. Nevertheless, their emissions are not analysed on the city level. The reason is that there still is too little experience regarding these novel types of mobility and that research does not yet sufficiently cover this field: A few statements: "Shared e-mobility systems are still in its infancy period in most places" or "research on micromobility is still in its nascent stage" (*Liao and Correia, 2022*). And "… there is a lack of a wide academic literature about shared e-scooters" (*Badia and Jenelius, 2021*). As a consequence micromobility, shared vehicles and mobility hubs also are measures which are not addressed in Transport models and the effects of such measures are therefore not in sight in the partner cities' mobility predictions.

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[5] And vice versa, that policies of the city have impacts on mobility in those other territories.

[6] Then again, the CO_2e emission from the production of ICE vehicles is much lower than those of EV vehicles, more specifically their batteries.

[7] There is a positive and a negative side to the shorter life, but the negative one tends to dominate, at least for micromobility ([e-] scooters, [e-] bicycles etc.). Positive is that shared vehicles are used more intensely and therefore replaced more quickly by new and – therefore often – more energy-efficient vehicles than this is the case for private vehicles. Negative is that the quicker replacement also seems to be necessary because shared vehicles are treated less carefully, implying that more vehicles need to be produced and recycled for a certain amount of traveling than initially expected, meaning that the climate ranking position of a shared vehicle changes in comparison with the corresponding private vehicle. Such effects can only be shown by means of LCAs.

As a substitute for skipping the measures shared vehicles, novel mobility types and mobility hubs when predicting the change of mobility and analysing the derived reduction of CO_2e emissions we in the last chapter of this Summary take a brief look at the outcomes of some papers published in journals to gather indications about their mobility effects and CO_2e reducing potential.

1.5 The climate aims and planning periods of the partner cities (EK, AvB, FR)

The climate aims of the partner cities show quite some variety and also dynamics: in three of the partner cities the aims have changed in the run of the project, as described in the city chapters. Climate aims for the project are climate neutrality in 2050 (Bydgoszcz), 2040 (Leipzig), 2030 (Plymouth), and 42% reduction of the 1990 CO_2e emissions in 2030 (Thessaloniki).

The planning periods for the measure packages in the project, as proposed by the municipalities, are for Bydgoszcz 2021-2050, for Plymouth 2015-2034, for Thessaloniki 2018-2030, and for Leipzig 2015-2035. At the end of these periods Bydgoszcz and Plymouth would need to be climate neutral. Thessaloniki's aim of 42% reduction between 1990 and 2030 has been estimated to be equivalent to about 52% reduction between 2018 and 2030. Leipzig's climate aim comes down to 80% reduction until 2035.

1.6 Demonstrations for interregional learning (EK, AvB)

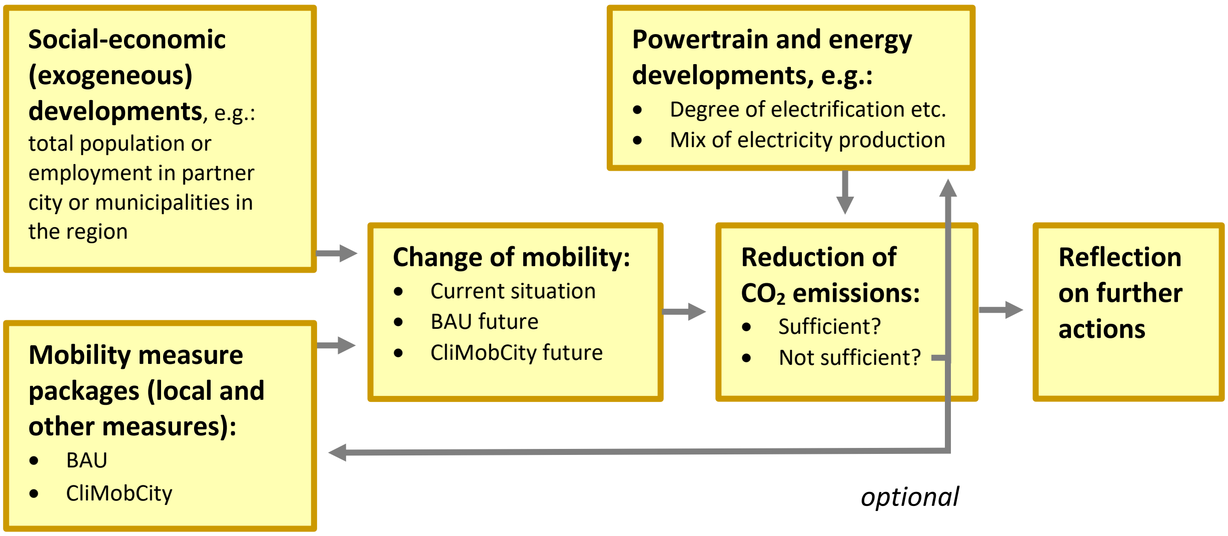
The learning in the project has taken place by means of **demonstrations**: each partner city demonstrated the carbon reduction effects of explorative policies in their own city. The **demonstration steps** were as follows.

1) Each city clarifies the content of strategic measure packages which have already been decided in strategic municipal plans, whether the measures are already implemented or not. We call these **business as usual (BAU) measure packages** or policies. The package describes all future transport infrastructure, future transport services and the characteristics of these (e.g. speed limits, public transport service frequencies, transport capacity; parking process and regulations), furthermore the economic structure and land use, like where how many people live and work. The BAU package also includes measures to be implemented in the municipal area but are decided on higher governance levels than the municipality, like highway infrastructure, services or properties (e.g. speed limits, road pricing on the highway parts near to the city) or train infrastructure and services.
2) Each city defines one or more measure packages which expectantly will lead to a sufficient or at least to substantial reduction of CO_2e emissions from mobility in a space-efficient way. We call these **CliMobCity measure packages**. Again the package will consist of transport measures (infrastructure, transport services, properties of these) and measures regarding land use and the social-economic structure.[8] And again, also the CliMobCity measure packages may include measures belonging to the decision domain of higher governance levels. The measure packages do not represent decided policies, but instead have an explorative nature serving to identify more climate-friendly mobility solutions. The measures in the CliMobCity packages were allowed to supplement the BAU measures or replace them.
3) Each measure package, BAU or CliMobCity, is embedded in projections of expected developments in the surrounding of the envisaged partner city. For the combination of BAU **measure package** and **surrounding projections** we use the term BAU **scenario**. For the combination of CliMobCity measure package and surrounding BAU projections we use the term CliMobCity scenario. The content of the surrounding projections is hardly discussed in the project, but especially present in the transport models used by the partner cities for their demonstrations.

[8] The total of population, work places etc. will be the same in BAU and CliMobCity packages, but the social-economic structure, e.g. spatial distribution of houses, population, work places etc. may be different.

4) Each city predicts the change of mobility due to these measure packages and other scenario developments.
5) PIK analyses the reduction of CO_2e emissions that results from the change of mobility as well as from the expected shift from fossil fuel vehicles (like gasoline or diesel vehicles) to post-fossil fuel ones (like electric or hydrogen) vehicles and – with reference to electric vehicles – from the changing energy mix of electricity production.[9] The rate of replacement by post-fossil fuel vehicles is derived from published powertrain scenarios or corresponds with municipal policies, for instance the aim to have x% electric vehicles by a certain future year.
6) If the reduction of CO_2e emissions turns out to not sufficiently respond to a city's reduction aim, the city can revise or supplement its CliMobCity measure package or powertrain input. In the project such took place in a fully what-if fashion without first again predicting the change of mobility, namely in the so-called forecasting lever exercises or backcasting lever exercises;
7) Each city reflects on the results of demonstrations, in particular the CO_2e emissions for further policy-making, and provides feedback to the project.
8) TUD draws integral conclusions and gives recommendations to the partner cities.
9) The cities learn from their own demonstration and from the demonstrations of the other partner cities.

The following figure visualises these steps in a simplified way:



If the reduction of CO_2e emissions is unsatisfactory, one can try to reinforce:

- mobility measures (lower feedback arrow in the figure above) to search for measures that provide more modal shift, shorter travel distances etc. in favour of less vehicle kms;
- powertrain measures (upper feedback arrow in the figure above) attempting to accelerate the shift to post-fossil vehicles and the energy mix for electricity production. Only part of the measure decisions will be in municipal hands, like vehicle charging infrastructure or zero emission zones or awareness raising to residents, organisations in the municipality, the energy sector and supralocal governments.

The findings from the own demonstrations and the learning from the demonstrations of the other partner cities are to support understanding of the relation between measure packages, exogeneous social-economic developments, change of mobility, shift to sustainable powertrains, energy mix of electricity production, and reduction of CO_2e emissions and in this way give orientation to decision-makers of the municipalities and stakeholders in the city's region for developing appropriate policies.

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[9] The production of hydrogen has for pragmatic reasons been calculated as being green in all scenarios.

1.7 Types of mobility and city measures to systematically reduce CO_2e emissions of mobility in cities (EK, AvB)

Regarding the reduction of CO_2e emissions of mobility, the project distinguishes core changes of mobility and (supporting) measures needed to achieve that core change.

Core changes of mobility relevant for the reduction of CO_2e emissions are:

1) reduce mobility demand in terms of number of (motorised) trips[10], at all or during peak periods;
2) decrease average distance travelled in motorized transport modes;
3) shift to climate-friendly transport modes, such as public transport employing electric vehicles, and active travel modes[11];
4) shift from private to shared car;
5) increase occupancy rates (number of people or tons of freight) of motorised vehicles;
6) reduce net vehicle weight;
7) substitute fossil fuel by post-fossil fuel vehicles, assuming that electricity, hydrogen etc. increasingly come from green sources;
8) reduce parking demand of cars
9) smoothen traffic flow on roads.

These changes of performance cumulate in the reduction of fossil fuel vehicle-kms in the city, the ultimate performance change relevant for the reduction of CO_2e emissions. Most fossil fuel vehicle-kms are present in the road sector.

Very likely, if none of these core changes (1-9) emerge, there will be no reduction of (fossil) fuel (road) vehicle-kms, hence no energy saving and no reduction of carbon emissions from vehicle use.

The above indicated changes affect CO_2e emissions directly and indirectly. The latter is via space-saving. **Reduction of space requirement results in mobility changes and thus indirectly reduces fossil-fuel consumption and CO_2e emissions.** Spatial measures are therefore an important element to consider in measure packages. The following table enlists examples of supporting measures per core change of mobility. For illustration, imagine a city achieving climate neutrality mainly by substituting fossil fuel cars by post-fossil fuel cars. Given the relative large space requirement of private cars per passenger-km and given the expected growth rates of mobility of like annually 1-2%, such focus may lead to road infrastructure demand for which – in many cities – the space in the built areas is insufficient. In this case either expensive multi-level infrastructure may be needed or restructuring of the city to make space for the widening of road junctions and links. In the latter case the city becomes less dense implying an increase of average travel distance and then also less people choosing walking or bicycling as travel mode; the energy consumption and hence CO_2e emission increase.

The spatial dimension is not intensively analysed in this project, but discussed as an important background to the average travel distance and urban sprawl in the four cities, as a background to public transport use and active travel in Thessaloniki and Leipzig, as a main measure in one of the CliMobCity measure packages of Bydgoszcz ("reurbanisation") and – in all city chapters – briefly discussed in terms of road traffic flow, road capacity and the distribution of public space for the infrastructure of modes.

The table also indicates whether the supporting measures are ones that can be decided on the local/regional or higher level. The success of some supporting measures depends on decision-making on several levels. For instance, the replacement speed of fossil fuel cars by electric cars is influenced by European policies like vehicle emission standards and by national subsidies/taxing encouraging the substitution. In parallel the electrification needs to be facilitated by installing networks of vehicle electricity charging points, which typically is a decision/activity on the municipal level. Also other

10 In this report we use the term "trips" in the sense of a door-to-door journey.

11 I.e. walking and biking.

	Core changes of mobility	Energy saving	Space saving *	Examples of supporting measures	Primary decision level (M = municipal or regional; NEU = national or European)
1	Reduce number of trips, at all or in the peak	X	X	• Promoting** working from home • Promoting teleconferencing • Promoting shift of activities to off-peak periods (like work times) • Substitute private by shared cars	
2	Reduce average travel distance	X	X	Land use measures like: • Increase building densities • Increase functional mix *** in cities	 M M
3	Shift to sustainable modes (walking, bicycle, public transport)	X	X	• Make public transport and active travel more attractive • Make mobility by individual car less attractive • Densify city along public transport lines and around train stations • Facilitate the replacement of privately owned by shared cars **** • Facilitate sustainable types of micro-mobility	M M M M M
4	Smoothen traffic flows on roads	X		• Traffic measures ***** • Improve driving lessons, traffic education	M NEU
5	Increase occupation rates of motorised vehicles	X	X	• Occupation standards or pricing/taxing for the use of roads, entry of sustainability areas or entry of shopping areas by freight vehicles ******	M
6	Increase utilisation rate of motorised vehicles and reduce number of vehicles needed	X	X	• Facilitate substitution of privately owned by shared cars, e.g. by means of mobility hubs	M
7	Reduce vehicle weight	X		• Weight/size standards or pricing/taxing for the use of roads, entry of sustainability areas or entry of shopping areas by freight vehicles	M (and NEU)
8	Substitute fossil by post-fossil (e.g. electric) vehicles	X		• (Local) emission standards • Subsidies for clean cars • Extend network of electric charging points and hydrogen filling stations • Substitute private car by shared electric car trips	NEU NEU M M
9	Reduce parking demand of cars		X	• Facilitate substitution of privately owned by shared cars, e.g. by means of mobility hubs • Other parking fees for big cars	M M

* Space saving on its turn reduces the average travel distance and makes more people shift to active travel, therefore also although indirectly reduces energy consumption.

** E.g. information campaigns, subsidies.

*** E.g. promote vicinity of shopping centres, schools etc. to living, or keep/make medical or other (like waste collection points) services well distributed across the town.

**** This typically reduces the number of car trips. The higher utilisation rate of a shared car also implies that fleet renewal to climate-friendly models is takes place faster than of private cars.

***** E.g. introduce certain speed limits, green waves of signal lights or the differentiate road types with liveability focus on some road types and smooth flow focus on other road types.

****** Like allowing to use preferential lanes given a minimal car occupancy. Or prescription of minimal loading degrees of vans and trucks distributing goods to the cities.

local measures like environmental zones, local taxes and parking fees distinguishing the degree of cleanliness of vehicles, will influence the replacement rate.

1.8 Measure packages of the partner cities (EK, AvB)

The main focus of the project was to compare (the input and output of) scenarios per partner city. Therefore the description of policies and mobility, emission and spatial effects takes place city-wise (Chapters 2, 3, 4 and 5). In extension also some comparison of scenarios between the cities took place (in Chapter 6).

We observe that the measure packages of the different cities differ significantly in scope and ambition level. Regarding the **BAU measure packages**, **Thessaloniki**'s policies are centred around the planned inauguration of two metro-lines, one regional rail line and a maritime line, hence on modal shift. Also **Leipzig**'s BAU policies are a lot about modal shift, aiming for a substantial reduction of car shares. The city's investments into better regional train, tram and bus lines, some of which are new lines, are important measures to achieve such. **Bydgoszcz**'s BAU scenario contains a bundle of new tram lines/links to be implemented, but also a significant expansion road network. The BAU measure package of **Plymouth** is rather road oriented despite of some public transport measures like the implementation of dedicated bus lanes.

Also the **CliMobCity measure packages** between the cities differ largely by scope and ambition, ranging from 1) proposing familiar types of measures to upgrade existing strategic plans to 2) much out-of-the-box thinking and strategical exploration of less familiar measures.

The CliMobCity measure packages of **Plymouth**, **Thessaloniki** and **Leipzig** supplement the BAU packages. The **Bydgoszcz** CliMobCity measure packages partly supplement the BAU measure packages (e.g. improving public transport on top of the network expansion already proposed), partly replace them (e.g. cancelling of main road investments, reurbanisation in favour of the central city area). Of all partner cities Bydgoszcz's demonstration is driven the most by out-of-the-box thinking. The explorations focus on the year 2050, corresponding with the city's climate aim. The other cities have directed their demonstrations to the time horizons of prevailing strategic plans (Thessaloniki 2030, Leipzig 2030/35, Plymouth 2034). **Plymouth** defined a rather ambitious measure package containing all types of measures that have been applied in or considered for other cities in the UK outside of London that could be applied in Plymouth, and which is more bus- and active travel-minded than the city's BAU package. In **Thessaloniki** and **Leipzig** the CliMobCity packages focus on increasing shares of post-fossil powertrains (electrification etc.) for private and shared mobility, and public transport busses or municipal vehicles respectively. As already indicated, all four partner cities in the CliMobCity framework plan to accelerate the introduction of mobility hubs for passengers, providing a shared car supply and charging infrastructure.

1.9 Models used for the demonstrations and their nature (EK, AvB, FR)

For the prediction in the demonstrations of the change of mobility and CO_2e emission caused by the measure packages two types of models have been employed, the transport models of the partner cities and the carbon model of PIK.

The **carbon model** is adapted from the transport module of the EU Calculator model (EUCalc),[12] adjusting it from the country to the city level and to the needs of the project. Initially it was a **what-if model** which can be used without preceding mobility modelling: one can mimic a specific future scenario by setting so-called “levers” (= choosing certain values of different input variables) in the model. The available levers describe mobility or powertrain changes, such as:

- a modal shift lever, pointing out a change of e.g. walking, bicycle, metro, tram, bus use or car shares;
- a “time-spent” lever representing the average distance travelled;
- a powertrain lever, describing the expected penetration of electric and hydrogen cars and the remaining use of gasoline and diesel cars responding to different emission standards.

In total the model has 8 main and 3 background levers for passenger mobility and 5 levers for freight transport (see *Appendix-PIK-Report* [PIK, 2023]).

The levers can be set in any reasonable position.[13] **The challenge when using the carbon model is – for each city – to choose the right position for each lever.** The precise setting or position of the levers can be based on the output of other models, on findings from literature and/or on expert opinions. The setting by experts or on the basis of literature is no simple activity, as a city’s mobility pattern and its future changes are the result of complex societal interactions, of which the effects are difficult to estimate by hand. Also, taking appropriately account of the spatial dimension of a city’s mobility is challenging.[14] **This all is where the cities’ transport models come in.** These provide a lot of mobility information that can be used as input for the carbon model, hence to position the carbon model’s levers.
For the BAU and CliMobCity scenarios in the cities’ demonstrations the mobility input to position the levers in the carbon model mainly came from the cities’ transport models. In this combined use of transport models and the carbon model the latter loses its what-if quality, as the positioning of the carbon model levers is guided by the output of the transport modelling.
PIK for positioning levers supplementarily used information collected from reviewing scientific and professional literature (see *Appendix-PIK-Report* [PIK, 2023]).

At this place we need to anticipate on the results of the CO_2e analyses described in the following chapters: in none of the partner cities the CO_2e reductions in the CliMobCity scenarios were sufficient. Therefore, additional analyses, namely so-called forecasting lever exercises took place exploring the CO_2e reduction of additional mobility changes like more modal shift, shorter average travel distance and/or faster electrification of vehicles. In these explorations of CO_2e emissions without preceding transport modelling the carbon model was used in its what-if mode. The carbon model levers were set into positions reflecting a change of mobility and/or of powertrains.

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12 Developed between 2016 and 2019 in the framework of Horizon2020 by PIK and other European consortium members.

13 In parallel there is also a city version of the EUCalc in development, called the same as its project name: EUCityCalc. It also has a module to calculate the CO_2e emissions of mobility. However, its levels are fixed to predefined input levels like little, medium, much and very much model shift.

14 Residents, work, transport and city measures all have geographical locations, and the mobility performance and its indicators are influenced by the spatial structure of a city. Mobility choices like which mode or route to take, depend on the relative attractiveness of transport alternatives, and also this is influenced by spatial characteristics. The impact of (a changing) spatial context is hard to estimate without applying a transport model. Data from literature or from expert interviews tend to be very general, often not sufficiently capturing the spatial dimension of a certain city, even where they refer to city typologies.

For two partner cities[15] also backcasting lever exercises were conducted. The city's reduction aim was then the starting point and the lever exercises were to identify which mobility or electrification changes would lead to the required CO_2e reduction. Also here, the carbon model was used in its what-if mode.

1.10 Prediction of the change of mobility (EK, AvB)

Each partner city has employed its transport model to predict the mobility in the base year and for the future scenarios (BAU, CliMobCity).

Three of the partner cities, namely Bydgoszcz, Thessaloniki and Leipzig applied a 4-step[16] multi-modal macro transport model developed using VISUM software of the German consultancy firm PTV and operated by respectively Gradiens Sp. z o. o. (for Bydgoszcz), CERTH/HIT (for Thessaloniki), and PTV (for Leipzig). The models include the modes road, train, metro, tram, bus (whatever public transport mode is or will be present in a city), bicycle and walking, road freight, partly also taxi's.

Plymouth applied the unimodal model SATURN Highway Assignment Model, operated by WSP. This model covers the last step of a 4-step approach, namely the assignment of trips to (road) routes. The model starts from an origin/destination matrix[17] which was constructed using information from local mobility surveys.

For all scenarios (base year, BAU, CliMobCity), transport demand and modal split in Thessaloniki, Bydgoszcz and Leipzig is predicted on the basis of demand functions in the transport model: travel demand is estimated on basis of population and e.g. workforce size and their distribution in space. The choice of travel mode (e.g. car, public transport, bicycle) is modelled, taking account of its attractiveness in comparison to other modes and of the mobility preferences of travellers. And lastly, transport flows allocated to transport modes is assigned to specific routes. In the Plymouth model demand functions are only used for route assignment. The other demand characteristics are estimated on the basis of modal shift assumptions conducted by experts from the consultancy firm WSP and the municipality of Plymouth (see Plymouth chapter in this Summary Report). The experts' estimations require further validation by demand modelling.

The **central output from the transport modelling relevant for the carbon reduction** are the vehicle-kilometres of motorised vehicles, such as of cars or public transport vehicles (distinguishing train, metro, tram and bus, and taking into account scheduled services). The transport model of each city produces such data for the base year, the BAU scenario and the CliMobCity scenario(s). By comparing the vehicle-kilometres per mode and type of infrastructure (like road) in the base year with those in future scenarios, one can get a first indication about the perspectives to reduce CO_2e emissions by mobility and land use measures.

Important **challenges** for the **multi-modal macro transport models** are:

- as partly already indicated above, to improve the capability to model shared car mobility, shared micromobility (shared bicycles and scooters), the implementation of mobility hubs, and the benefits of smart mobility;

[15] The backcasting lever exercises were only carried out for Thessaloniki and Leipzig. The reason was that their climate aims for the project were intermediate ones, while striving for climate neutrality would first be envisaged in a later period. Such constellation suggested that there is more to choose in the CliMobCity package, as at the end of the CliMobCity period not all road vehicles already need to be post-fossil fuel ones, contrary to the partner cities already aiming for climate neutrality in the target year. The vehicles running in those cities must all be post-fossil fuel ones at the end of the CliMobCity period.

[16] The 4 steps are the prediction of the "production/attraction", "distribution" and "modal split" and the "assignment" of flows to the links and nodes of each network, like road network or public transport network.

[17] This describes the flows (number of trips) between different areas in- and outside of Plymouth.

- to reduce the incapability to model changing travel preferences of residents and other actors. In long periods as from now to 2050, the period envisaged by Bydgoszcz, a change of preferences is likely to occur;
- to improve the incorporation of freight logistics in the freight traffic modelling.

The first challenge has in Thessaloniki partly been addressed in a former project. The penetration of shared electric cars (offered at mobility hubs) in Thessaloniki was modelled by applying MOMENTUM simulation tools (mentioned in the *Appendix-Thessaloniki-Report* [MoT, 2022]). In general, however, the knowledge in this field and the incorporation is still limited and the incorporation of findings into the macro transport modelling absent. Without the identification in the transport models of the changes of mobility due to the supply of shared vehicles and to mobility hubs, also the carbon model can't analyse the reduction of CO_2e emissions of such novel types of mobility.

Regarding the second challenge, transport models, also advanced ones, assume current mobility preferences of a certain group of people (e.g. certain ages, gender, education) to remain unchanged in the future, typically because there is little information about the possible change of preferences. For such reasons many experts hesitate to apply transport models for periods as long as 30 years (like from now to 2050). Bydgoszcz has responded to this challenge by – on the basis of experts' opinion – varying the parameters in the utility function of different modes, leading to lower shares of the private car and higher shares of public transport. Both the approach and the outcomes are yet to be validated by further research, but perhaps appropriate for long term explorations.[18] For the other three cities the time horizon of envisaged measure packages was less far away, meaning that the use of current travel preferences for the future is (more) acceptable.

Freight logistics contrary to shared mobility are rather well explored applying specific logistic models, and their findings are partly incorporated into the macro transport models. However, the logistics are changing rapidly due to changing energy frameworks (e.g. the emerging shift to post-fossil fuel trucks), changing operations (e.g. e-commerce and home delivery, scale of warehousing and flow consolidation), and changing policy instruments (e.g. increasing size of zero-emission zones), making it difficult to identify good balances between commercially viable and sustainable configurations, let alone to incorporate findings into macro transport models. Yet such is very important, as the logistics have a heavy weight in overall CO_2e emissions in a city.

1.11 Analysis of the reduction of CO_2e emissions (FR, EK, AvB)

Recalling, for the BAU and CliMobCity scenarios the mobility related input was provided by the cities' transport models, and wherever the information from the transport models wasn't sufficient, by using data collected from reviewing scientific and professional literature.

More precisely speaking, the mobility input consisted of passenger-kms per mode and activity (box B in the following figure), derived from[19] the time spend, speed and number of travellers per mode (box A). The passenger-kms were then transformed to vehicle-kms per mode, activity and road type, using information about vehicle occupation and utilisation and road types (box E). Combining the vehicle-kms with powertrain shares (% diesel, gasoline, electricity, hydrogen, other fuels) and fuel efficiency rates (e.g. fuel used per 100km; also dependent on box F) allowed to determine the energy

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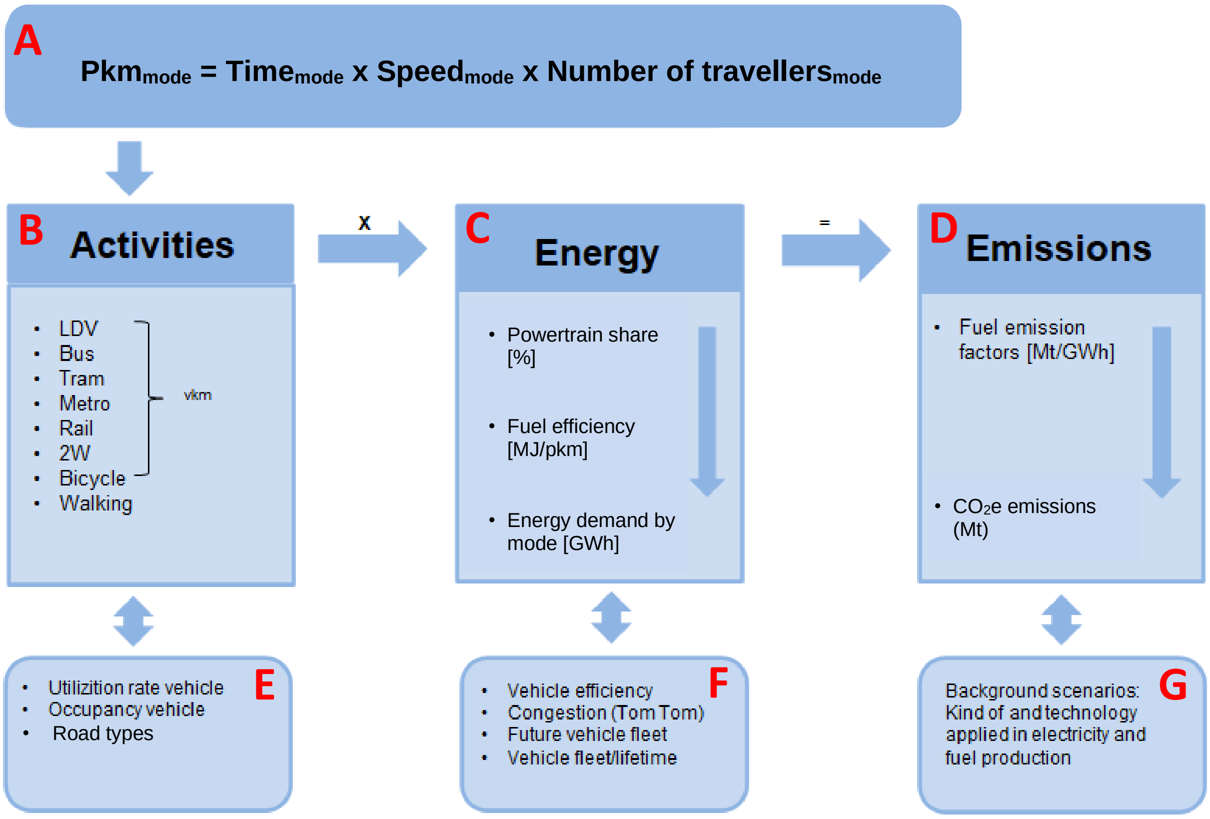
[18] Without such validation this variation rather resembles a sensitivity analysis than a modelling variant.

[19] The carbon model of PIK has a special characteristic: the model focusses on *average trip time* rather than on *average trip distance*, and on *time spent per mode* instead of *vehicle-kms per mode*. The non-transport reader will rather understand distance than time but is familiar with the decomposition of distance to time and speed, given the equation *speed = distance/time*.
This approach is a consequence of the required format of the input parameters of the PIK model (more detailed information can also be directly derived from some mobility models, but that type of input can't be used by the PIK model).

demand per mode (box C). This demand in combination with fuel emission factors (box D), which relate to the mix of sources used in electricity power plants (coal, gas, nuclear, sun, wind etc.), leads to the CO_2e emissions of the mobility.[20] Energy mix scenarios (part of box G) are different per country (UK, Poland, Germany, Greece) and time horizon (e.g. 2030 or 2050).[21] For each partner city the national powertrain structure and energy mix for electricity production has been assumed to be valid also on the city level. The approach and methodology is explained more in detail in the *Appendix-PIK-Report* (PIK, 2023).[22]



In recent years scenarios have been published outlining the present or expected share of fossil fuel and post-fossil fuel vehicles in 2050 for different European countries. One such replacement profile is referred to as the **EU reference scenario** (Taylor et al., 2019; also see *Appendix-PIK-Report* [PIK, 2023]).[23] As a more ambitious alternative, the **Tech scenario** has been developed in which the share of post-fossil fuel vehicles is larger (same source). PIK has derived country specific powertrain shares for the end of the planning period of each partner city Thessaloniki: 2030; Plymouth: 2034; Leipzig: 2035) by interpolation from the values for the base year and 2050. For Bydgoszcz, its planning period ending in 2050, no interpolation was needed. The following table shows the published or interpolated shares for cars. Comparable information for trucks and busses is presented in the *Appendix-PIK-Report* (PIK, 2023).

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20 Electricity production from nuclear plants is free of CO_2e emissions, but produces radioactive waste for thousands of years. Such effects lie outside of the scope of the project, but draw attention to the fact that there are other dimensions to sustainable mobility than CO_2e emissions. Both the CO_2e emissions and the very long lasting radiation of nuclear waste can in sustainability terms hardly be valued positively.

21 The energy mix is assumed to be uniform in a country. The validity of this assumption deserves attention.

22 Pkm = person-kms, Vkm = vehicle-kms, LDV = light duty vehicle (including cars), MJ = megajoules, GWh = gigawatts per hour.

23 A newer EU study has updated the scenario, the EU LTS scenario, but the changes only refer to mobility behaviour, not toe the share of different types of powertrains or the energy mix for electricity production.

Share (%) of battery electric cars (BEVs) and hydrogen cars in the countries of the partner cities in the year of their planning horizon in the 2050 CliMobCity demonstrations (**EU reference scenario**; **Tech scenario**)		
	% BEV* cars	% Hydrogen cars
Plymouth, 2015	1	0
Plymouth JLP (BAU), 2034	13; 39	5; 17
Plymouth UK max (CliMobCity), 2034	13; 39	5; 17
Plymouth, 2050	31; 66	13; 28
Leipzig, 2015	1	0
Leipzig Mob. Str. (BAU) 2030/35	12; 36	5; 15
Leipzig Mob. Str. (ClMobCity), 2030/35	12; 36	5; 15
Leipzig, 2050	31; 65	13; 28
Bydgoszcz, 2021	0.2	0
Bydgoszcz W0 (BAU), 2050	16; 30	7; 13
Bydgoszcz W1 (CliMobCity), 2050	16; 30	7; 13
Bydgoszcz W2 (CliMobCity), 2050	16; 30	7; 13
Bydgoszcz W1+ (CliMobCity), 2050	16; 30	7; 13
Bydgoszcz W2+ (CliMobCity), 2050	16; 30	7; 13
Thessaloniki, 2018	0.2	0
Thessaloniki SUMP (BAU), 2030	1.3; 8	0.2; 3
Thessaloniki SUMP + shared electric mobility (CliMobCity), 2030	1.3; 8	0.2; 3
Thessaloniki, 2050	25; 52	11; 22

* BEV = Battery electric vehicle.
Source: *Appendix-PIK-Report* [*PIK, 2023*] on the basis of *Taylor et al. 2019*)

Next to the replacement of powertrains the **energy mix of electricity production** is expected to change, and also this process is different per country. *Annex 2* shows the expected energy mix in the year of the cities' planning horizon ("energy mix A"). Typically the share of fossil electricity production still is substantial then. Again PIK derived values for the year of the cities' planning horizon by interpolation from base year and 2050 values.

1.12 The name of scenarios in the analysis of CO_2e emission and reduction (EK, AvB)

The analyses of CO_2e emissions and their reduction is conducted for different **overall scenarios**, each being a **combination of the cities' measure packages** (BAU, CliMobCity), a **powertrain scenario** and a **energy mix scenario**. The following table gives an overview of overall scenarios for which the CO_2e emission was analysed, and explains of which combination of measure package, powertrain scenario and energy mix scenario each overall scenario consists.

Regarding the combinations of the cities' measure packages with **powertrain** values and energy mix values the project dealt with one **ambivalent** detail, namely that the shift to electric and other post-fossil fuel vehicles can be part of the powertrain scenario or of a city's measure package. In Bydgoszcz and Plymouth the CliMobCity packages mainly consist of mobility measures. The electrification policies of these two cities are reflected by the powertrain scenarios pointing out a modest (EU reference) to larger (Tech) share of post-fossil fuel vehicles in the future. In Thessaloniki and Leipzig, the CliMobCity package largely consists of ambitious electrification measures which deviate from the EU reference and Tech scenario. Specific types of electrification (like of public transport busses or other municipal vehicles) were taken along as part the CliMobCity package.

Content of scenarios for the analysis of CO_2e emissions				
OVERALL scenario		Mobility and city measure packages (scenarios[24])	Scenario of power-train shares	Scenario of energy mix for electricity production
Name	Colour of lines in the CO_2e figures in the city chapters			
		Base year	EU ref	Mix base year
1a		BAU scenario	EU ref	Mix A
1	Blue	CliMobCity scenario(s)	EU ref	Mix A
2	Orange	CliMobCity scenario(s)	Tech	Mix A
3	Grey	CliMobCity scenario(s)	Tech	Green
4-7		Forecasting lever exercises, starting from overall scenario 3	Tech	Green
4		10 %-points smaller share of cars and other LDVs in favour of other modes		
5		10% less time spent (essentially = less vehicle-kms)		
6		10 %-points larger share of post-fossil fuel vehicles (replacement of fossil fuel vehicles)		
7		Combination of overall scenarios 3, 4, 5 and 6		
8-10		For Thessaloniki and Leipzig: also backcasting lever exercises, starting from overall scenario 3	Tech	Green

In all cases, the structure of the carbon model guarantees that electrification measures that could have been seen as part of a powertrain scenario or the CliMobCity measure package, are not double counted.

1.13 Further structure of the Summary Report (EK, AvB)

The following chapters are the city chapters, one per partner city. The beginning each city chapter lets the reader make acquaintance with the city by outlining – at a glance – a few historic backgrounds, the spatial structure, the current city's transport networks and mobility pattern.

Then, after mentioning the climate aim, follows a description of the approach and results of the steps in the project's demonstrations. Recalling, these steps are: (Section 2) define measure package(s) → (Section 3) explore the change of mobility → (Section 4) analyse the reduction of CO_2e emissions. The last section in each city chapter, Section 5, consists of a reflection of the partner cities on the demonstration results for further policy-making. The Summary Report ends with a chapter in which the lead partner wraps up the demonstrations' results, adds observations from literature study about novel types of mobility, and gives recommendations for further policy-making and for similar approaches in new projects.

1.14 Way of presenting performances in figures (EK, AvB)

We describe the change of mobility data in relative terms:

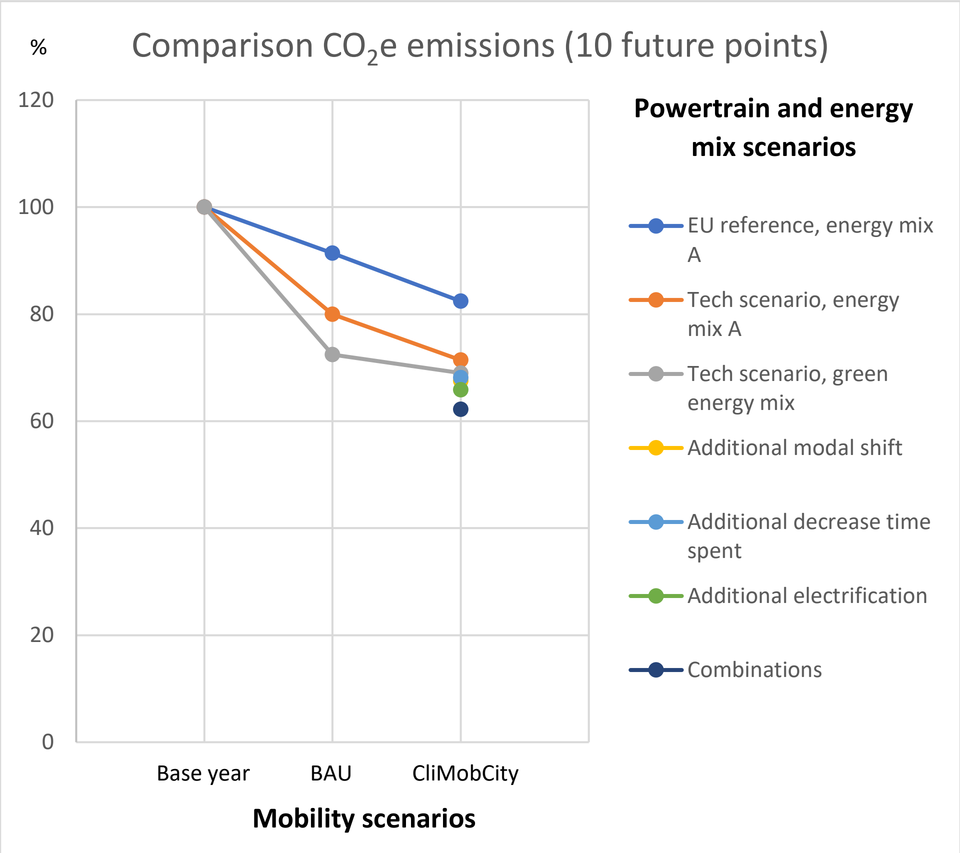
- percentage values for the share of mobility modes;
- index values for other comparisons, the base year being 100% (see following two figures).

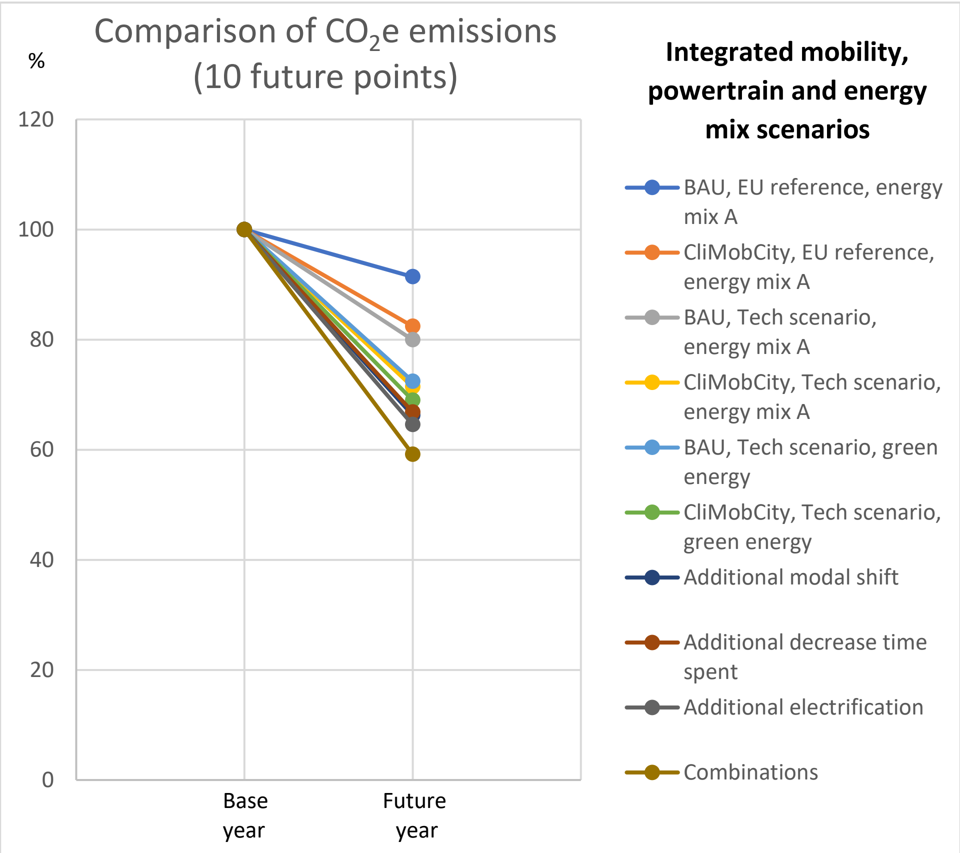
These relative values enable to quickly understand the magnitude of changes. They also make it easier to compare the mobility and CO_2e reduction between the partner cities, which is interesting to do, although comparison of cities is not the main subject of project.

[24] For use of terms measure package and scenario see Section 1.6

We present the index CO_2e values in a specific way, distinguishing mobility scenarios (on the X-axis) and powertrain and energy mix scenarios (on the Y-axis), as shown in the following figure. This way of presentation provides a change pattern which one can rather easily recognise and memorise.
It, however, deserves special attention in the following regards. The curves look like developments, which they are not except for the connection between the base year and the BAU scenario. All other graphic connections must be interpreted as comparison (like more CO_2e reduction in the CliMobCity than in the BAU scenario.

We could, to avoid such misinterpretations, have chosen for another way of presentation, as shown in the following figure. It refers to the same dots as the figure before, but each dot is now graphically directly connected to the base year value, the lines then always representing a development. In this regard there is no misunderstanding possible. However, the visual result is not easy to recognise and memorise (the problem of "not seeing the forest because of so many trees").


%
Comparison CO_2e emissions (10 future points)
120
100
80
60
40
20
0
Base year
BAU
CliMobCity
Mobility scenarios
Powertrain and energy mix scenarios
EU reference, energy mix A
Tech scenario, energy mix A
Tech scenario, green energy mix
Additional modal shift
Additional decrease time spent
Additional electrification
Combinations


Comparison of CO_2e emissions (10 future points)
%
120
100
80
60
40
20
0
Base year
Future year
Integrated mobility, powertrain and energy mix scenarios
BAU, EU reference, energy mix A
CliMobCity, EU reference, energy mix A
BAU, Tech scenario, energy mix A
CliMobCity, Tech scenario, energy mix A
BAU, Tech scenario, green energy
CliMobCity, Tech scenario, green energy
Additional modal shift
Additional decrease time spent
Additional electrification
Combinations

2 BYDGOSZCZ: Measure packages, change of mobility and of CO_2e emissions

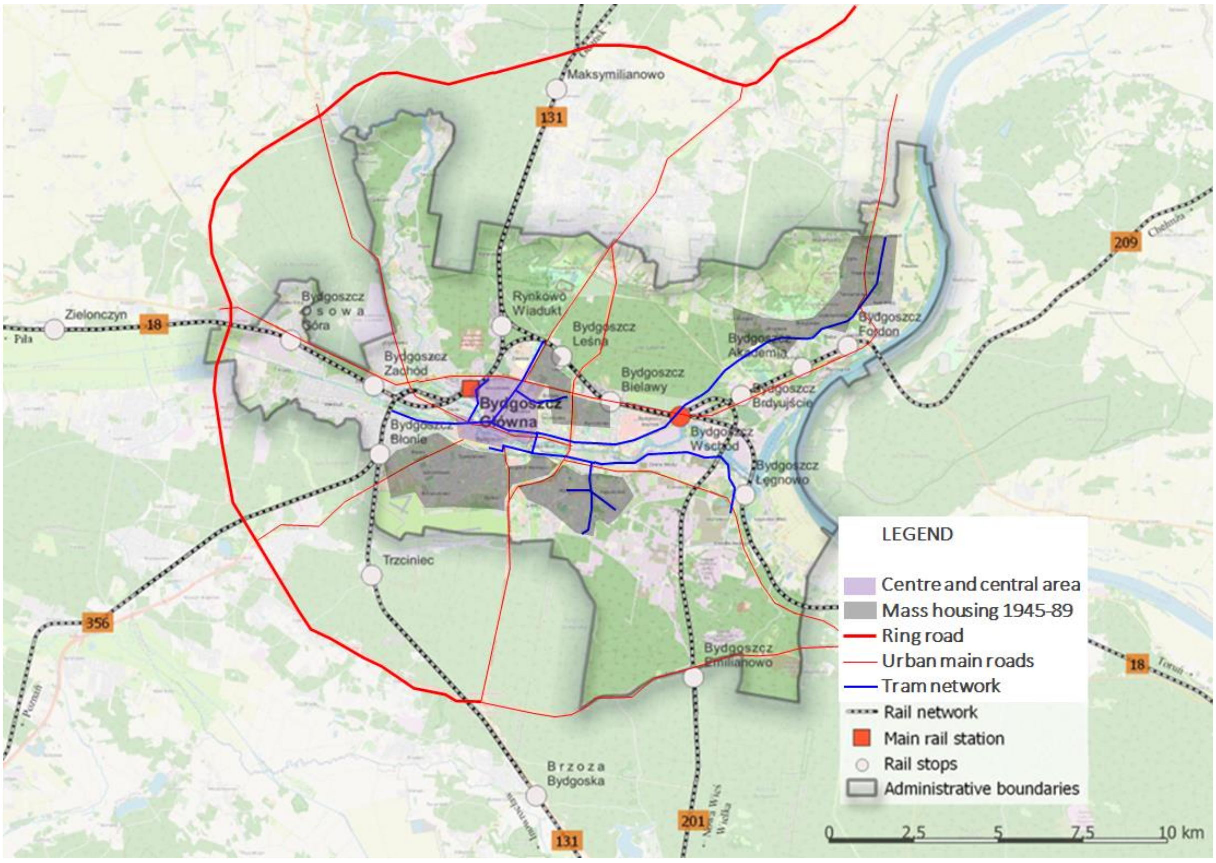
(MoB = Municipality of Bydgoszcz)

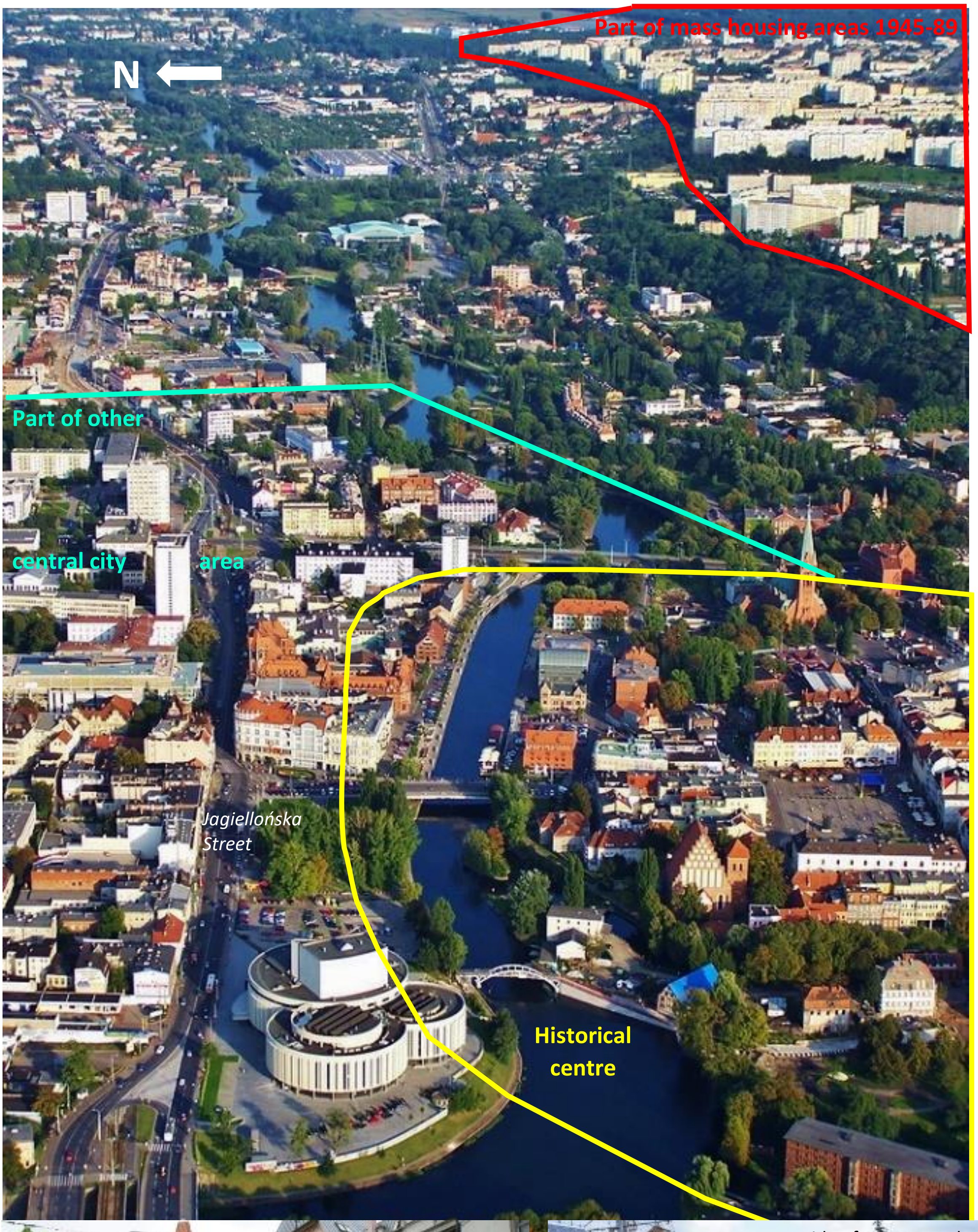
2.1 Current situation and backgrounds (AD, HL, EK, AvB)

The city of Bydgoszcz in northern Poland has 348,000 inhabitants. It is the capital of the (Kuyavian-Pomeranian region (voivodeship)) and hosts the office of the county (powiat) of Bydgoszcz, which surrounds the city of Bydgoszcz. The Bydgoszcz functional urban area (FUA) is home to approximately 600,000 inhabitants. Moreover, together with nearby city of Toruń, it forms a major Bydgoszcz – Toruń metropolitan area (850,000 inhabitants).

Bydgoszcz arose at a strategic location for connecting the Vistula and Brda river regions. In the 19th and 20th century Bydgoszcz evolved to an industrial city, locomotive, rail freight and passenger wagon, and tram repair and construction becoming a spearhead, next to chemical industry. Industrial employment today accounts for 30% of total employment. Other large sectors are trade, transport and communication (26%) and finances, insurance and services (44%).

The city has a well-preserved historical centre. In the 19th century larger dense urban areas arose next to the historical centre, and the first parts of the electric tramway and train network were installed. The historical centre and 19th century urban area together form the city's central area (see following map). This central area became surrounded by green low density residential areas. During the communist rule (1945-89) social housing, typically in 4- to 10-story high buildings, dominated residential development in newly developed areas outside the city centre, especially in eastern areas, and the tram network was extended to access these areas (see map). After the country's




N
Part of mass housing areas 1945-89
Part of other
central city
area
Jagiellońska
Street
Historical
centre


Jagiellońska Street


Tram stop outside of
central area

liberalisation in 1989 the content of dynamic urban change has changed, the focus now being on road and tram infrastructure improvement, centrally located shopping malls outside of the centre, and the reconstruction and maintenance of existing buildings. New housing had less priority, also due to the city's decline of population since 1990. The decline is partly marked by residents' migration to surrounding municipalities. Rather recently, infill of empty or obsolete properties in the central city with compact housing, hotels and offices has started.
Next to the built areas Bydgoszcz also has extensive green areas: 32% of the city consists of forest land, hosting several Natura 2000 areas, one landscape park, and three protected landscape areas and 98 nature monuments.

Corresponding with the urban structure and transport network, present-day (2021) mobility flow patterns in Bydgoszcz exhibit a radial pattern, with travel flows primarily stretching between the older central Bydgoszcz centre and suburban areas. The most important flow stretches between Bydgoszcz central area and its eastern Fordon subcentre. The Fordon area has historically evolved as separate city and has been incorporated into Bydgoszcz city boundaries in 1970s. Travel volumes have been growing along this route ever since, as Fordon area has eventually become one of main residential areas in Bydgoszcz, plus the site of technical university campus.
Some mobility flows including tangent ones also relate to concentrations of industrial estates in (south-) eastern Bydgoszcz, and to lesser extent in western Bydgoszcz areas.
Regarding modal shares, car mobility plays an important role. About half of all trips in, from and to Bydgoszcz are car trips, 22% public transport trips and 26% walking. Bicycle mobility is almost absent (1.3%). City public transport consists primarily of tram and bus services. Tram lines (the blue lines in the map above) are mostly concentrated in the central city part and on main travel axes in Bydgoszcz, while bus lines also stretch towards suburban and peripheral developments. Buses account for about 65% of all public transport mobility, with the remainder mostly served by trams. The train system is barely used for within-city trips, and its popularity is rather limited in the agglomeration area. Regarding powertrains, about 2% of registered cars were BEVs.

2.2 Policies (AD, HL, EK, AvB)

2.2.1 Climate mitigation aim

The climate mitigation aim of the municipality of Bydgoszcz (MoB) is that the city becomes climate neutral by 2050. This aim also applies for mobility.

2.2.2 Overview of mobility and city measure packages

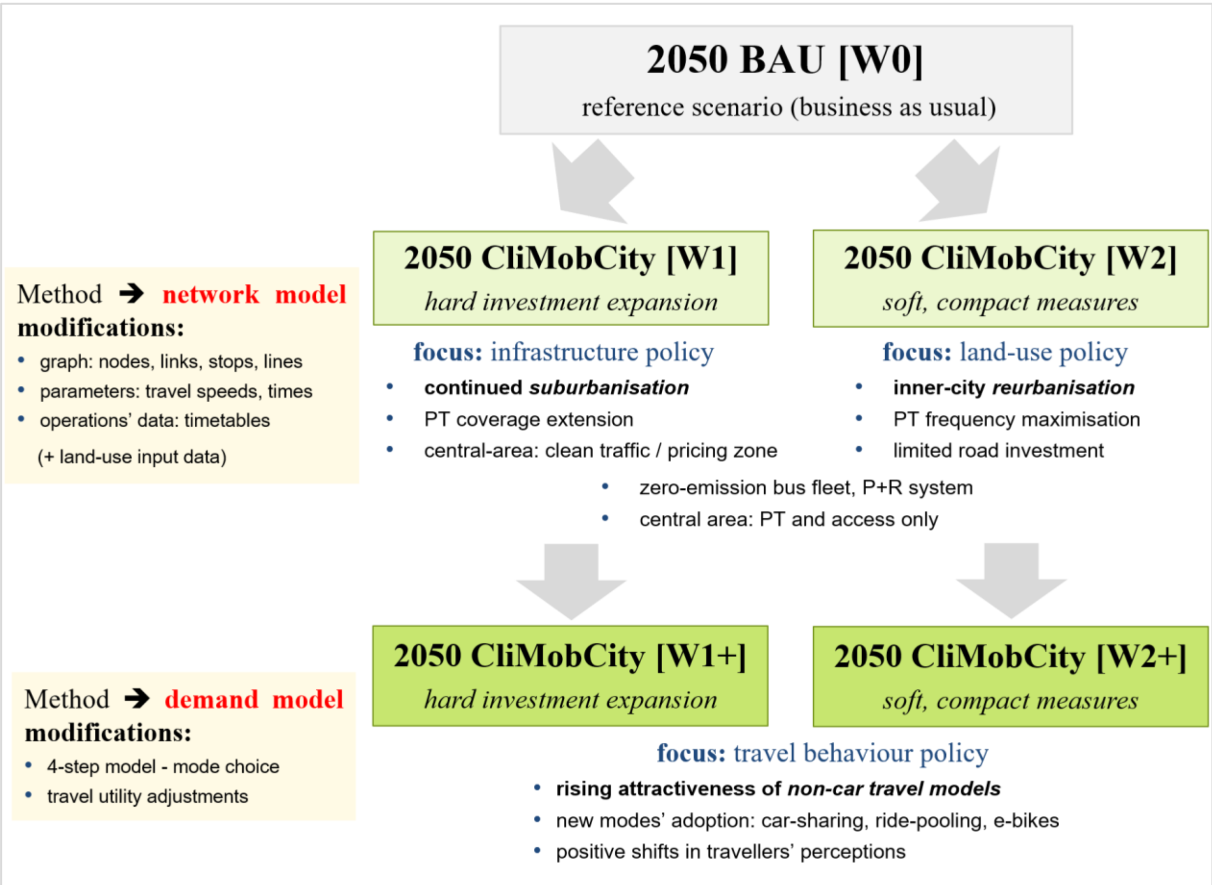
For the project there are the descriptions of mobility and CO_2e emissions for the base year (2021), the **W0 (BAU)** scenario and four **CliMobCity scenarios**: **W1**, **W2**, **W1+** and **W2+**, these focussing on the year 2050.

The measures in the **W0 (BAU)** scenario and corresponding input in the transport model relate to the municipal strategic documents, including *Spatial Development Masterplan for the City of Bydgoszcz* (*SUiKZP*; MoB, 2009), *Sustainable Transport System Development Plan for the Bydgoszcz Metropolitan Area* (MoB, 2013), and inputs and information on approved transport projects and investment plans from city authorities, especially the *Municipal Road and Public Transport Department* (*ZDMiKP*; MoB, 2022).

The direction of measures to be included in the **CliMobCity scenarios** came forward from discussions with the city (three departments, in the mobility, spatial and energy sector) and stakeholders (the regional authorities FUA and ERDF), the pedestrian Ombudsman, researchers from the Bydgoszcz and Krakow universities, and transport consultancy practitioners involved in the development of the city's SUMP. Mainlines in these discussions were:

- that current car traffic restrictions in the city centre are observed to be appropriate and can be extended and intensified;
- the appreciation of low emission zones in the central city parts, in the future perhaps to be coupled with an access fee or a (general) congestion pricing system, but without severe access restrictions in the wider central area;
- that a part of the road investment scheme is oversized and should be tempered;
- that the bicycle infrastructure network should be further expanded;
- that the **WO (BAU)** tram network in Bydgoszcz covers most of the main travel routes and passenger demand corridors. No new *major* tram lines beyond those in **W0 (BAU)** have been proposed during the meetings. However, service frequency and reliability should be improved, enhancements in the form of (more) dedicated infrastructure for trams and also for busses should be considered;
- that the regional rail system has limited potential for the city, partly because of running parallel to tram corridors, partly because of deviating with the spatial pattern of passenger flows and its poor accessibility to/from main urban developments;
- that efforts should be taken to densify the central city parts and (also in absolute terms) decreasing population in the city periphery (see figure below);
- that there should be more alignment of spatial development with public transport development (TOD), densifying the city e.g. around the stations and along tram lines.

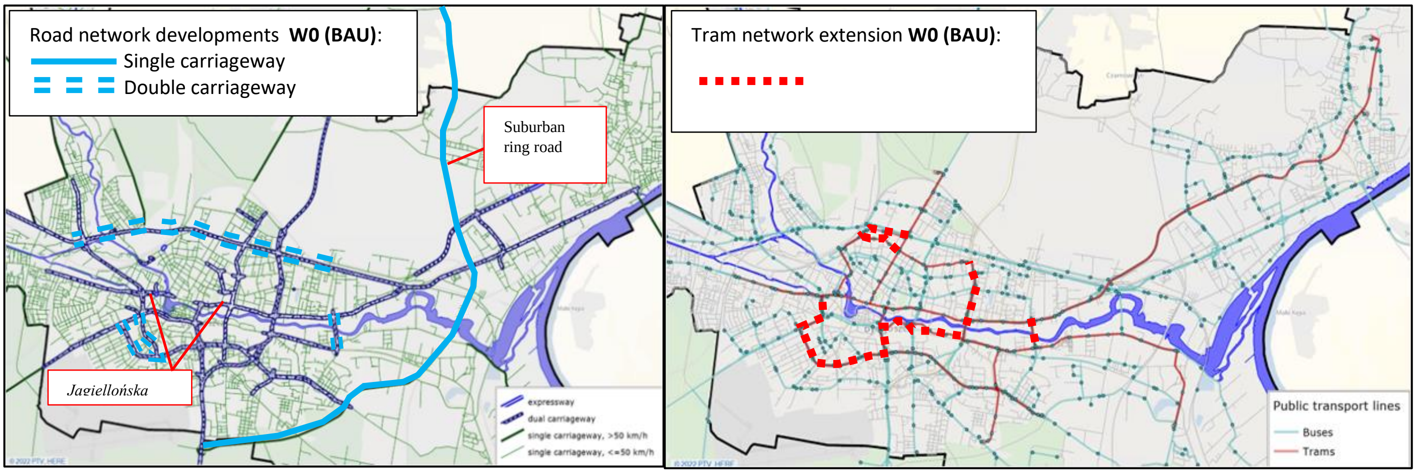
All has led to the definition of two CliMobCity scenarios for 2050, one (**W1**) focussing on the expansion of the tram and rail network, the other (**W2**) on re-urbanisation and corresponding transport measures such as increasing public transport frequencies in the central city areas (see following figure). In addition, to get some insight in the potential effects of changing travel preferences, scenario variants have been defined, **W1+** and **W2+**. They consist of the same measures



as in **W1** and **W2** respectively, but add a variation of travel preferences. The background to introduce these variants is that transport models, also advanced ones, assume current mobility preferences of people to remain unchanged in the future, typically because there is little information about the possible change of preferences. For such reasons experts hesitate to apply transport models for periods as long as 30 years (here from 2021 to 2050). For the Bydgoszcz exploration this problem has been tackled by – on the basis of experts' opinion – varying the (coefficients of the parameters in the) utility function of different modes, mimicking a relatively lower preference for individual car use and therefore leading to lower shares of the private car. The utility variation has the quality of a sensitivity analysis and needs to be validated by further research, but could represent an appropriate approach for long term issues.

2.2.3 Content of the BAU measure package

The major elements in **W0 (BAU)** scenario are projections of population and work force and their spatial distribution, and future changes of transport infrastructure and service networks (road, public transport, bicycle, pedestian) as decided and described in the mentioned strategic mobility and spatial plans. The city population is expected to decrease from 348,000 inhabitants in 2021 to 336,000 inhabitants in 2050 (≈ -3.5% over the period, -0,1% per year). The **W0 (BAU)** scenario forsees the continuation of current suburbanisation processes, hence limited changes in population distribution from the city centre towards eastern Bydgoszcz (Fordon) and agglomeration area. Workplace distribution will be likewise tilted towards eastern Bydgoszcz, influenced by expanding service and industrial developments in the south-eastern part of city and also in north-eastern areas. The total number of workplaces in Bydgoszcz is projected to rise slightly from 236,000 in 2021 to 244,000 in 2050 (≈ +3.4% over the period, 0,1% per year). The future road network is designed to accomodate more car traffic while improving traffic flow. The suburban ring road and improvements of two routes bypassing the central area will allow to deviate more traffic to outside of the centre (left picture in the following figure). In the tram network lines and links are planned to be added creating a fully closed ring around and through the central city part and accessing a more centrally located large mass housing area that currently is only accessed by bus (compare right picture in the following figure with the map above). Further, the tram network is improved by integrally implementing double track and improving service performances by better ICT support (enhancement of ITS priorities and dynamic passenger information systems etc.).



Source: *Appendix-Bydgoszcz-Report*

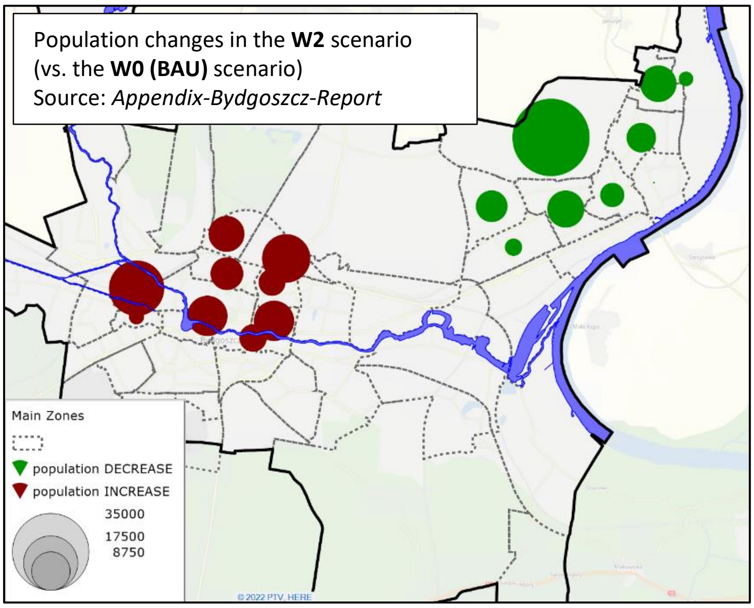
2.2.4 Content of CliMobCity measure packages

The primary objective of the CliMobCity scenario **W1** is a 'hard' outward infrastructure expansion strategy accompanying the sustained suburbanisation towards outer areas, whereas the CliMobCity scenario **W2** emphasises the soft mobility and re-urbanisation policy. The following table informs about the most important measures per scenario (for more detailed description see *Appendix-Bydgoszcz-Report*).

Bydgoszcz 2050 – CliMobCity intervention scenarios		
sectors:	**[W1]** - '*hard' infrastructural development*	**[W2]** - *'soft' city reurbanisation*
land-use development	• **population:** sustained suburbanisation towards outer areas; TOD around main PT hubs • **services:** new investment (and industrial) opportunity areas, e.g. Emilianowo (south-eastern Bydgoszcz)	• **population:** 35% shift of population of certain suburbs from these suburbs towards the city centre • **services:** 2 focus areas: Bydgoszcz (main centre) and Fordon (eastern sub-centre)
public transport	• **zero-emission bus fleet** (100% of buses)	
	• **travel speeds**: 10% higher for city buses and trams (new bus lanes, ITS priorities measures) • **new tram lines** to the north and south of the Bydgoszcz central areas • **Bydgoszcz Metropolitan Rail system** – the main W-E rail corridor with 2 lines and new rail stations in Bydgoszcz • **travel convenience:** perceived transfer disutility 2x lower with improved PT interchanges and ITS-fed travel information	• **travel speeds**: 20% higher for city buses and trams (further enhancements in new bus lanes and ITS steering priorities, greater separation from road traffic)[25] • **increased PT frequency** (up to 2x) for main tram and bus lines – especially in Bydgoszcz central area • **travel convenience:** perceived waiting disutility 2x lower with greater PT frequency and ITS-fed travel information
road traffic	• **historical inner-city core:** car-free zone (authorised access only) • **central Bydgoszcz area:** local access and PT only (no through traffic) • **Clean Traffic Zone** in the Bydgoszcz city centre and the eastern Fordon sub-centre	
	• **road narrowing:** main E-W route in central area and inner-city radial routes (approaches) • **Tempo 30 zones** implemented in central Bydgoszcz and (selected) local suburbs	• **road closure:** main W-E route (*Jagiellońska*) in central area – local traffic and PT only • **Tempo 30 zone** implemented in central Bydgoszcz • **suburban ring road cancelled** in eastern Bydgoszcz area
Park and Ride system	• **P+R** facilities located at the main rail and city PT interchanges	• **P+R** facilities located at the main city PT interchanges

25 Justifying the travel speeds' improvements difference of 10% in W1 vs. 20% in W2 scenarios: Since the W1 scenario focuses on *infrastructure expansion*, in the W2 scenario more money can instead be diverted towards improving the *existing transport services*.

Some highlights: in **W1** the projected **population and its distribution** remains the same as in **W0**. In **W2** the overall city's population is the same as in **W0**, but 35% of the future BAU population in the Eastern town is assumed to be settled in the central city part instead of the Eastern town (including Fordon; see figure to the right), attracted by new houses there, attractive brownfield re-developments and accompanying measures and policies, and shifting the city's functional centre of gravity from an eastern to a more central location. The project acknowledges that in reality such shift is perhaps not completely realistic. But it is of relevance to explore such scenario. Perhaps one can move to such future in smaller steps. This demonstration is also helpful for underlining the problem of uncontrolled (sub)urban sprawl, nowadays faced by many Polish cities.



Population changes in the **W2** scenario (vs. the **W0 (BAU)** scenario)
Source: *Appendix-Bydgoszcz-Report*

In **W1** the **tram network** proposed in **W0 (BAU)** is adopted and two lines are added implying the need for same additional tram tracks. The P+R node infrastructure is organised at stations of the regional train network. In **W2** the tram network is limited to the expansion proposed in the W0 scenario, while service frequencies and speeds are increased, especially in the Bydgoszcz central area.
In both scenarios P+R nodes are implemented at strategic points in the public transport network.

The main **road**s in the central city are narrowed and the central area becomes a tempo 30 zone (**W1** and **W2**). In **W2** the east-west road Jagiellońska (see BAU figure above) is closed for most road traffic, providing more space at its most narrow part for the tram, bus, bicycle and pedestrian system. Also, in **W2** the suburban ring road projected in the BAU scenario (see BAU figure above) is cancelled.

2050 CliMobCity package **W1+** and **W2+**: same measures as in **W1** and **W2** respectively, but assumed changes in travel preferences, expressed in higher perceived attractiveness (utility) of active travel, public transport and car as passenger, and in lower attractiveness of car as driver. As indicated above, these two packages have the quality of a sensitivity analysis rather than of a true variant.

2.2.5 Towards post-fossil fuel vehicles (AD, EK, FR)

For Bydgoszcz, national documents show the direction of policies to support and facilitate the substitution of fossil fuel by post-fossil fuel vehicles. The Polish government in its *National Recovery Plan for the years of 2021 – 2027* (Ministry of Funds and Regional Policy, 2023) recommends that cities of the size as Bydgoszcz from 2026 launch car duty (tax) based on their emission levels, and envisage low/zero emission zones. Next, by 2026 there should be an 100% increase in number of BEVs present in 2020. The resulting share would still be very small given the very low baseline level in 2020. And, from 2025 the fleets of public authorities should for at least 50% consist of electric vehicles. The Polish Association of Alternative Fuels in its *Outlook 2022* meanwhile expects 14,5% of new car registrations to be electric already by 2025.

According to the EU reference scenario, Bydgoszcz' road fleet in 2050 might consist of 16% electric and 7% hydrogen vehicles. In the more ambitious scenario, the Tech scenario, 30% of all vehicles might be electric and 13% hydrogen ones (see following table). In other words, in 2050 respectively 77% or 57% of all cars are expected still to be fossil fuel ones. One may summarise that although the EU reference and the Tech scenario point out more replacement of fossil fuel by post-fossil fuel vehicles than the cited national documents do, the remaining fleet of fossil-fuel vehicles in these scenarios still is very large. This will hamper the CO_2e reduction. But, given the national guidelines and forecasts valid at the time of this research, one will not be able to say the carbon analyst should have assumed higher shares of post-fossil fuel vehicles.

	EU reference					Tech			
	% BEV cars	% Hydrogen cars	% Together	% Fossil fuel remainder		% BEV cars	% Hydrogen cars	% Together	% Fossil fuel remainder
Bydgoszcz, 2021	0,2	0	0,2	99,8	Bydgoszcz, 2021	0,2	0	0,2	99,8
Bydgoszcz, 2050	16	7	23	77	Bydgoszcz, 2050	30	13	43	57

2.3 Expected change of mobility in the city (AD, EK, AvB)

2.3.1 Approach

Application of a 4-stage multimodal mobility model (developed in PTV Visum software, used as strategic tool by the MoB and updated by Gradiens Sp. z o. o.) of the Bydgoszcz city and its agglomeration area. The model includes passenger travel modes: road, public transport, bicycling, walking, and also freight traffic.[26]
Regarding freight, there is a separate part in the demand model dedicated to freight traffic. This part was developed based on survey and traffic counts, and then calibrated to meet the model requirements. It is divided into light (vans - LGVs) and heavy (trucks - HGVs) traffic.[27]

The effects of shared cars and micro-mobility are not sufficiently known yet, let stand well incorporated into transport modelling. The shift to post-fossil fuel vehicles is taken along in the analysis of the reduction of CO_2e emissions.

2.3.2 Outcomes of the mobility forecast: BAU and 2050 CliMobCity

Concerning the change of mobility between 2021 and 2050:
(**Trips in, from, to and through Bydgoszcz**)

- The total number of trips (private car, public transport, bicycle and walking) is 2,7 trips per inhabitant and evolves to 2,8 in 2050, which is 4% more than in 2021.[28] In combination with the

[26] Freight is calculated with separate procedures for generation of transport demand, modal choice and traffic assignment.

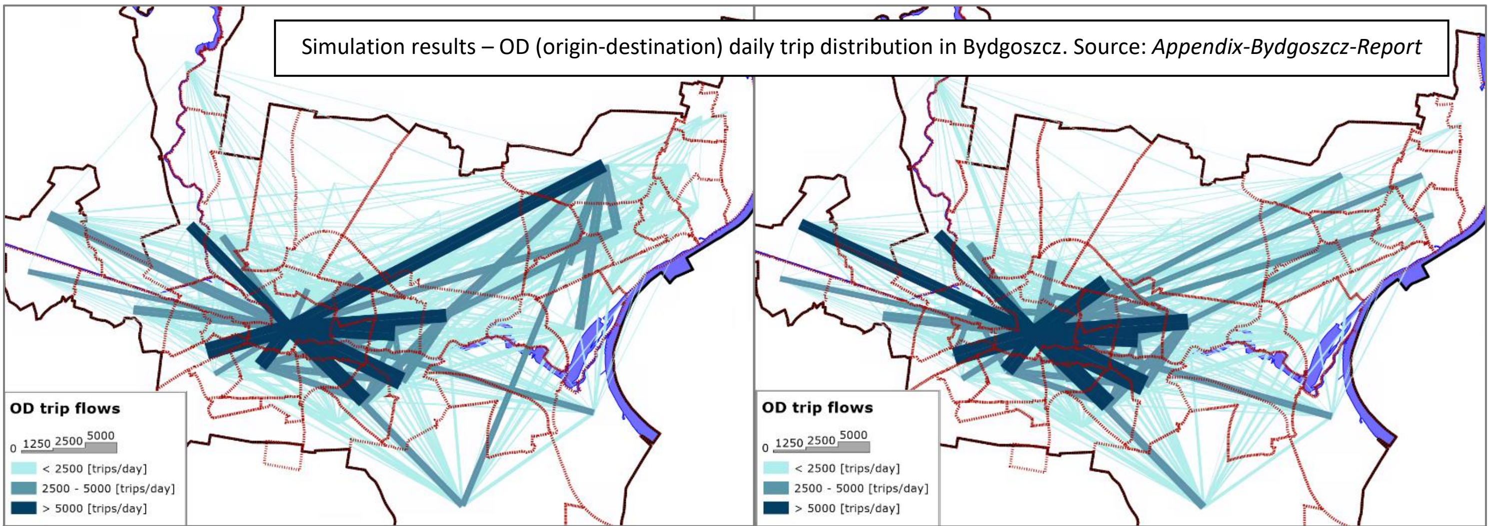
[27] Trip modelling is based on the selected factors (and explanatory attributes), like the number of inhabitants, workplaces, shopping centres and so on.
The freight model is based on vehicular traffic demand modelling, which calculates traffic volume forecast. The current Bydgoszcz model does not deal with the amount of goods carried by this traffic, nor with the mode choice for freight transportation. As such the freight traffic model is developed analogously to other Polish cities. However, many cities do not even account for freight traffic in their modelling tools and use passenger-traffic models only.
Gradiens for freight uses the 3-stage procedure, as the mode choice stage is not used in it. Trip generation is based on the selected factors (as mentioned above).

[28] This is much more than in Poland in general, but Poland in general is catching in: "Socio-economic welfare and development often drives the growth in transportation needs, this aspect has been reflected in terms of rising mobility rate (i.e. number of daily trips per person) of approx. 35% by the year 2050 – i.e. corresponding to 1% annually.

decline of population during the same period the total number of trips is rather stable. The increase is 1-2% increase in the entire period, dependent on the scenario.

- Car trips (including passenger trips) increase by 8% between **2021** and 2050 **W0 (BAU)** and by less in most 2050 CliMobCity scenarios. In **W2** and **W2+** versus 2021 car trips increase less than in **W1** and **W1+** respectively. In **W2+** the number of trips declines by 7% compared to 2021.
- Public transport trips decline from 2021 to 2050 **W0 (BAU)**, which is remarkable given the substantial expansion of the tram network. This improvement can apparently not compete against the improvements in the road network. In **W1** and **W2** there are 7% more public transport trips than in 2021. In **W1+** and **W2+** this is 17% and 23% respectively more.
- Walk trips decline in **almost all the scenarios** in comparison to 2021 (down to about -20%), however the least in **W2** and **W2+** (change is -5% and +4% respectively) which indicates that more destinations can be reached within a walking distance in the densified central area.
- Bicycle trips decline in **W0 (BAU)** in comparison to 2021, but are also no success in **W1** and **W2**. Only in the **plus scenarios**, there is a substantial increase of bicycle trips (more than 20%).
- Regarding the spatial pattern of trips:
  - The **W0 (BAU)** scenario results in relative increase of long-distance flows between Bydgoszcz centre and suburban areas (following figure). This is partly the result of faster road and public transport mobility, but primarily the consequence of sustained suburbanisation processes, which also leads to relative growth in flows from/to eastern Fordon area. A certain increase in tangent flows between Fordon and south-eastern Bydgoszcz is also observable, reflecting extra trips between new housing developments (Fordon) and service/industrial estates (south-eastern Bydgoszcz). The evolution of such travel demand structure fosters the dominant role of private car in everyday trips in Bydgoszcz.

Simulation results – OD (origin-destination) daily trip distribution in Bydgoszcz. Source: *Appendix-Bydgoszcz-Report*



2050 [W0] BAU	2050 [W2] CliMobCity

- The **W1** scenario envisages analogous flow distribution as the **W0 (BAU)** scenario, with only minor differences in modal split in central Bydgoszcz area. Inner-city road narrowing results in certain shifts towards alternative modes (walking, cycling, PT) but only in case of short-range trips, without significant impact on the city-wide scale.
- Land-use assumptions in **W2** substantially alter the flow structure. This resembles much more the *compact-city* structure, as *brownfield* housing (and services) developments are now promoted instead of *greenfield* expansion. Travel flows span now over relatively shorter

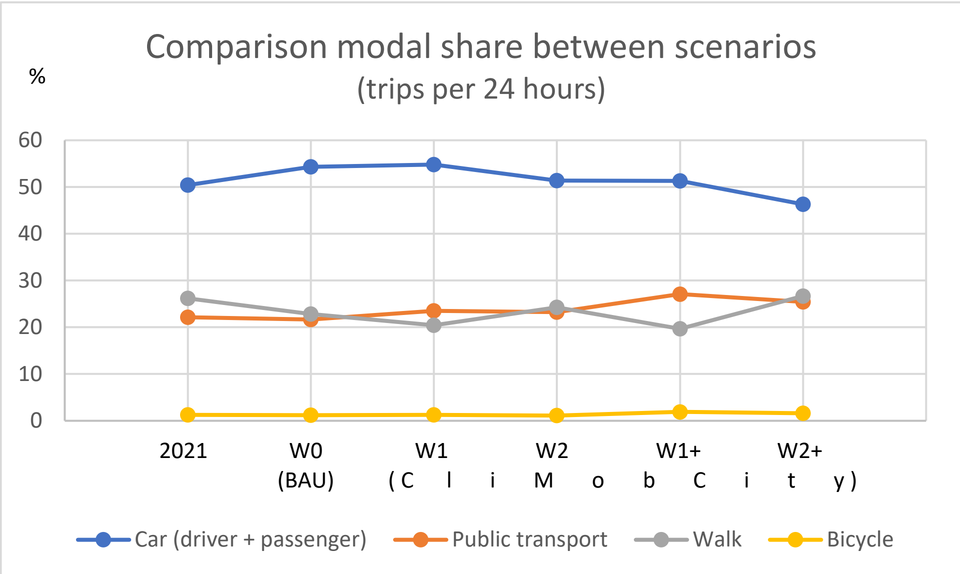
Present-day mobility rates in Polish cities are estimated at 1.5 – 2.2 [trips/person/day], which is noted to be visibly lower than estimates for Western countries" (Appendix-Bydgoszcz-Report, p.25).

distances and 'radiate' between Bydgoszcz centre and suburban areas. In particular, there evidently are less tangent and long-distance travel flows compared to **W0 (BAU)**. Public transport patronage declines in the eastern Bydgoszcz areas due to assumed population outflow. Interestingly though, these occur mostly along the local and feeder bus routes in Fordon area, but not along the main W-E tram route itself (except for its very far-east section).

- Public transport routes show a diverse picture of growth and decline in **W1**, in comparison to **W0 (BAU)**. In **W2** public transport flows in the central city part are substantially larger than in the **W0 (BAU)** and **W1** scenarios, clearly the growing route segments are in the central city part, while the routes to/from the city's Northeast witness a substantial decline of passenger volume.

(Modal share expressed in trips**)**

- Car mobility has the largest share of all modes (+/- 50%). The share increases to 54% in the period between 2021 to 2050 **W0 (BAU)** or **W1**. In the **other three CliMobCity scenarios** the share is lower than **W0 (BAU)** (see following figure), and in **W2+** even lower than in 2021.
- In contrast the share of public transport is higher in the **CliMobCity scenarios**, especially the **plus-scenarios**, than in **W0** or the **base year**.



This type of presentation supports understanding of the relation between different results (dots).
But be aware of that:

- lines between the base year dot and BAU dots represent alternative developments in time;
- lines between BAU and CliMobCity dots serve the comparison, but don't represent developments in time.

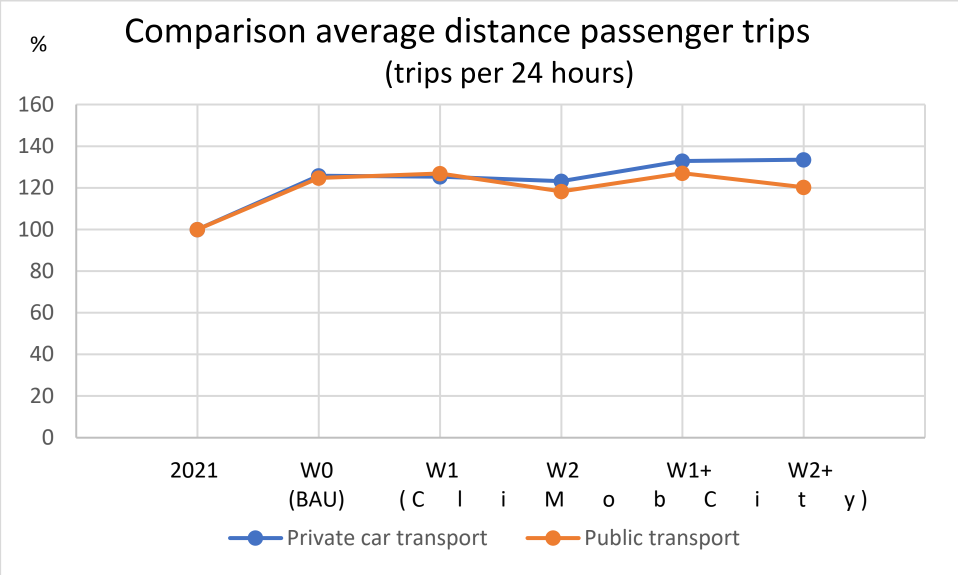
(Average distance)

- The described change of travel pattern impacts average passenger travel distance. In 2021 this was almost 10 kilometres for private car transport and almost 5 km for public transport, the weighted average of both modes being 8,4 km. Between 2021 and **W0 (BAU)** the distances increase by about 25% (following figure). Such is also the case from 2021 to **W1** or to **W1+**. In the 2050 CliMobCity scenarios **W2** and **W2+** the public transport distance increase less, but still are about 20% higher than in 2021.[29] The car distance in **W2** is slightly lower than in **W1** and **W0**

[29] The plausibility of the larger average distance in **W2** and **W2+** in comparison to 2021 despite of the relocation of a major share of Fordon population back towards city centre can be explained as follows.

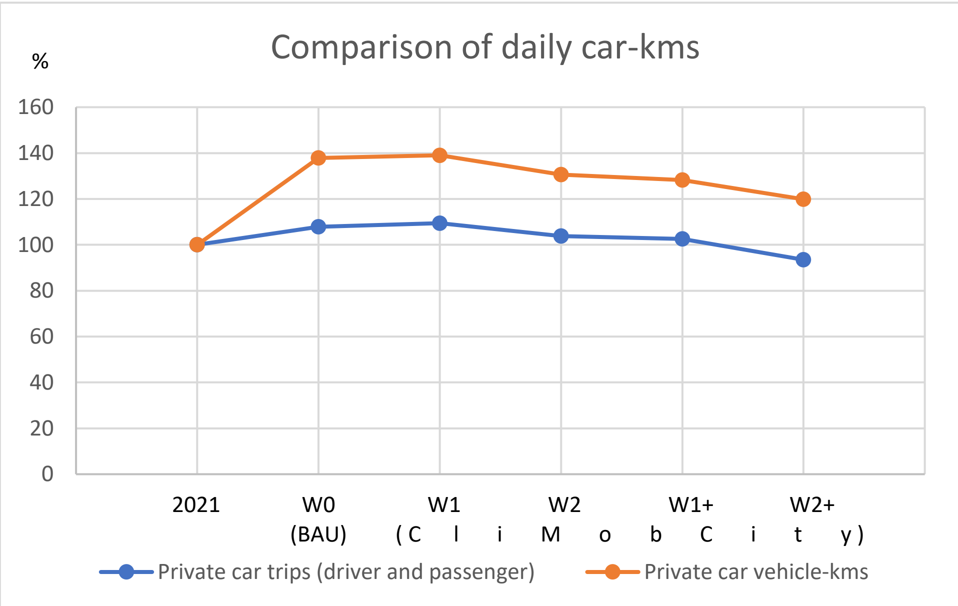
a) Other 2050 BAU developments remain unchanged, so many inhabitants still have to reach far-distance workplaces or urban areas etc.

(BAU). The change of travel preferences in the scenarios **W1+** and **W2+** reduce the car share, as shown above, but also increases the average passenger distance by car.



(Vehicle-kms and passenger-kms)

- The increasing number of car trips in combination with the increase of average travel distance by car leads to almost 38% growth of car-kms between 2021 and **W0 (BAU)** (following figure).

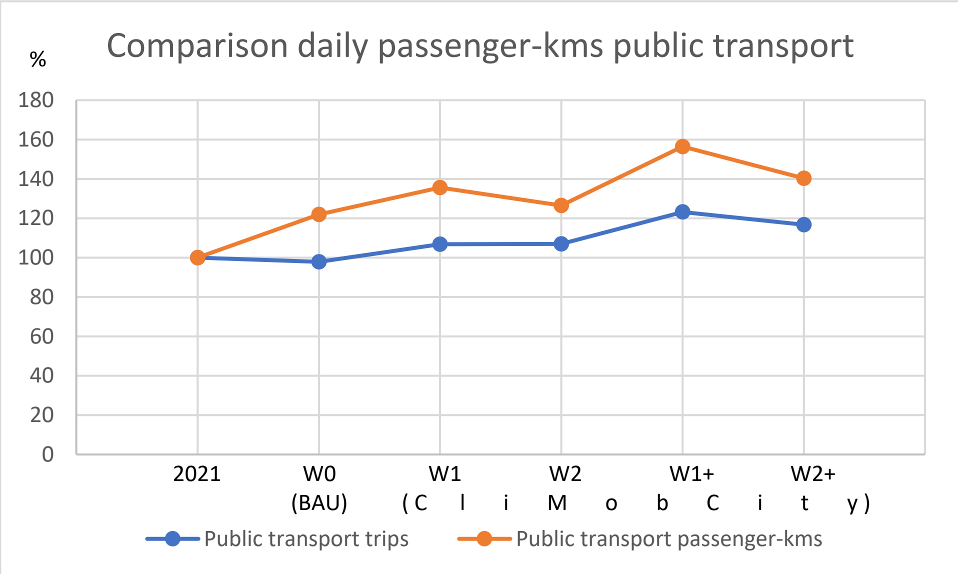


- In **W1** the car-kms are on a similar level as in **W0 (BAU)** as the number of trips and average distance is similar. In **W2** there are less car-kms than in **W0 (BAU)**, but still much more than in the base year. The increase is +31% instead of +38%, corresponding with the shorter average

b) Shorter trip distances for many Bydgoszcz users in **W2** versus **W0** are compensated, in turn, by certain share of users making longer trips by car (extra detour due to central-area road restrictions and closures) and by PT (since we increase its popularity and modal share, but it also attracts new users with longer access distances). Hence, the 2050 **W2/W2+** changes versus 2021 are partially 'distorted' by the effects (a) and (b).

distances. The level of car-kms in **W1+** or **W2+** is smaller than in respectively **W1** or **W2** because of the lower valuation of car mobility and therefore smaller number of trips (in W2+ = +20%).

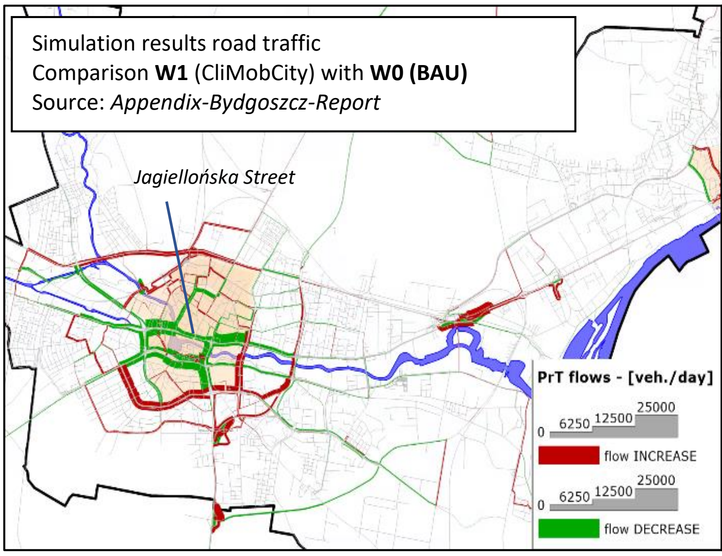
- Road freight vehicle-kms change from 2021 to **any CliMobCity scenario** in comparable proportions as from 2021 to **W0 (BAU)**, namely about +30% (HGVs) or -8% (vans/LGVs).
- Public transport passenger-kms in **W0 (BAU)** increase in comparison to 2021 by roughly 20% (following figure). This change is solely the consequence of the increase of average PT travel distance because the number of trips decreases slightly. In **W1** the passenger-kms increase even more, this time also due to the larger number of PT trips involved from outer areas. Regarding **W2** the growth from 2021 is smaller than for **W1**, which clearly results from the shorter average travel distance in the re-urbanised city. **W1+** and **W2+** have more passenger-kms than respectively **W1** and **W2**, a consequence of the larger trip number (and not of longer distance) caused of a higher valuation of PT by travellers.

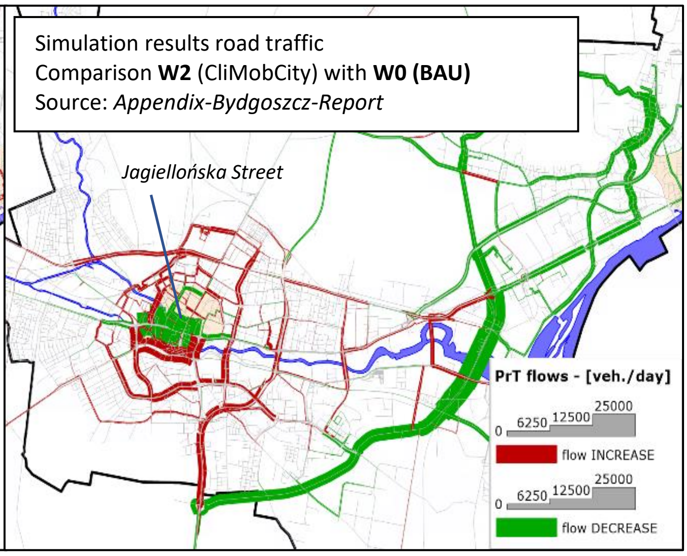


(Traffic impacts)

- The increase of vehicle-kms is a first indication for additional pressure on the road network, but not necessarily conclusive, as the additional vehicle-kms can also rain down on roads in the periphery of the city where the traffic pressure isn't large. On the other side, part of the vehicle-kms will emerge in areas where roads already had relative large traffic volumes. For all Bydgoszcz it looks like additional road traffic on the network is averagely in balance with the road infrastructure, average network speed being an indicator. In **W0 (BAU)** the speed is 3% higher than in 2021. In the **CliMobCity scenarios** the average network speed is 2-6% higher.
- A closer look to the road network shows that the traffic volumes in specific areas change differently. The downgrading of W-E streets in the central area in **W1** leads to traffic volume reductions there, and in return traffic increases on other W-E roads and some N-S streets (left map in the following figure). In **W2** the downgrading of W-E streets in the central area is extremer (Jagiellońska Street is closed for general traffic) plus that there is no suburban ring road which together increases the traffic pressure on streets in the central area (right picture).
- The closure of Jagiellońska Street in **W2** for most private road traffic is highly appropriate, given the frequency increase of public transport lines (some with a doubled service frequency), and the increased number of passengers entering and exiting the public transport vehicles in that street ("In particular, passenger numbers along the main W-E tram route rise by 20-50% (up to extra 10,000 - 18,000 [pass./day]"[30]), and given the narrow road profile, resembling now a mixed-use urban boulevard.

[30] See Appendix-Bydgoszcz-Report, p. 41.





A rough interpretation of results

- The development from 2021 to 2050 **W0 (BAU)** is marked by the assumption of increasing prosperity and extended suburbanisation. Main symptoms are the increase of number of car trips and of average trip distances (car and public transport). This development is supported by the extension of the road network in ways that benefit longer distance travel (including the building of so-called the suburban ring road). The paradoxical outcome is that although travel speeds are (on average) higher in 2050 BAU compared to 2021, mean travel times are actually longer.
- At the same time substantial investments into the tram network are projected, increasing the connectivity, especially in the central city parts. But this doesn't induce a modal shift to more public transport. In contrast, there are less public transport trips in **W0 (BAU)** than in 2021. Apparently, the improvements of public transport services are less attractive than the improvements of the road network.
- At the end, total car-kilometrage being the most important variable for CO_2e emissions, increases between 2021 and **W0 (BAU)** by about 40%!
- An alternative development is one leading to scenario **W1** (the first CliMobCity scenario). Main elements in this development are the addition of two tram lines and of two regional train lines plus new stations for these, and the narrowing of streets in the central city area. This together makes more travellers choose public transport than in 2021, but the volume of car trips and car-kms does not decline. Still the improvements of public transport services appear to be less attractive than the improvements of the road network.
- Another alternative scenario is **W2** (the second CliMobCity scenario). Main elements in this scenario are the re-urbanisation (an absolute decline of 35% of BAU residents in the Eastern periphery in favour of densifying the central city area), the increase of public transport service frequencies (up to a double frequency), especially of tram lines in the central area, the narrowing of streets in the central area and closure of Jagiellońska Street for most road transport, and the cancelling of the suburban ring road. This together lets in **W2** the number and share of public transport trips increase in comparison to 2021, while the volumes of car trips and car-kms decline.
- In the CliMobCity scenarios **W1+** and **W2+** the transport networks are the same as in **W1** and **W2** respectively, but a slightly changed attitude of travellers is assumed to be present, implying other choices of modes. The assumption is modelled by changing a few behavioural parameters in the model. The perceived utility of alternative, sustainable transport modes is relatively greater than that of using private car as driver. It must be emphasized that this intervention in the model is not based on research, but on expert's intuition, the results representing not more than those of

a sensitivity analysis. Validation by research is required. However, one can imagine, that increasing awareness of the climate challenge, perhaps brought about by awareness campaigns, could on the longer term indeed change mobility preferences in such direction. The result of this modelling was more travellers choosing public transport and cycling in **W1+** and **W2+** in comparison to **W1** and **W2** respectively, clearly at the dispense of car. Moreover, only in **W1+** and **W2+** is average car occupancy higher (though by less than 10% higher) than in other scenarios. Car-kms are less in **W1+** and **W2+** than in any other scenario. Still there are 20% more car-kms in **W2+**, the scenario with the lowest number of car-kms in 2050, than in 2021.

- A look to the modelling results shows that in Bydgoszcz ca. 15% of motorised trips correspond to bicycle trips of max. 10 minutes, and about half of motorized trips to max. 20-minute cycling trips. These findings indicate a potential for modal shift from car to bike in these trip categories. In order to reap this potential, strategic investments in bicycle infrastructure development as well as accompanying measures such as promotion and even car-use restrictions would be needed. These can effectively influence everyday travel habits.
- From **W0 (BAU)** one might learn how important a more effective cooperation of pull (to public transport, active travel and shared car use) and push (out of the private car) measures are and therefore reflect on push pull combinations that have not yet been considered.

2.4 Analysed reduction of CO_2e emissions[31] (FR, EK, AvB)

The ultimate result of mobility changes from 2021 to 2050 **W0 (BAU)** is the increase of road vehicle-kms by about 30% (HGVs) and almost 40% (cars). Without shift to post-fossil vehicles this would mean an increase in CO_2e emissions as well. However, there is some shift to post-fossil vehicles. In the EU reference scenario the share of post-fossil fuel vehicles shifts from 0.2% to 23%. This stabilises CO_2e emission to +1% from 2021 to **W0 (BAU)** (see blue line in the following figure).

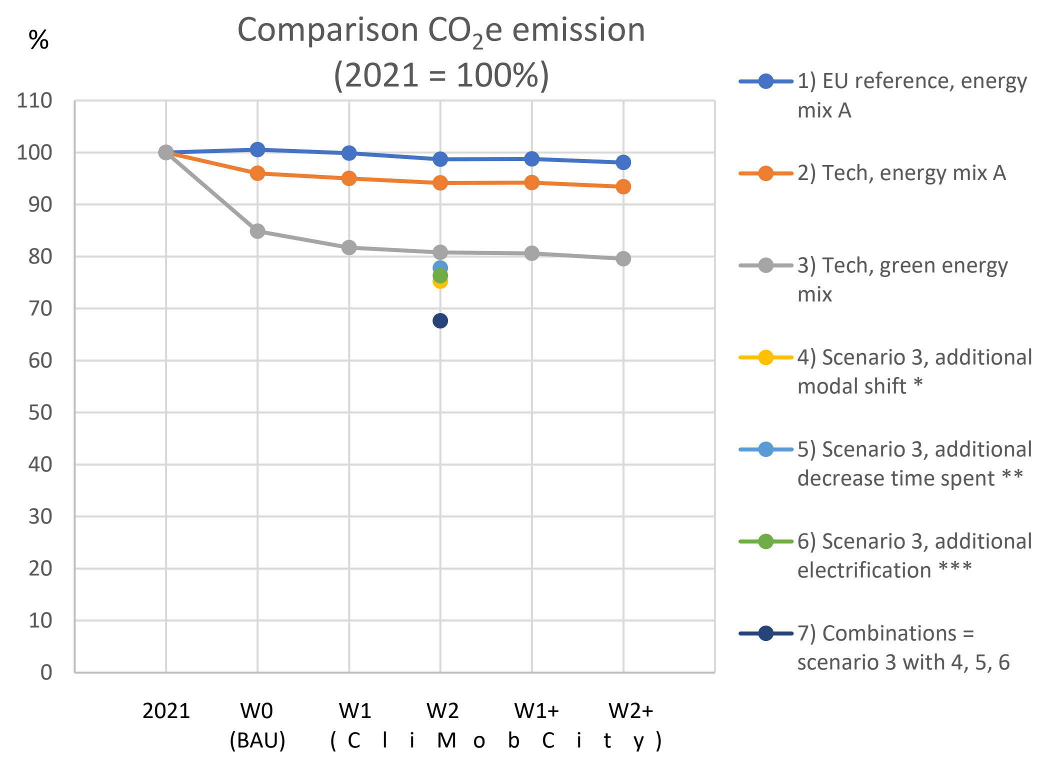
In the CliMobCity scenarios the CO_2e emission is the same as in 2021 (**W1**), -1% (**W2**), -1 (**W1+**) and -2 (**W2+**), all given the EU reference scenario for powertrains (blue line). In the CliMobCity scenarios the emissions are less than in **W0 (BAU)**, as the public bus fleet is 100% post-fossil. In **W2** there is more reduction than in **W1** because of a smaller increase of car-kms due to the more effective combination of pull- and push measures and the shorter average travel distance. In **W1+** and **W2+** there are again less car-kms in comparison to respectively **W1** and **W2** due to more sustainable mobility preferences of residents.
Based on the Tech scenario of shift to post-fossil vehicles the (orange line) or the same with green electricity production (grey line = overall “scenario 3” in the figure) the comparison of emissions between scenarios provides a similar picture, just lower each time. On the grey line the reductions are 18% (**W1**), 19% (**W2**), 19% (**W1+**) or 20% (**W2+**) respectively. From the energy mix for electricity production further reduction can’t be expected, as the maximal contribution has already been provided.

After the electricity production has become green, further emission reduction can only be achieved by **additional efforts** in the sphere of behavioural change or technological improvement. The following figure shows the results of some **forecasting lever exercises**. Here the lever positions in the carbon model adjusted reflecting the following changes:

- (overall scenario 4) additional modal shift: 10 %-points less share of car trips etc. than in scenario 3 in exchange for 5 %-points more bus and active travel share;
- (overall scenario 5) 10% less time spent than in scenario 3 (e.g. less distance travelled);
- (overall scenario 6) 10 %-points additional share of post-fossil fuel vehicles than in scenario 3;
- or (overall scenario 7) combinations of these measures.

These scenarios provide an additional CO_2e reduction of respectively 6 %, 3 %, 5 % or 13 %.

[31] For a more detailed description of the results and approach of the CO_2e analysis see the Appendix-PIK-report.



*	Share of cars and other LDVs: -10 %-points; of public transport busses and active travel: each +5 %-points.
**	10% less time spent, because of less road vehicle-kms and/or more fluent traffic flow.
***	Share of post-fossil fuel vehicles: +10 %-points at the dispense of the share of fossil fuel vehicles.

This type of presentation supports understanding of the relation between different results (dots).
But be aware of that:

- lines between the base year dot and BAU dots represent alternative developments in time;
- lines between BAU and CliMobCity dots serve the comparison, but don't represent developments in time.

In overall scenario 7 the **remaining** CO_2e emission is 68% of the 2021 emission. This for 54% consists of car emissions and for 46% of freight emissions (see *Appendix-PIK-Report*).

Further reduction will depend on further mobility, land use and powertrain (electrification et.) measures. We discuss such options in the last chapter, Chapter 6, of this report.

As already indicated, the transport modelling does not show the effects of measures entailing shared cars, micro-mobility services and corresponding hub nodes on future mobility, while these may have the potential to reduce CO_2e emissions of mobility in substantial amounts. But whether this is likely, is not sufficiently validated by research yet and certainly depends on the context of implemented concepts. Also this additional reduction is briefly discussed in Chapter 6 of this report.

2.5 Feedback from the municipal reflection on the CO_2e reduction (HL, AD)

The CliMobCity project delivers research-based insights into valid challenges, facing the contemporary urban transport systems. Analyses conducted for the Bydgoszcz city demonstrate how projected transport changes and land-use developments may affect CO_2e emissions from transport sector. Based on transport and environmental models, findings underline the potential BAU risks and the necessity of additional measures. These encompass a wide range of solutions, including public transport investments, cycling and walking promotion, need to reduce car traffic especially in central area. Recommendations provided in the Project Summary extend beyond transport fields, underlining for example the long-term interactions between land use and transport developments.

The CliMobCity analysis provides research underpinning that proposed measures do not sufficiently reduce carbon footprint and further interventions are necessary towards mitigating negative climate effects of transport externalities. Such knowledge will be instrumental in shaping future, long-term policies. Findings of this projects have been already discussed with decision-makers who are currently drafting strategic documents for the Bydgoszcz city and its functional urban area, such as the sustainable urban mobility plan (SUMP), the spatial development masterplan (SUiKZP) and the city transportation plan.

It should be underlined, though, that achieving climate neutrality is a long-term process, which can be tainted by various implementation issues. Awareness of the CliMobCity results should remain present in the minds of municipal policymakers in the field of transport and spatial planning, also for elaborations of strategic plans like to medium-term mobility or spatial plans and programmes. While a 100% zero-emission public transport fleet will soon become a reality, the notion of clean transport zones (low-emission zones) requires public acceptance and can only be introduced gradually, as such solutions are yet unknown in Polish cities. National regulations also play an important role and determine the effectiveness of various policy tools. The adoption of binding spatial development plans is a time- and work-intensive process, and since these undergo public consultations, they need to achieve a certain consensus. The CliMobCity analyses also underline the fundamental impact of energy mix in the ultimate mitigation of climate impacts from transport – which can be hardly influenced without national-level policy changes.

Therefore, future policy decisions should definitely take into account the consideration of climate impacts, especially from transport sector in Bydgoszcz. Such interventions may require further time and efforts, though, to become eventually effective. Findings from the CliMobCity projects will provide a valid research-based contribution, assisting this long-term process.

3 PLYMOUTH: Measure packages, change of mobility and of CO_2e emissions

(MoP = Municipality of Plymouth)

3.1 Current situation and backgrounds (DF, EK, AvB)

Plymouth is a port city situated between the River Tamar and the River Plym and at the border of the counties of Cornwall and Devon in the far south west of England. Plymouth's rich history as a royal naval dockyard began when the English naval fleet was based in there in the 15th century. In the late 16th century, Plymouth became home to wealthy maritime traders in wool and the early slave trade, and was the departure point for attempts to settle in North America (amongst them the Pilgrim Fathers). In the 17th century Plymouth declined as a commercial port. However, in the 18th century its importance as a royal naval dockyard grew once again. Several new docks were built and the dockyard became the region's major employer with thousands of workers, bringing some prosperity to the city and supporting the development of other industries in the city during the 19th century. The arrival of the railways to Plymouth in the late 19th century boosted the city region's economy by enabling early season soft fruit and locally caught fish to be transported quickly to markets in London. During World War Two the city was heavily bombed due to its importance as a naval port.

Bedford Street, Plymouth, 1941.

After World War Two a Beaux-Arts-inspired 'Plan for Plymouth' guided the redevelopment of the devastated city centre. Between the late 1940s and early 1960s remaining pre-war buildings and slum housing in the city centre were demolished and replaced with wide, modern, east-west boulevards and a grand north-south avenue that linked the railway station to the waterfront.

The city's urban area expanded northwards and eastwards throughout the post-war era with the building of mostly low-density housing estates. The city now has around 122,000 dwellings and the population has grown to around 262,000 (Office for National Statistics (ONS) mid-year estimate 2022). Most residential areas have low densities. In recent decades the MoP sought to increase urban density and avoid urban expansion by successfully focussing new development on brownfield sites within the city boundary. However, as opportunities for such development depleted, some urban extension developments have been planned to the east (e.g. Sherford) and north (e.g. Woolwell) of the city.

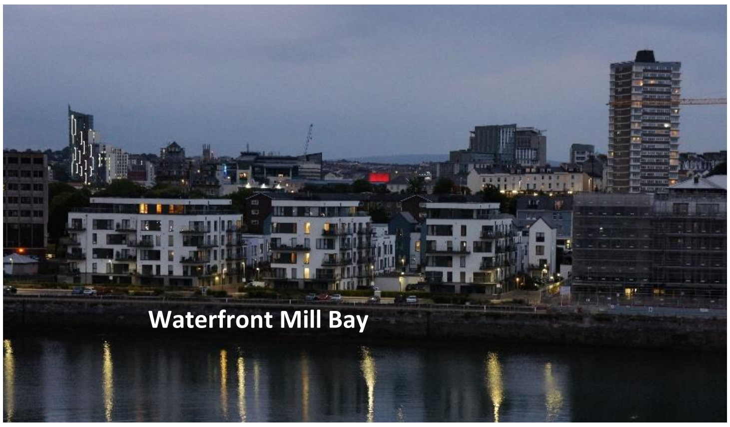
The post-war era was a period of great economic change for Plymouth. Whilst Her Majesty's Naval Base Devonport (HMNB) remains the largest naval base in Western Europe and is of vital importance to the UK's defence capability, it has gradually transitioned from mass employment ship-building to a


1943, Plan for Plymouth city centre


Plymouth city centre today


Royal Parade, rebuilt Plymouth city centre, 1958


Small remainder historical centre, recreational port


Waterfront Mill Bay


Pre-war residential row house neighbourhood

much smaller, high skill employer focussed on warship and nuclear submarine refitting. Similarly, whilst Plymouth's fishing industry still lands 13.2% of England's total fish catch each year putting it in the top 3 fishing ports in England, technological changes have resulted in it employing fewer than 500 people in 2020.

Responding to these trends MoP sought to diversify the city's economy. By the mid-1970s many new industries had come to Plymouth, and a government-subsidised Ro-Ro ferry route had opened up to connect the city to France and later Spain. More recently the city's university has grown substantially in both size and international stature and there is an emerging cluster of high tech marine industries based in the city. Despite this, however, Plymouth is within the 20% most deprived local authority districts in England, with unemployment higher and wages and economic output lower than the national average.

Plymouth's distribution of employment sites are distinctive: in addition to being concentrated in the city centre and Devonport (the location of the Naval Base), there are also employment clusters in the north of the city at and around Derriford Hospital and in the east of the city at Langage Business Park. Together, the proportion of jobs in the city performed by people who commute into the city from outside is relatively low. Furthermore there exist relatively few car-dependent 'big shed' retails parks, which are perceived as a threat to the viability of the city centre retail economy.

Historically, Plymouth has not been a major tourist destination. However, the city has been actively developing its tourism 'offer' and promoting itself nationally and internationally as 'Britain's Ocean City' during the last decade and over 5,000,000 people now visit Plymouth each year. Plymouth offers a beautiful waterfront setting, its historic Barbican area, proximity to Dartmoor National Park, the UK's first National Marine Park, and three nearby Areas of Outstanding Natural Beauty.

Regarding mobility, the *Appendix-Plymouth-Report* gives an abundant picture of the current transport network in the city. Central elements of the road network (see following figure) are the A38 national highway traversing the city from east to west and a set of radial urban main roads connecting the city centre to other parts of the city and surrounding areas. The rebuilt city centre has roads with wide lanes. Controlled parking zones prevent non-residential parking in residential areas during critical periods of a day.

The public transport network consists of local bus and regional train lines. Until the mid-1980s all bus services in Plymouth were planned and operated by the MoP-owned bus company Plymouth Citybus. In 1985 the UK government deregulated the bus industry outside of London and created a free market for local bus service provision. Since then, "almost uniquely in the developed world, buses in Britain (outside London) have been organised on a predominantly commercial basis, with operators themselves deciding where to run and what to charge. Following that change, profitable routes and times of day were flooded with buses at the expense of other routes and times; services became unstable and confusing; the quality of vehicles fell and fares in many places rose sharply. Services which could not be run commercially, previously cross-subsidised from the profits of busier routes, now had to be supported by the taxpayer. The money available for this fell substantially over the last ten years, causing severe cuts to supported services." (Department for Transport, 2021). Bus use between 1986 and 2017 outside of London dropped by roughly 50%, while car use increased by more than 70%. Plymouth belongs to the group of cities described in this document.[32]

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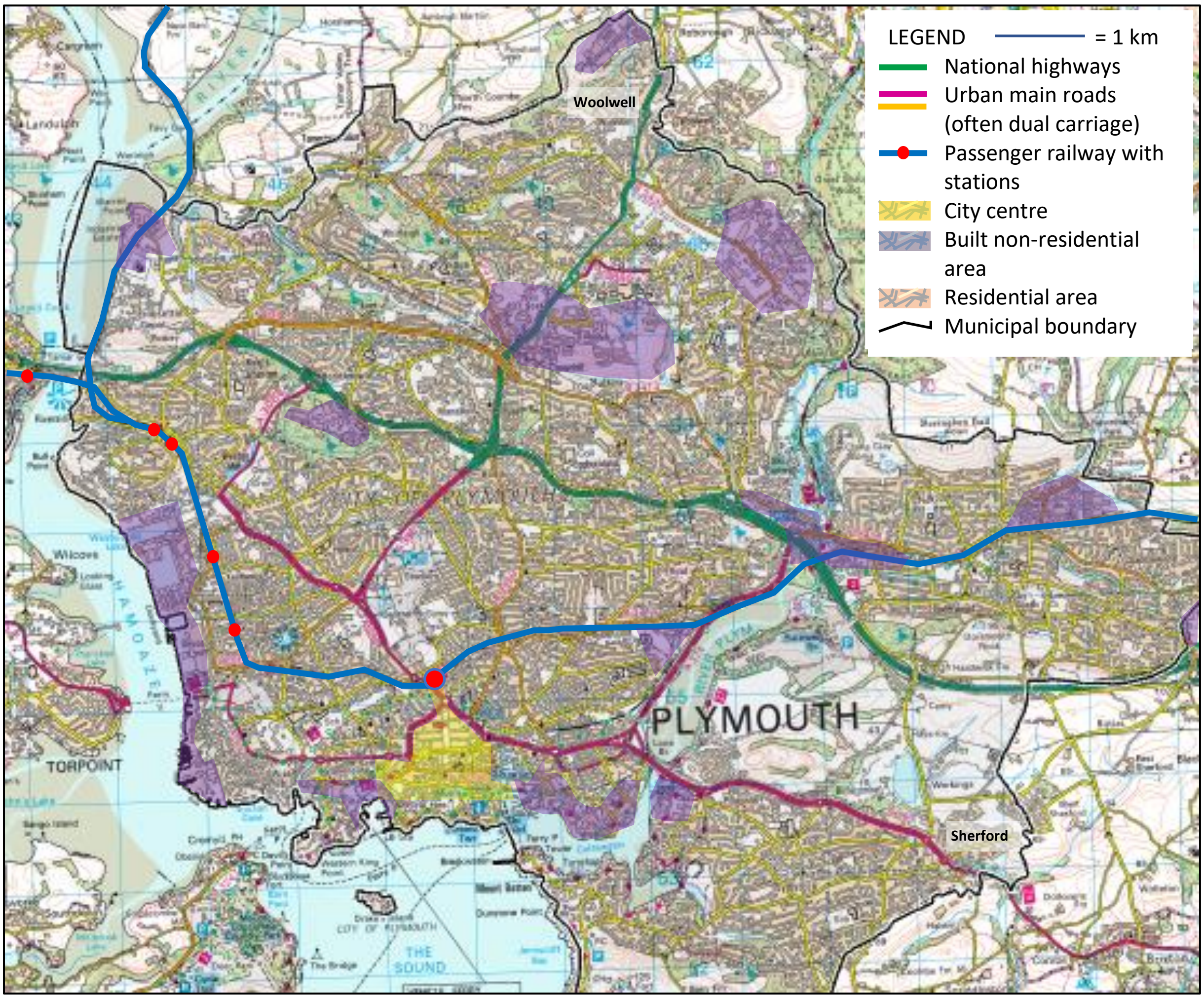
[32] None of this is to say that the MoP did not try to deliver improvements either alone or in partnership with the private bus service operators. For example in recent years, the city has renegotiated its bus shelter contract, which will result in the city's network of bus stops and shelters being renewed to a higher standard, with many including new real time journey information. The city takes opportunities to deliver improvements when and where we can, but these opportunities are limited and piecemeal.

Plymouth Citybus remained in council ownership but had to compete for passengers with new private sector bus service providers. In 2012 the MoP sold Plymouth Citybus to the Go Ahead Group for £12m. Plymouth Citybus remains the largest provider of bus services in the city and operates a comprehensive route network. Stagecoach Southwest is the second-largest bus service operator serving Plymouth. Most of its services connect Plymouth to towns in Devon and Cornwall. Although the city's bus network is comprehensive and bus services typically run throughout the day and evening from Monday to Friday, not all services run on Sundays and frequencies in the evenings and on weekends can be limited. MoP subsidises a small number of bus services (e.g. Sunday services that are not commercially viable and would not operate otherwise) on the basis of social need. Three park and ride sites are in operation from where travellers can switch from car to bus for onward travel to the city centre. Since 2000 bus patronage levels remained steady at around 19m bus journeys per year until 2020.

Regarding regional train, at its height, Plymouth's rail network had 32 stations and several branch lines. For various reasons, including the famous and large scale 'Beeching' cuts to the national rail network in the 1960s, the vast majority of these stations and lines no longer exist (for remaining lines and stations see following map). None of the lines are electrified.

Bicycling plays a very modest role in the city, although this is changing significantly, a result of improvements to bicycling infrastructure, and other measures such as the provision of free cycle training for children and adults.



3.2 Policies (DF, JG, EK, AvB)

3.2.1 Climate mitigation aim

When the project 2050 CliMobCity started, Plymouth's target was to reduce carbon emissions by 50% in the period 1990-2034, as documented in the *Plymouth Plan* (*PP*, MoP, March 2019) and the *Joint Local Plan* (*JLP*, MoP, March 2019) of Plymouth and neighbouring municipalities. Both plans have the time horizon of 2034.

Since the MoP's *Climate Emergency declaration* in March 2019 its target has been to achieve net zero carbon emissions by 2030 and it has subsequently produced a series of *Climate Emergency Action Plans* (*CEAPs*) (MoP, 2019, 2021, 2022) and a more recent *Net Zero Action Plan* (*NZAP*) (MoP, 2023) to drive decarbonisation efforts. This has become the climate aim for the project.

The local decarbonisation target is much more ambitious than the national one. However, national targets have also become more ambitious and in June 2019 the UK government introduced a law requiring the UK to reach net zero carbon emissions by 2050. Previously, the national target was to reduce carbon emissions between 1990 and 2050 by 80%.

3.2.2 Overview of mobility measure packages

The *PP* and *JLP* also set out the local transport policies and city measures intended to enable decarbonisation up to 2034. For the 2050 CliMobCity project the *PP and JLP* represent BAU policies. We call this the **JLP 2034 (BAU) scenario**.

In the framework of 2050 CliMobCity, Plymouth has defined a more ambitious measure package, referred to as the **UK Max scenario** which also covers the period up to 2034. The **UK Max scenario** includes "all known interventions, both physical measures and policy, …" "that have been applied elsewhere in the UK and go beyond BAU policies". The **UK Max scenario** "is a theoretical exercise and assumes that funding is available for each of the proposed measures, therefore monetary constraints have not been factored into the assessment" (WSP, 2021).

The CEAPs and newly published NZAP have the planning horizon of 2030, but contain concrete implementation measures only for the first few years (e.g. in the 2019-*CEAP* up to 2023) and otherwise mention planning activities that need to take place to identify further measures. The implementation measures show overlap with the **UK Max scenario.**

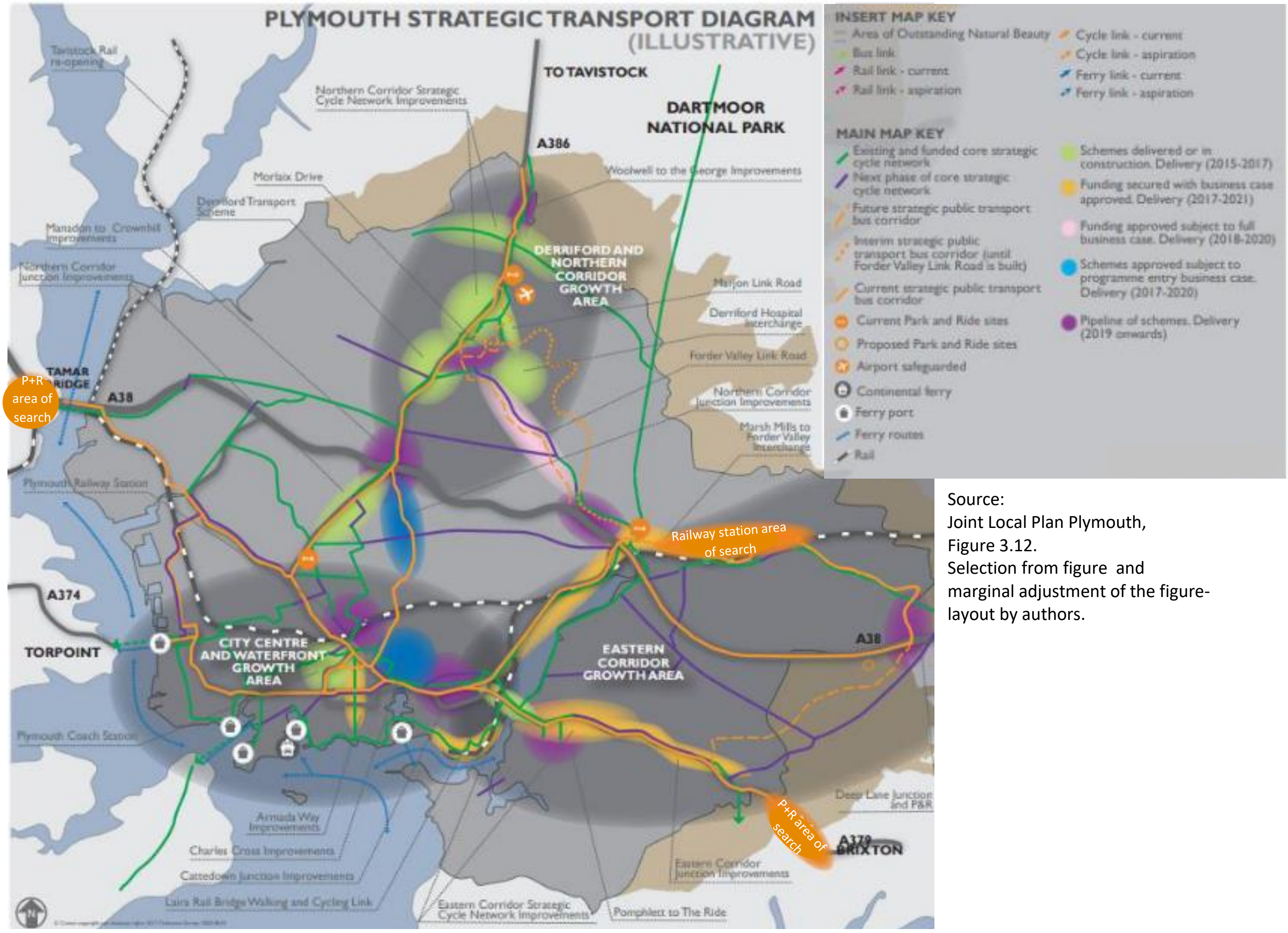
The demonstration in the 2050 CliMobCity project can be seen as a response to the need for identifying more measures. Two of the actions in Plymouth's Action plan for 2050 CliMobCity, to be conducted until end of July 2023, are about feeding back project findings that are useful for future strategic planning (e.g. successors of the *PP* and *JLP*) and for the update of the *CEAP and now the NZAP*.

In all scenarios the municipality's population is projected to grow from 263,000 inhabitants in 2015 to 298,000 inhabitants in 2034 which is 13% (= 0,7% per year). Although Plymouth only accounts for 4% of the JLP's land area, nearly 70% of the residents live in the city, now and in 2034.

3.2.3 Content of the BAU measure package

The *PP* and *JLP* both give an outline of **types** of measures relevant to mobility and spatial development, and of **directions** of future performance (e.g. "delivering a healthy city"), rather than identifying specific concrete measures to be developed, financed and implemented.[33] For instance, the plans strive for more modal shift to active travel and public transport, and the continuation of supporting a the High Quality Public Transport Network,[34] which is to connect "Plymouth's three Growth Areas", the City Centre and Waterfront, Derriford and the Northern Corridor and the Eastern Corridor (see following figure). There is the aim to investigate new rail stations along the existing rail line, and new P+R locations in the periphery of the municipality. Other policy areas are bicycle network development, pedestrian area development, parking regulation and pricing for housing (see three figures below) or other uses, or more charging infrastructure for electric cars.

The MoP is working with stakeholders to repurpose many city centre buildings into accommodation (apartments) and to develop a diverse, attractive leisure offer and night-time economy.



Source:
Joint Local Plan Plymouth, Figure 3.12.
Selection from figure and marginal adjustment of the figure-layout by authors.

For the transport modelling the measure types and directions needed to be concretised. Otherwise one can't model the future mobility. The modelling input for the **JLP 2034 (BAU)** consisted of:

- 5 measures to support public transport (e.g. bus lane or road improvement for train station);

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33 Funding for local transport investment in England is very centralised. Municipalities have few opportunities to independently generate significant tax or levy income for transport investment purposes and (other than funding for highway maintenance, which is reliably funded on a formula basis) are typically only able to secure transport investment funding by submitting competitive bids to an evolving array of purpose-specific national funding pots. This makes it challenging for municipalities to develop and successfully implement long term strategic transport delivery plans.

34 According to the *Plymouth Plan*.

- Almost 30 measures referring to junctions and roundabouts: change of slip lanes, upgrade signal light system, reconstruction roundabout the signalised junction v.v., allowance or prohibition of left or right turns; other capacity increase or traffic flow improvement; 1 to prioritise active travel;
- less than 10 measures referring to links: new ones or extra lanes. 1 to support Bretonside development (in the city centre).

Note, that this list also contains public transport measures, although we are dealing with an unimodal road (cars, LGVs, HGVs, busses) transport model. The impact of the public transport measures is expressed by introducing a modified origin/destination matrix describing the road trips between all areas in Plymouth and some surrounding municipalities.

3.2.4 Content of the CliMobCity measure package

Extending beyond **JLP 2034 (BAU)** policies the measure package that forms the basis for the **UK Max (CliMobCity)** modelling includes a wide range of public transport and active travel oriented measures

Type	Intervention
Bus	Bus gates at all viable locations
	Bus lanes along all viable links / lengths
	City-wide bus service improvements in line with 'Bus Back Better Guidance' following the Brighton example
	Park & Ride at Sherford
Rail	Devon Metro
Walking & Cycling	Implementation of undelivered routes on our Strategic Cycle Network
	Implementation of all routes in our Local Cycling and Walking Implementation Plan
	School Streets delivered across city
	Clean Air Zone across city centre, waterfront and key corridors?
	Bikeability in every school[35]
	Walk to School Programme
	Increased number of cars equipped with anti-collision capabilities, resulting in reduced collisions with cyclists
	Further increase in online shopping and deliveries from LGVs
	Plymouth to be one of governments 12 'Mini-Holland' funding (Gear Change report)
	Improved cycle parking at rail stations
	Low Traffic Neighbourhoods
	Buses that carry bikes (Go Ahead subsidiary East Yorkshire)
	Closing street to through traffic (Hackney Council)
Electric vehicles	New Council Staff Travel Policy to encourage sustainable business travel
	Mobility Hubs including EV charge points, e-bike charge points, and e-car club cars
	Assume as many charge points per capita as the best local authority
	Replacement of (fossil fuel) bus fleet with battery and fuel cell electric vehicles
	Introduction of public e-scooter hire facility
Behaviour change	Promote / provide free eco-driving training
	Plymotion continues at increased scale
Parking	Increase council parking charges
	Clear Air zones with charges for non-compliant vehicles
	Workplace Parking Levy based on Nottingham model
Other	e-Car club
	20 mph *(ca. 30km/h)* speed limits on all residential streets

Source: WSP (2021).

[35] Bikeability is a nationally recognised programme of bicycle proficiency training for children, typically delivered in schools (though this is not delivered in every school in the country).

as the table above shows.[36] There are 4 bus, 1 rail, almost 15 active travel, 5 electric vehicle, 2 behavioural change, 3 parking, and 2 traffic flow measures. One of the bus measures refers to the Brighton example of the delivery of national "Bus back better policies", and is itself actually already a measure package. Its aim is to increase bus use back to or beyond the levels since 1986, the year of bus deregulation in the UK.

Regarding rail, "Devon Metro" in the Plymouth region involves the reinstatement of the Tavistock to Plymouth branch line (see following figure). Projected service intervals are eventually hourly, and travel times are shorter than by car, relieving traffic on the parallel highway route and reducing carbon and other emissions, assuming that rebound effects can be avoided.

The figure also shows changes in the road network like introducing a maximal speed of about 30km/h on residential streets, the lowest level in the road typology.

Source: ↑
Turner (2019)
Red circle and turquoise box added by authors.

Source: →
Heart of the South West Local Transport Board (2013 and 2016)

3.2.5 Towards post-fossil fuel vehicles (JB, EK, FR)

Plymouth and other English cities and the national policy with regard to replacement of fossil fuel by post-fossil fuel cars and vans focus on electrification.

The MoP has a number of transport and planning policies in place that are supportive of the transition to post-fossil fuel vehicles. However, the city has not, so far, published any targets or projections for this transition in any public-facing policy / strategy documents. The MoP is currently commissioning consultants to produce an *Electric Vehicle Charging Infrastructure Strategy*. This work will start in August 2023 and is expected to take 3 to 4 months to complete. Its outputs will generate forecasts of future EV uptake / demand and EV charge point infrastructure requirements and delivery models / pathways in Plymouth.

[36] They are described in a note developed by the MoP and its modelling consultant (WSP, 2021).

At the national level, the report *Taking charge: the electric vehicle infrastructure strategy* (UK Department of transport, 2022) states: “By 2030, we estimate that up to 10 million vehicles, up to a quarter of all cars and vans, will need to be zero emission at the tailpipe. Some scenarios predict even higher levels of adoption to meet carbon targets. For example, UK’s Committee on Climate Change (2020) estimates that battery electric vehicles will comprise 27-37% of the car and van fleet by 2030.” These values lie between the values of the EU Reference and the Tech scenarios (see following table).

	EU reference				Tech				
	% BEV cars	% Hydrogen cars	% Together	% Fossil fuel remainder		% BEV cars	% Hydrogen cars	% Together	% Fossil fuel remainder
Plymouth, 2015	1	0	1	99	Plymouth, 2015	1	0	1	99
Plymouth, 2034	13	5	18	82	Plymouth, 2034	39	17	56	44
Plymouth, 2050	31	13	44	56	Plymouth, 2050	66	28	94	6

On the way to such replacement levels the share of post-fossil fuel vehicles in the total of purchased road vehicles is frequently highlighted. “In November 2020, the Prime Minister put the UK on course … to decarbonise cars and vans, announcing that all **new** petrol and diesel cars and vans will be phased out by 2030” (Department of Transport, 2022; highlighting by authors). MoP monitors data on the purchase of electric vehicles. In 2019 MoP commissioned Exeter University’s Centre for Energy and the Environment to produce a report called *Carbon Neutral Plymouth* (Lash et al., 2019). A recent draft update of the study observes that the development of the market share of post-fossil fuel cars is on an exponential trajectory. Assuming it is justified to extrapolate that course, a 100% post-fossil fuel car purchase will be reached in 2035, which is slightly later than the UK aim. Acceleration of the post-fossil fuel replacement is needed, as the extrapolation of the exponential trajectory might transpire to have been an optimistic assumption.

3.3 Expected change of mobility in the city (DF, EK, AvB)

3.3.1 Approach

In order to estimate some of the mobility effects of the **UK Max (CliMobCity)** measure package, an adapted *SATURN Highway Assignment Model* (WSP) has been applied. The model capability is limited to:

- the assignment of vehicles to routes. The preceding three steps, typical for a 4-steps transport model (modelling of the production/attraction per area, geographical distribution of trips, modal split modelling) are absent.
- road transport, distinguishing cars, busses, light duty and heavy duty vehicles.[37] It is not a multimodal demand model and provides no data about non-road mobility.

The input to the assignment model is a description of the road network and a set of trips of which the origins and destinations are known, the so-called origin destination table.[38] The model then assigns the trips specific routes. There are origin destination tables and assignments for the base year, the **BAU scenario** and the **CliMobCity scenario**.

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37 These vehicle categories are not modelled separately, but derived from splitting road volumes predicted by the model.

38 The road origin-destination table for the base year describing the geography of the base year set of trips, is produced on the basis of local mobility surveys. The origin destination table for future years is produced by combining the base year table with nationally published growth rates and using nationally published future mobility production and attraction values for small areas in the UK.

The model focusses on road transport. The effects of shared cars and micro-mobility are not sufficiently known yet, and not yet well incorporated into transport modelling. The shift to post-fossil fuel vehicles is taken into account in the subsequent analysis of the reduction of CO_2e emissions.

In the **CliMobCity scenario** modal shift to other modes than car mobility is one of the objectives. This modal shift can be reflected by artificially reducing the number of trips in the road origin destination table.
To this end consultants have:

a) first derived modal shares for the base year from Census 2011 data about travel to work shares in Plymouth;
b) then for certain measures estimated the magnitude of modal shifts impacts. The following table shows these estimates: for instance, the share of bus trips increases 4.6 %-points because of improvements in bus services, 0.3 %-points due to Plymotion, and another 0.33 %-points due to other policies, together 5.23 %-points. The share of car trips declines by 14 %-points, with all measures contributing to this in different amounts;
c) then used the difference between old and new road shares to determine the change of the number of car trips between the base year and the **CliMobCity scenario**;
d) then changed the origin destination table in corresponding amounts, and corresponding with the types of measures involved. This led to more modal shift for Plymouth-internal mobility than for mobility from and to Plymouth and to more modal shift for the central area of the municipality than for other parts of the city.

Before assigning the trips of the new **UK Max (CliMobCity)** origin destination table to routes, minor adjustments to the model road network were also made, reflecting the road measures. An example is closing a street for through traffic or the improvement of road junctions.

For a more precise follow-up analysis, all modal share results, trip volumes of non-road modes would require validation by advanced modelling. This work was beyond the scope of this project.

The described approach for the modal shift applies for the **CliMobCity scenario**. Although it would be reasonable to assume that part of this modal shift already emerges in the BAU scenario, no modal shift in the **BAU scenario** was specified. Therefore in the CO_2e analysis all modal shift will be assigned only to the **CliMobCity scenario**.

Modal shift between 2015 and 2034 (UK Max) (Source: *MoP, WSP, 2022*)

		% Decrease	% Increase				
Initiative	Modes to benefit	Car Trips	Bus	Trains	Cycling	Walking	Other
Bus Improvements	Bus	4,60%	4,60%	0,00%	0,00%	0,00%	0,00%
Walking and Cycling Improvements	Cycling	5%	0,00%	0,00%	3,75%	1,25%	0,00%
New Council Travel Policy	Walking / Cycling	1%	0,33%	0,00%	0,33%	0,33%	0,00%
Mobility Hubs	Other	1%	0%	0%	0%	0%	1,00%
Plymotion at Your Doorstep	Walking / Cycling	1,20%	0,30%	0,30%	0,30%	0,30%	0,00%
Workplace Travel Grants	Walking / Cycling	1,20%	0,00%	0,00%	0,40%	0,40%	0,40%
Total		**14,00%**	**5,23%**	**0,30%**	**4,78%**	**2,28%**	**1,40%**

The description of current and future mobility in the following sections focusses with regard to trips on the flows in, from and to the city, and with regard to vehicle-kms and passenger-kms on all trips (including trips through Plymouth). The consultancy firm provided model output information about (the spatial pattern of) road trips, road trip-kms, road vehicle-kms and road trip times, distinguishing types of roads and types of road vehicles. Concerning the trips from and to Plymouth the consultancy was not able to distinguish the trip part taking place within the municipal area or outside. As a result, the vehicle-kms and travel time communicated to the project are larger than they should be according to the geographical approach the project applies for the carbon analysis (see chapter 1). As, also, no distance information could be provided to the project, it is difficult to correct the vehicle-kms and travel time to the desired level.

Attempting to estimate the scale of difference at stake, the project consulted the origin destination matrix. It shows that the car trips from and to Plymouth represent 26% (2015) to 32% (**UK Max, CliMobCity**) of all car trips in, from and to the city.[39] From a rough estimation of involved distances inside and outside of Plymouth, one might expect that total vehicle-kms or travel time relevant for the CO_2e analysis should be up to 15% to 20% less than what was reported, but the range is uncertain.
Without having sufficient certainty about the needed reduction, the project decided to stick to the provided data. As the changes of mobility CO_2e emissions are not presented in absolute terms, but in relative terms and as the trips to and from Plymouth are only a smaller part of all trips, the shown changes may resemble those if trip parts outside of the municipal area were excluded.

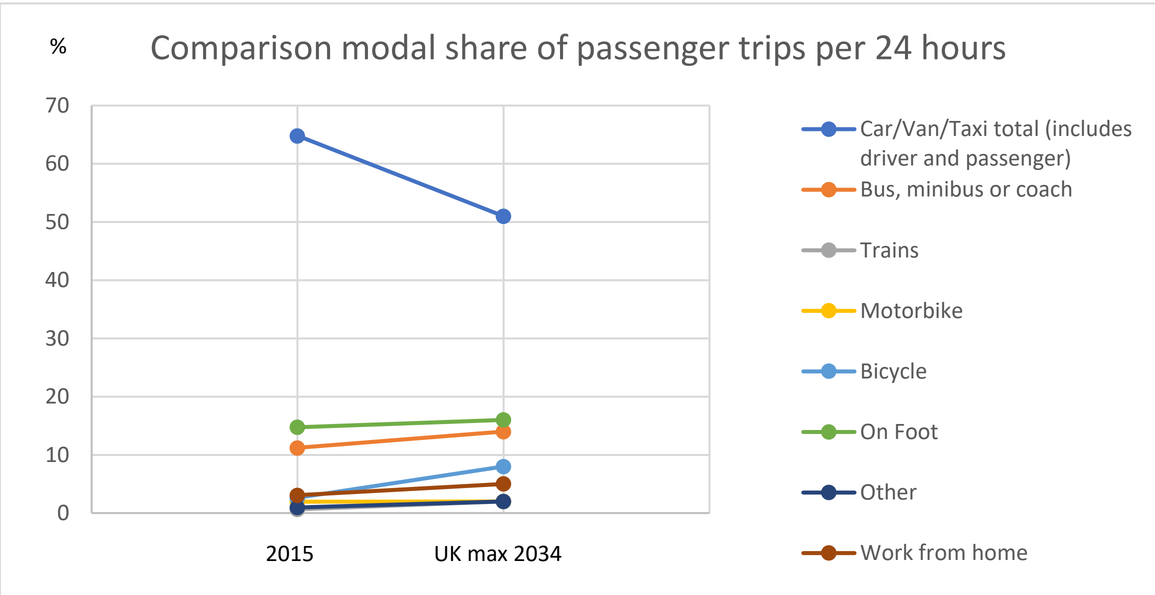
3.3.2 Outcomes of the mobility forecast: BAU and 2050 CliMobCity

(**Car trips in, from and to Plymouth**)

- While the population growth in the period 2015-2034 is projected to be 13%, the total number of *car* trips in, from and to the municipal area increases by 22% (**JLP 2034, BAU**) or only by 4% (**UK Max, CliMobCity**).[40]
- The number of trips of all modes together is not indicated by the model, but does increase.[41]

(**Modal share** expressed in trips)

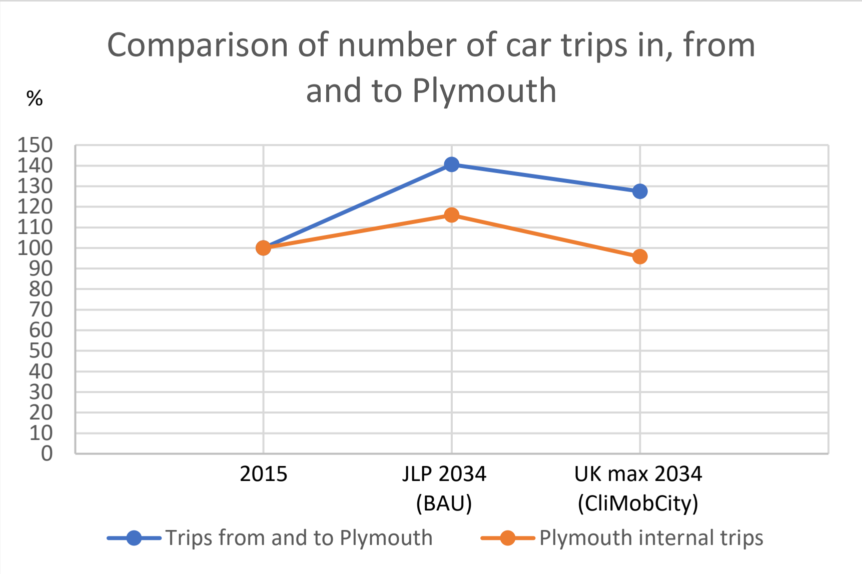
- The share of car trips declines by almost 15 %-points. The winners are bicycling (+5 %-points), trips by bus (+4 %-points), walking (+2 %-points), trips by "other" modes (each about +1 %-point) in the **CliMobCity scenario**.



[39] Or 22% (2015) to 25% (UK Max, CliMobCity) of all car trips in, from, to and through the city.
The increase is (BAU): 16% (internal), 41% (from/to), 54% (through), 27% (total incl. through), and (CliMobCity): -4% (internal), 28% (from/to), 46% (through), 11% (total incl. through).
[41] This conclusion comes from calculations combining the predicted car trip development and modal shift estimates.

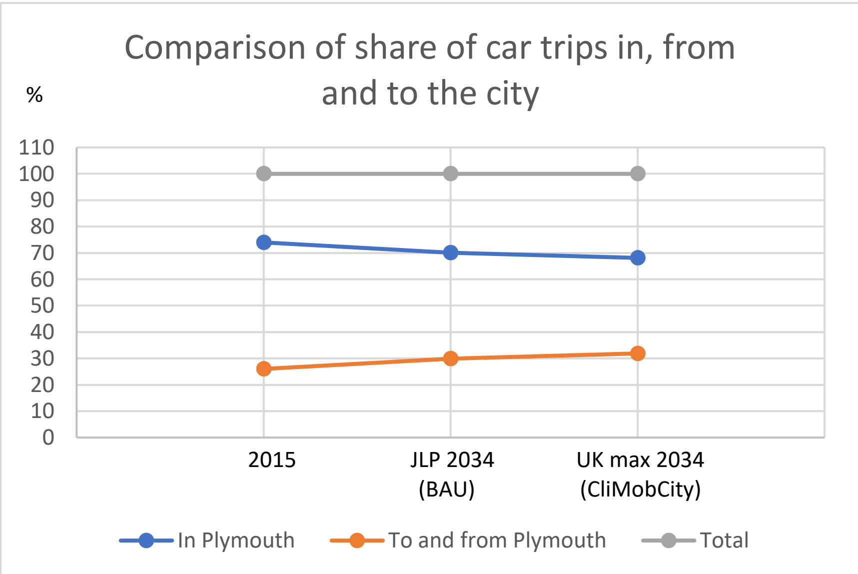
(**Average distance**)

- The transport model employed can't, as is explained, provide the average distance of passenger or vehicle trips.
- The shares of Plymouth-internal car trips (namely 74% of trips in/from/to Plymouth[42]) and their growth rates (see following figure) indicate that average distance is increasing: the growth rates are larger for trips from/to Plymouth which are very likely to have a longer average distance than



This type of presentation supports understanding of the relation between different results (dots).
But be aware of that:

- the line between the base year dot and BAU dots represents a developments in time;
- lines between BAU and CliMobCity dots serve the comparison, but don't represent developments in time.

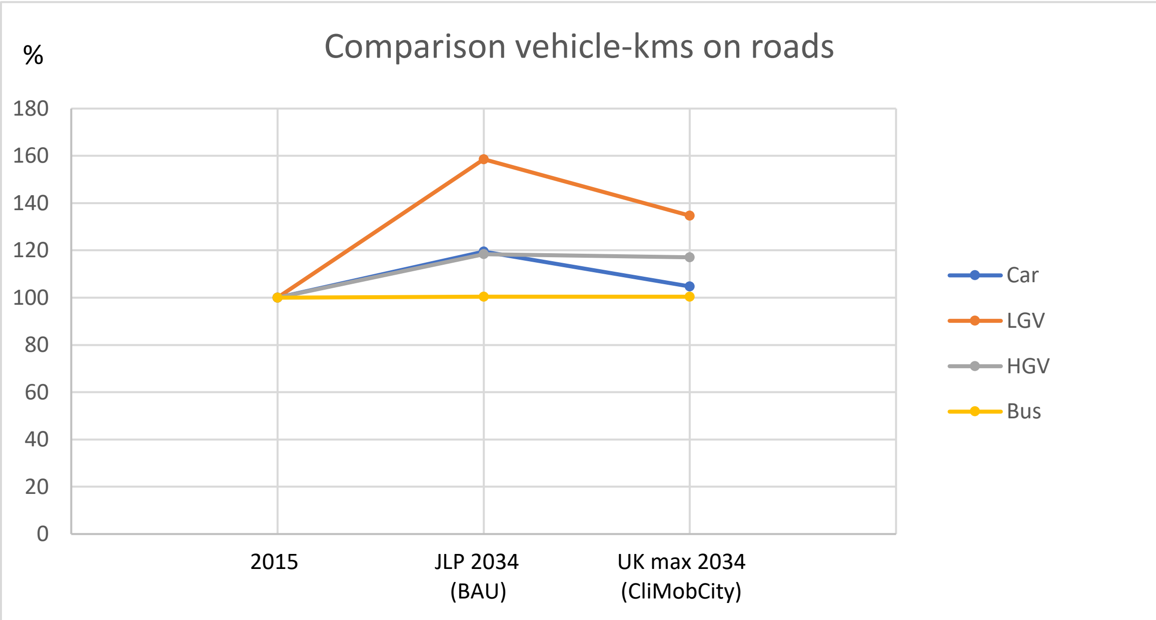


[42] Or 62% of all trips including throughgoing trips.

the internal trips do. The trips which may be expected to have longer average distances than the Plymouth internal ones and which have even higher growth rates than the trips from/to Plymouth, underline the trend of increasing average car distance. [43]
For the **CliMobCity scenario** a large part of distance increase is caused by the modal shift taking place. The shift is larger for Plymouth-internal trips than for other trips, and within that larger in the central area of the city than in other city parts. This can be concluded from comparing the car trip pattern for 2015 and the **CliMobCity scenario**.

(Vehicle-kms and passenger-kms[44] in, from, to, through Plymouth)

The kilometrage (per hour) of road vehicles increases from 2015 to 2034: for cars +19% (**BAU**) or +5% (**CliMobCity**), for LGVs a (staggering) +59% (**BAU**) or 35% (**CliMobCity**) and for HGVs +18% (**BAU**) or +17% (**CliMobCity**). Bus-kilometrage remains unchanged in both scenarios.



(Traffic impacts)

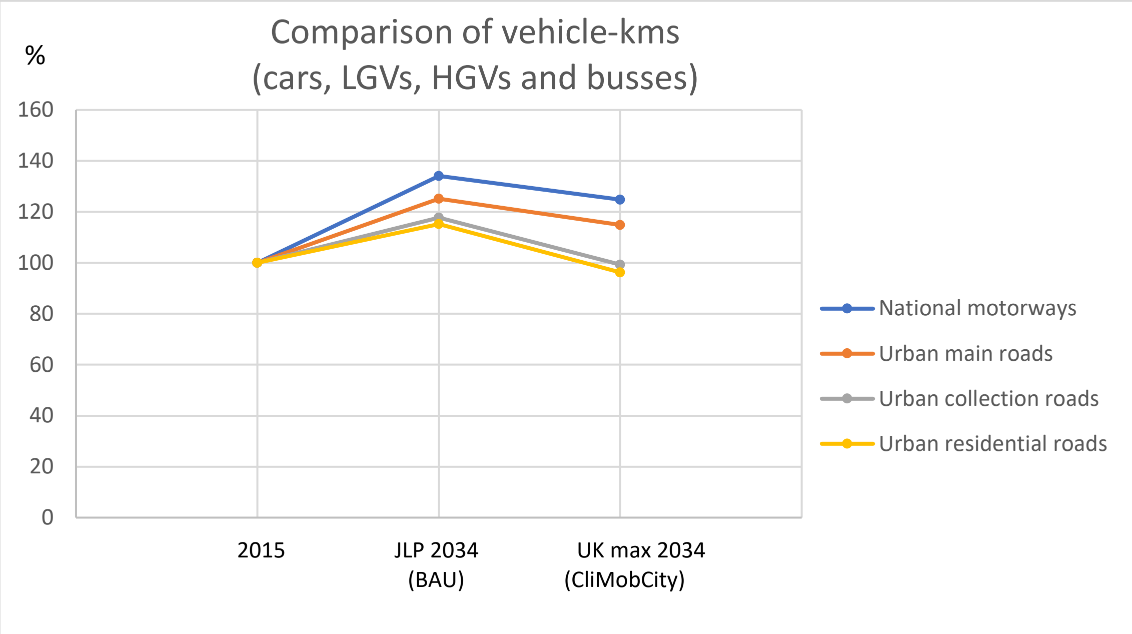
- There is a large increase of vehicle-kms between the base year and 2034, larger for **BAU** than for **CliMobCity**, for all road types, national highways showing the largest increase (+34% in **JLP 2034 [BAU]** and +25% in **CliMobCity**), residential roads the smallest one (see following figure). The modal shift from road to other modes in the **CliMobCity scenario**, mainly expected to take place within Plymouth and in particular in the more centrally located areas, implies a (near to) zero change of vehicle-kms between 2015 and 2034 on collection and residential roads.
- Traffic speed slightly changes. On highways a modest decline of average vehicle speed is expected between the base year and 2034. The decline is larger in the **BAU scenario** (5%) than in the **CliMobCity scenario** (3%). On urban roads, junctions are crucial for traffic flow, the average junction V/C (V = volume[45]; C = capacity = maximal volume) and queue lengths are key indicators. From the base year to 2034 the junction V/C increases by 15% (BAU) or stays the same (**CliMobCity**). A similar picture applies for each specific road types except for collection roads in where the average junction V/C declines towards 2034, less in the **BAU** than in the **CliMobCity**

[43] Such conclusions from the O/D-matrix of trips are, however, not confirmed, when comparing the development of the trips with the development of the people-kms or car-kms. Concluding, with regard to distance development there is no or only very uncertain output available.

[44] The growth rates of both are the same according to the model.

[45] Actually: intensity = number of vehicles passing per hour or other unit of time.

scenario. Queues are significantly longer in the BAU scenario, and slightly longer in the **CliMobCity scenario** than in 2015.



A rough interpretation of the results

- The number of car trips from/to/in Plymouth increases substantially (22%) between 2015 and **BAU**, but the increase is only 4% in **CliMobCity** despite of a 13% population increase.
- The shift of passenger trips from car to other modes in the UK max scenario mainly takes place in Plymouth's central area and for trips with shorter distances.
- Deviating from the preceding bullet, the Tavistock to Plymouth rail line project impacts longer local public transport trips. The shift from car to train trips correspondingly reduces car-kms considerably, some of which occurs in the Plymouth area. The trains are not expected to become electric. The reduction of CO_2e emissions will therefore be less than would be the case for (battery) electric trains.
- The **CliMobCity scenario** leads to less growth of road vehicle-kms than the **BAU scenario** does: still car-kms increase by 5%. For HGVs the growth in **CliMobCity** is 17% and for LGVs (vans etc.) even higher. These data representing the central input for the analyses of CO_2e emission must be understood as a first rough indication as they (e.g. for trips from/to Plymouth) include the vehicle-kms driven outside of the municipal area. This deviates from the intended geographical approach of the CO_2e analysis (see Introduction chapter).[46]
- This all gives reason for reflection, knowing that the reduction of fossil fuel road vehicle-kms is the central metric relevant for energy consumption and CO_2e emissions, and knowing that fossil fuel *vans* compared to other fossil fuel *trucks* emit the most CO_2e per ton-km of freight. To achieve the climate aim there must either be more behavioural measures for personal mobility and logistic innovation to reduce carbon emissions from road vehicle-kms, or CO_2e reduction will largely depend on the electrification of road (and train) vehicles or switching to other post-fossil fuel vehicles.
- Regarding electrification etc., the MoP currently has no formal targets regarding future shares of post-fossil fuel cars in the city's car fleet. Based on external scenarios (EU Reference, Tech) the share of fossil fuel cars may still lie between 82% and 44% in 2034, meaning a decrease in the

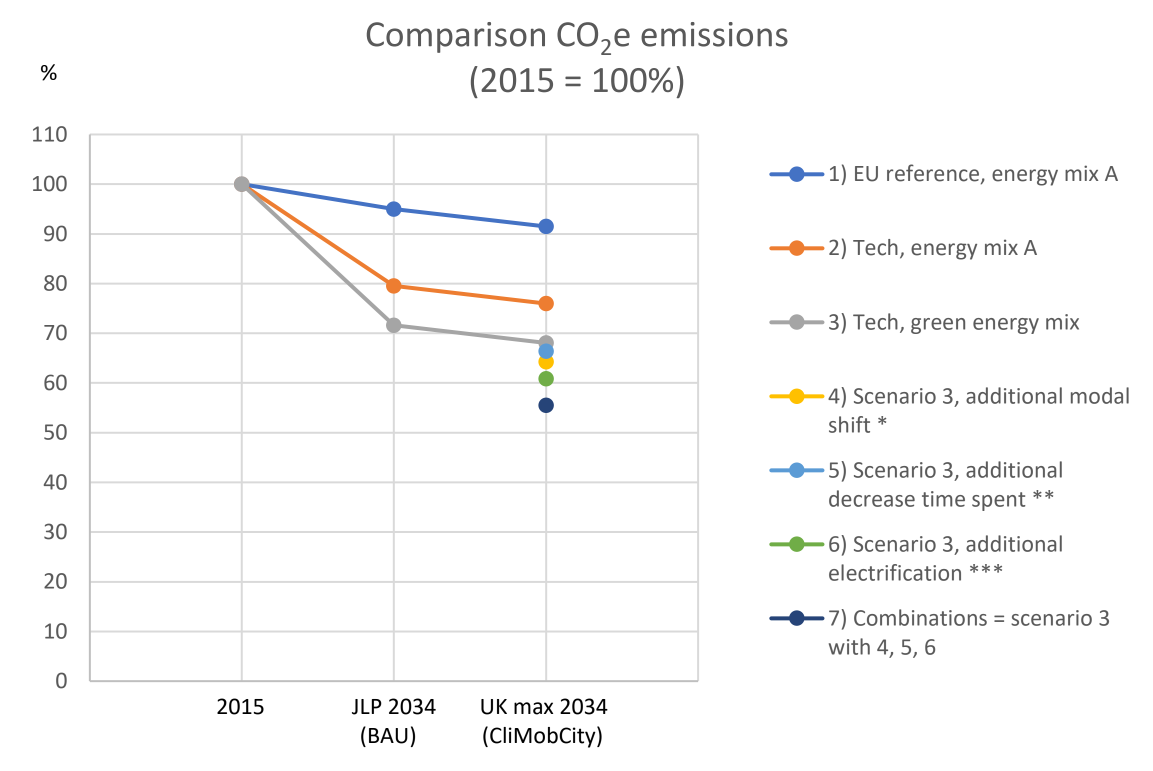
[46] Vehicle-kms limited to the municipal area could not be provided.

share of fossil fuel car of 17 to 55 %-points in comparison to the base year. The associated CO_2e reduction will be less given the energy mix of electricity production in 2034.

- The growth of vehicle-kms on national highways and urban main roads tends to increase problems at notorious congestion points. Nevertheless, the general picture is that traffic flow remains relatively stable on all road types.
- The prediction of future mobility in Plymouth is characterised by the absence of a multimodal transport model. The result is that – despite of the well-argued shift – there is little certainty about the extent the assumed modal shift would be backed by mode choices on the basis of comparative mode performances. Validation by improved approaches would be likely to add knowledge relevant for future decision-making.
- As already indicated, the transport modelling does not show the effects of measures entailing shared cars and corresponding mobility hub nodes on future mobility.

3.4 Analysed reduction of CO_2e emissions[47] (FR, EK, AvB)

From 2015 to **JLP 2034 (BAU)** car-kms and HGV-kms increase by almost 20%, LGV-kms by much more. Without shift to post-fossil vehicles this would mean an increase in CO_2e emissions as well. However, there is some shift to post-fossil vehicles: in the EU reference scenario the share shifts from 1% in 2015 to 18% in 2034. This provides a decline of CO_2e emissions of 5% (see blue line in the following figure).



* Share of cars and other LDVs: -10 %-points; of public transport busses and active travel: each +5 %-points.
** 10% less time spent, because of less road vehicle-kms and/or more fluent traffic flow.
*** Share of post-fossil fuel vehicles: +10 %-points at the dispense of the share of fossil fuel vehicles.

This type of presentation supports understanding of the relation between different results (dots).
But be aware of that:

- lines between the base year dot and BAU dots represent alternative developments in time;
- lines between BAU and CliMobCity dots serve the comparison, but don't represent developments in time.

[47] For a more detailed description of the results and approach of the CO_2e analysis see the Appendix-PIK-report.

In the **UK Max (CliMobCity)** scenario the volume of car- and other motorised vehicle-kms declines compared to 2015, and the CO_2e reduction is larger, namely 9% (still along the blue line = EU reference scenario), than in **BAU**.

If the replacement of fossil fuel by post-fossil fuel vehicles takes place more quickly, as in the Tech scenario (the share of post-fossil fuel vehicles reaching 56% in 2034), larger CO_2e reductions can be achieved. The CO_2e emission then from 2015 to **UK Max (CliMobCity)** then declines by 24% (orange line).

If also all electricity was produced renewably, the CO_2e emissions in between 2015 and **UK Max (CliMobCity)** would decline by 32% (see grey line in the following figure). The still remaining CO_2e emission level would be 68% of the 2015 level.

Experimenting with the levers in the carbon model in a **forecasting** what-if fashion shows that:
- (overall scenario 4) additional modal shift (share cars -10 %-points; bus + 5 %-points, active travel +5 %-points) provides another 4% CO_2e reduction;
- (overall scenario 5) 10 % additional reduction of the "time spent" (= arising from shorter distances) provides another 2% CO_2e reduction;
- (overall scenario 6) additional share of post-fossil vehicles of 10 %-points provides another 7% CO_2e reduction;
- (overall scenario 7) the combination of additional measures together provides a further 13% CO_2e reduction in comparison to scenario 3.

CO_2e emission in 2034 after these lever exercises is on the level of 55% of the 2015 emissions, barely half way towards the MoP's target of climate neutrality by 2030.[48]

All of these changes take place in the context of a growing population. The percentage **reduction** of CO_2e emissions **per capita** is 7 to 11 %-points higher than the total CO_2e percentage reduction, dependent on the scenario. This development is not shown in the following figure.

The emissions **remaining** after overall scenario 7 (55% of the 2015 emissions) are composed as follows: car 54%, HGV (e.g. trucks) 35% and public transport busses 11%. Closing the remaining gap would/will still require the planning and implementation of a whole set of additional, powerful measures to reduce the number of fossil fuel road vehicle-kms and average travel distance. We discuss major options in the last chapter of this report.

For all CO_2e results one should keep in mind that they are based on vehicle-kms including the part of the trip (e.g. a trip from/to Plymouth) driven outside of the municipal area which deviates from the geographical approach followed in the CO_2e analysis. The index results are therefore only a first indication of emission (changes).

As already mentioned, the transport modelling does not show the effects of measures entailing shared cars, micro-mobility services and corresponding hub nodes on future mobility, which may have the potential to substantially reduce CO_2e emissions of mobility. But whether this is likely, it is not sufficiently validated by research yet and certainly depends on the context of implemented concepts. We briefly also discuss this in the last chapter of this report.

[48] One immediately needs to emphasize that the mobility forecasts and CO_2e analysis refer to all mobility in Plymouth, but also include the distances of travellers from and to Plymouth covered outside of the municipal area, as mobility data limited to the municipal area could not be provided to the project. For the absolute results of carbon reduction this makes a difference. For the relative values presented in this chapter the difference will be rather small, as the municipal measures will to a larger extent also effect the kms driven outside of the municipality.

3.5 Feedback from the municipal reflection on the CO_2e reduction (DF, JG)

The UK Max scenario envisages the simultaneous, rapid, planning and implementation of all local transport interventions (30 physical and local policy measures altogether) in Plymouth that have been implemented at least once in the UK and that would, by a variety of means, aid in the decarbonisation of mobility in Plymouth.

Against the backdrop of very limited success to date in decarbonising mobility (despite this being an explicit national and local policy objective for around two decades), this deliberately ambitious theoretical exercise provided an unusual and valuable opportunity to assess the potential for the wide array of local measures currently delivered and deliverable in the UK to achieve decarbonisation of mobility at the scale needed to meet the city's decarbonisation target.

Given the sheer number and range (and in some instances, scale) of measures included in the UK Max scenario, model outputs indicating significant per capita carbon reductions were anticipated. Equally, however, the preponderance within the UK Max package of measures intended to improve the attractiveness of the sustainable modes 'offer' alongside the relative scarcity of measures available to UK local authorities that would serve to deter the continued predominant use of private internal combustion engine car use (by impacting on their speed, geographical access or cost of use), informed an expectation that the results would show that the UK Max measure package, while ambitious, would nevertheless prove insufficient to enable our decarbonisation target to be met. Consequently, model outputs suggesting a per capita CO_2e reduction of up to 20% are within range of expectations and seem plausible, if mobility measures as in UK max show the expected mobility change. If also the electrification of cars can be accelerated, a per capita reduction of perhaps 35% may belong to that range.

The CO_2e model results are also sobering: through the CliMobCity 2050 project it has been established that an extremely ambitious measure package which MoP, in common with other UK municipalities, has no immediate prospect of having the funding or organisational capacity to fully deliver in the necessary timeframe would only take the city around one third of the way towards achieving its decarbonisation target.

Consequently, responding to comparable preliminary CO_2e modelling outputs in 2022, MoP was determined to comprehensively exploit the many and diverse learning opportunities and insights that have arisen from participation in the 2050 CliMobCity project through site visits, seminar presentations, and the mobility and carbon modelling outputs to bring forward new or improved concrete measures or improvements to our policy instruments.

In addition to an Action Plan (AP) action relating to the construction of Plymouth's Mobility Hubs network (launched in March 2023), this resulted in an AP action to '*systematically assess other projects explored / showcased within the 2050 CliMobCity project*' for potential delivery in MoP both during and beyond the AP delivery period. It also resulted in an AP action to '*fully leverage the findings of Plymouth City Council's 2050 CliMobCity mobility and carbon modelling work in the forthcoming formal policy review of the JLP*' in pursuit of concrete improvements to our policy instrument via a formal, multi-stage policy review process that will be vital if we are to close the gap between MoP's current mobility carbon emissions trajectory and our Climate Emergency goal to achieve net zero by 2030.

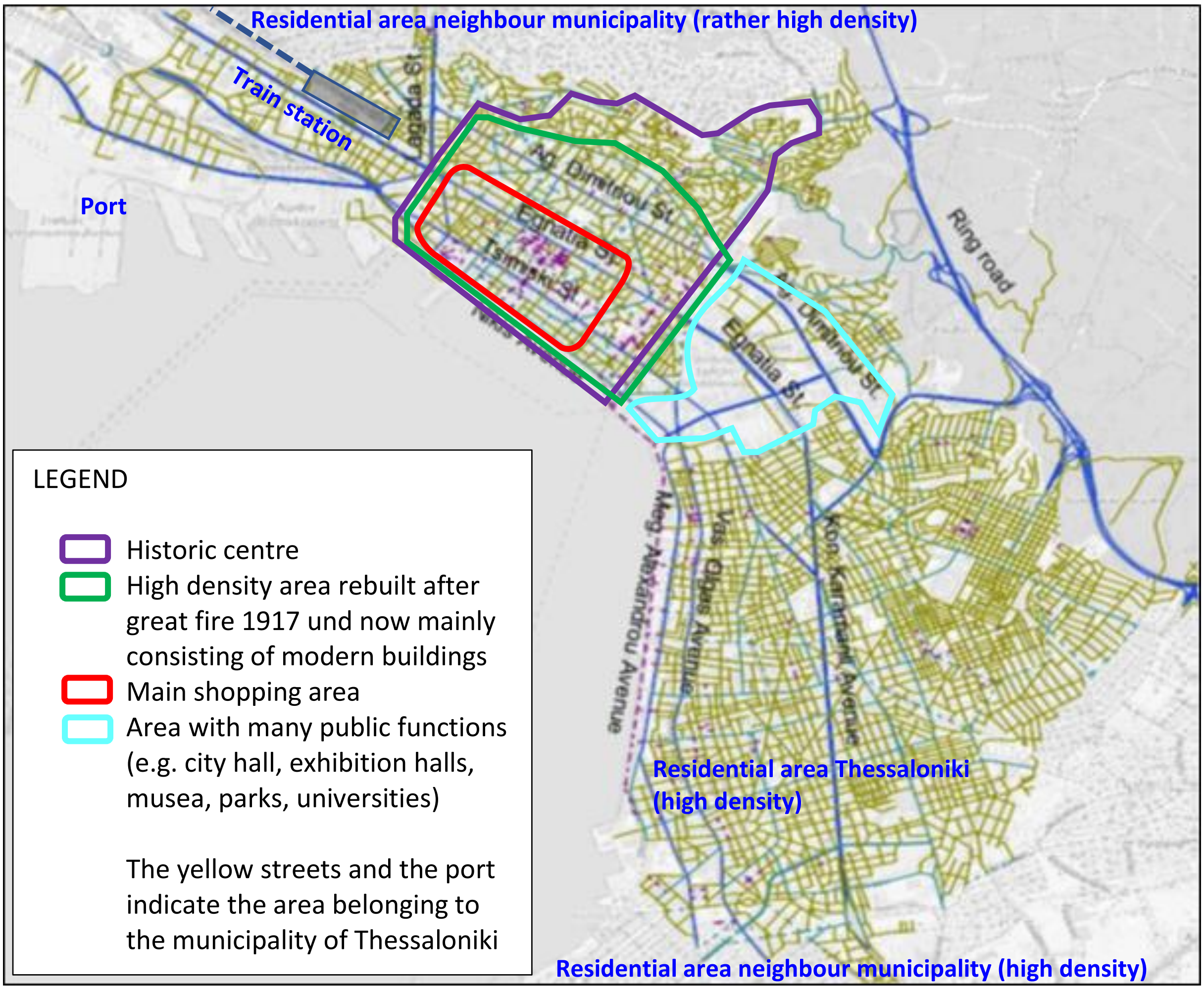
4 THESSALONIKI: Measure packages, change of mobility and of CO_2e emissions

(MoT = Municipality of Thessaloniki)

4.1 Current situation and backgrounds (PA, MM, RK, GP, EK, AvB)

The Municipality of Thessaloniki (MoT) is the second largest municipality (313,000 inhabitants in 2018) of Greece, behind Athens and before Patras
, and is the capital of the region of Central Macedonia. It is the central city of the officially defined “Urban area Thessaloniki” (= area of the MoT plus 7 neighbouring municipalities, together having 0,8 million inhabitants) and “Metropolitan area” (1,3 million inhabitants). Thessaloniki has an industrial fundament, but three quarters of employment are in services, mainly trade, but also tourism, education and transport. Its port, the second in the country, serves the city and northern Greece and has a gateway function to southeast Europe.

A large photograph from end of the 19th century in the city hall documents the city’s turbulent history: one can see monuments dating back to the Roman empire, a forest of minarets added to the large number of byzantine churches during the Ottoman rule, and 1- to 2-story high buildings moving up from the coast to the castle hill, all surrounded by a high and long city wall. The great city fire of 1917 destroyed much of this. The city was rebuilt along a new city plan, introducing broad boulevards parallel to the coast, and like 4 stories high (plus ground floor) art-nouveau buildings. The boulevards and historical monuments still exist, but during the 1950s to 1970s most buildings have been replaced by modern often 8-story high residential, office and hotel buildings, still with narrow streets now connecting the boulevards. Also outside the city centre building substitution took place,

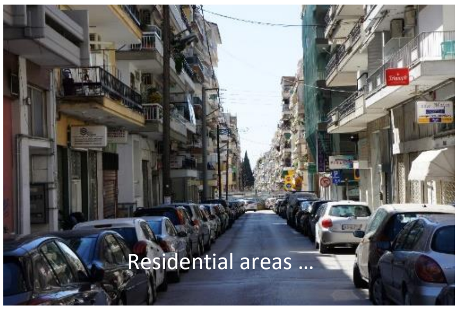



Thessaloniki in 1873 (Photograph in the City hall)

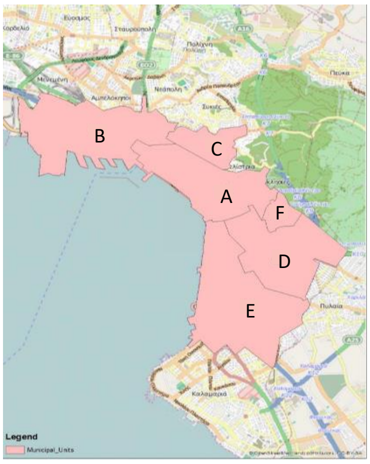

Boulevard (Egnatia Str.) in the city centre


Old historical structure on the hill


Waterfront of city center

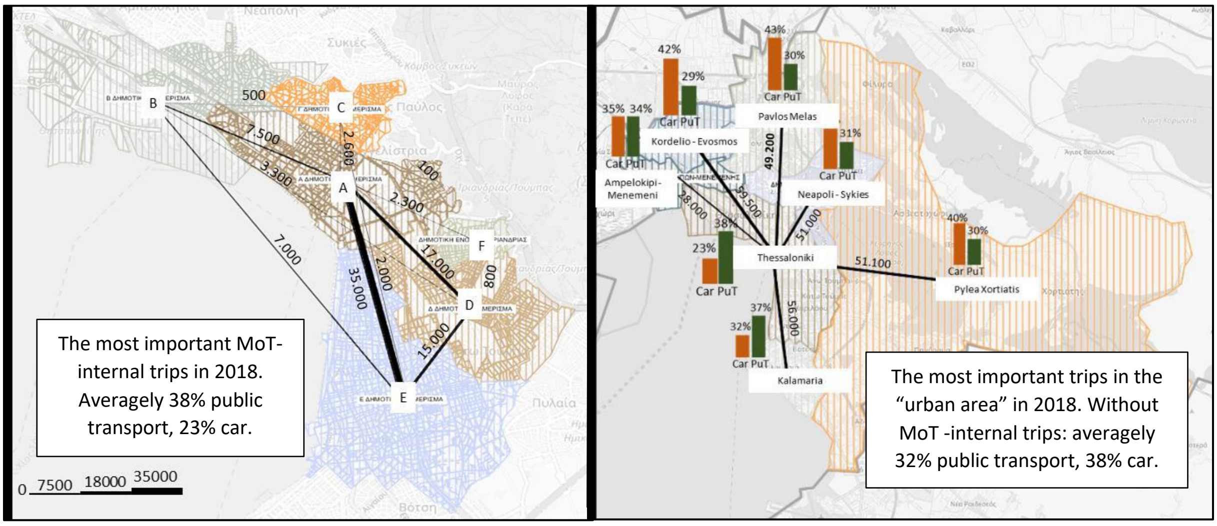

Residential areas …


… outside of the centre



resulting in compact areas with buildings often having 4-6 stories. In total Thessaloniki has a high building and residential density, averagely amounting to about 160 residents/ha (based on Census 2011), in some areas of the MoT (C, D, E in the map to the right) even to above the 200 residents/ha. In the city centre (area A) the residential density is lower despite of its higher building density, due to other functions like offices, hotels and shops. A relative high density is also present in some of Thessaloniki's neighbour municipalities, in particular Kalamaria, south of the MoT, having 143 inhabitants/ha.[49] This all makes Thessaloniki and its surrounding the most dense of all the four city partners in the project.

The mobility pattern consists of – just mentioning the most important ones – larger radial flows to/from the city centre, of tangential flows between high density areas, and of large radial flows between the MoT and neighbouring municipalities, as indicated in the following maps. Public transport has relative high shares: 38% in internal mobility (2 ends of a trip in the MoT) and 32% in inter-municipal mobility (1 end of a trip in the MoT). All public transport trips are bus ones.



Source: CERTH/HIT model, applied for SUMP of MoT 2021.

The indicated flows imply high traffic intensities on the main roads, in particular the boulevards through the centre of Thessaloniki (Nikis, Egnatia, Tsimiski, Dimitriou) which are crowded over day, largely by private car traffic, but also by many busses. A larger part of the car traffic is throughgoing without a trip end in the city centre and despite of the expressway bypassing the municipality. This (throughgoing) traffic is being addressed by municipal policies (see following two sections).

4.2 Policies (PA, MM, RK, GP, EK, AvB)

4.2.1 Climate mitigation aim

The climate mitigation aim of the municipality of Thessaloniki is, in line with the national aim (National Plan for Energy and Climate of Greece, 2019), to reduce CO_2e emissions by 42% between 1990 and 2030. MoT considers this aim to apply also for mobility. This has become and remained

[49] In other municipalities of the Thessaloniki urban area significantly lower densities dominate.

Thessaloniki's climate aim for the project, although Thessaloniki in the meantime has joined the EU Mission to deliver 100 climate neutral and smart cities in 2030.

The question arises what the equivalent reduction is for the period 2018-2030 to the formal aim of 42% reduction between 1990 and 2030. The answer requires knowledge about the CO_2e development of Thessaloniki between 1990 and 2018. As it turns out, neither the MoT nor the Hellenic Institute of Transport (HIT) or Centre for Renewable Sources and Energy Saving (CRES) can answer this question. The project has therefore made an attempt to give an answer. The following considerations led to the conclusion that the CO_2e emissions of mobility in Thessaloniki may have increased by roughly 20% between 1990 and 2018. 42% reduction requirement of the 1990 emissions then is equivalent to 52% reduction of the 2018 emissions.

> The reasoning of the 20% increase of CO_2e emissions for the city of Thessaloniki between 1990 and 2018 is as follows. The European Energy Agency (EEA) EEA publishes the CO_2e emissions of IPCC sectors, one of them being CO_2e emissions of domestic transport. In 2018 the **Greece** CO_2e emission of domestic transport was <u>20% higher</u> than in 1990. Between 1990 and 2008 the emissions increase, then they decline until 2014, whereafter they increase again up to 2019 (in 2018 +20% as mentioned) after which there is the COVID 19 dip.
> The question emerges to which extent national emission increases, here the 20%, are relevant for Thessaloniki. At this point we make use of the observation that **CO_2e emissions of mobility** tend to correlate with **economic growth in terms of GDP/capita**. The latter is published by the Greek Statistical Authority (2021) for the period 2000-2020. Reference geographical entities of potential interest for the city of Thessaloniki are Greece, the region Athens and the "prefecture" Thessaloniki, a NUTS 3 area. The index curves of the GDP/capita of the three areas have a similar shape, but they slightly divagate, Athens increasing the most, than the nation and then the region Thessaloniki. The region Thessaloniki however includes a lot of countryside, meaning that its developments do not relevantly display the developments of the MoT. From the level and shape one can derive the expectation that CO_2e emissions of the MoT, where the GDP/capita will be higher than of the region, have also increased, perhaps being on a comparable level as nationally.

4.2.2 Overview of mobility measure packages

The MoT has drafted a new sustainable mobility plan, the SUMP 2030 for two different time periods, 2025 and 2030. For the project demonstration the SUMP 2030 represents the **BAU** scenario, also

Scenario	A. Modal shift pillar	B. Innovation pillar	C. City Logistics pillar	D. Energy pillar
SUMP 2030 intermodal public transport strategy & scenario (BAU scenario for 2050CliMobCity)	• Pedestrianization and public space reallocation in the city • METRO operation • Bus Network reorganization & redesign • Maritime Public transport • New Bike infrastructure (total 46 km of bike lanes) • West Suburban railway	• Advanced traffic management & Control • Park & ride (1500 places) •	• New supervision to the parking slots for deliveries • Development of SULP	
2050CliMobCity scenario for 2030 (Electromobility and awareness raise campaigns)	• Shared electric mobility introduction scenario considered from municipality participation to MOMENTUM project) (2030) • Triggering behavioural changes through awareness campaigns for citizens' mode choice and the, associated to the choice, impact for the environment, the city and the individuals	• Electric fleet in bus network (2030 & 2050) • Cooperation with and use of THESSM@LL services for fact-based and data-driven decision making in sustainable mobility management and planning	• Electrification of the Municipal fleet	• Energy savings from street lighting

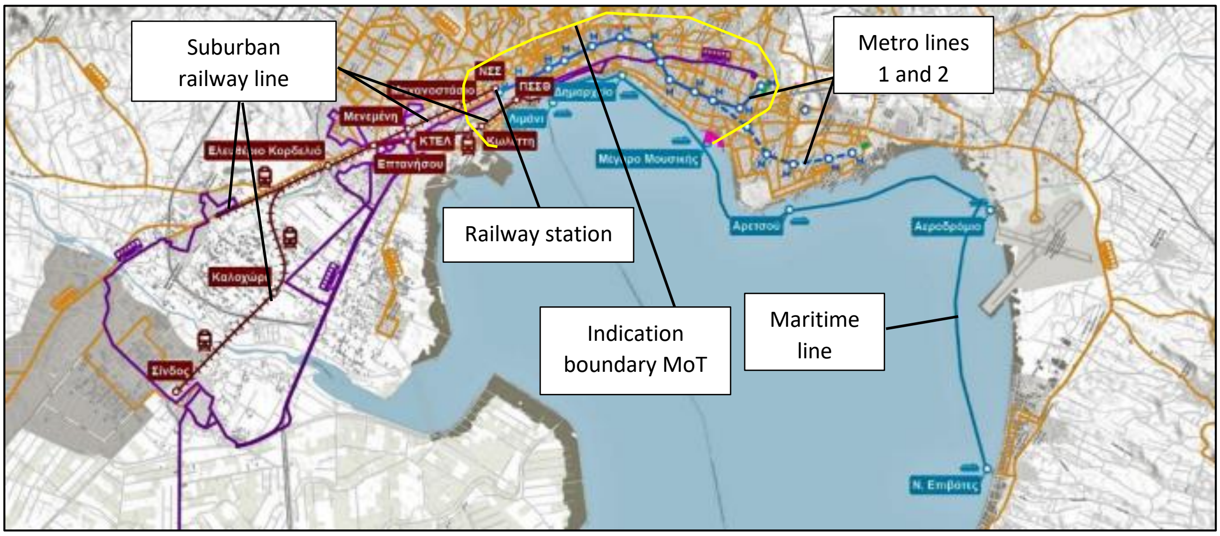
called the “intermodal public transport strategy and scenario” (see table above). The city in the framework of the project demonstration has defined a further measure package referred to as “electromobility and awareness raise campaigns scenario” (= **CliMobCity** scenario). Also this focusses on the year 2030. The **CliMobCity** scenario is to be seen as a supplement to the **SUMP 2030** scenario. So, one is either dealing with the **SUMP 2030** scenario **(BAU)** or with the combination of SUMP 2030 and **CliMobCity** scenario. The table above enlists the content of the measure packages, distinguishing between the pillars modal shift, innovation, city logistics and energy.

The population in the MoT is projected to grow from 313,000 (2018) to 330,000 (2030) inhabitants ≈ 6% (0,5% per year). The population of the Urban area of Thessaloniki is projected to increase from 794,000 to 811,000 ≈ 2% (0,2% per year).

4.2.3 Content of the BAU measure package

The most spectacular group of measures in the **SUMP 2030 (BAU)** scenario refers to public transport. Two metro lines have been decided and are under construction. And there will be the west suburban railway line and a maritime line (see following figure). Following these new services, the bus network will be restructured, many of the bus lines turning into feeder lines for the metro, rail or maritime lines which function as backbone. The restructuring is about the “abolishment of parts or of whole existing lines, where necessary, minimization of overlapping of the bus line routes, etc.”; *Appendix-Thessaloniki-Report*). While in the wider Thessaloniki area the bus service-kms are planned to increase, in the MoT the restructuring goes hand in hand with a reduction of bus-kms.

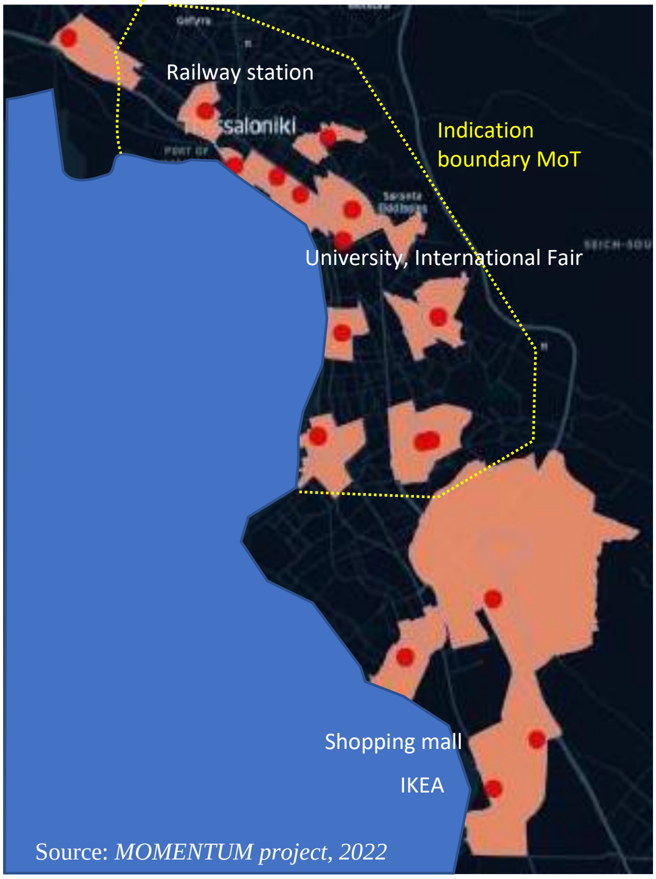
Road measures are directed to continue reallocation of road traffic in the city centre to other routes and redistribution of public space in favour of walking and bicycling. The package includes car access restriction in Tsimiski Street and the reassignment of lanes for private cars to lanes for sustainable transport modes in Egnatia Street. In parallel the pedestrianisation of roads and widening and other improvements of some sidewalks is to be continued, while the length of bicycle infrastructure will increase. Other fields of **BAU** policies refer to car parking (on road: parking is free for residents, otherwise to be paid and (smartly) controlled; off-road: parking in publicly usable pay garages and P+R sites).



Source map: *SUMP of MoT, 2021*.

4.2.4 Content of the CliMobCity measure package (including post-fossil fuel vehicles)

The **CliMobCity measure** package focusses on specific electrification projects. One regarding the establishment of 17 electric car sharing stations, 13 placed within the MoT, at points of interest (university, railway station, International Fair, along some nodes of the metro, a large shopping mall and IKEA). The figure to the right shows the locations for the electric car sharing stations (red dots) and their service areas (pink). In total 100-200 electric cars are subject of the exploration for the project.



Another project is the electrification of public bus lines. More than 30 bus lines (remaining after the restructuring of the bus network because of the metro inauguration) have been proposed to be electrified by 2030. (*Appendix-Thessaloniki-Report*).

4.2.5 Towards post-fossil fuel vehicles

(PA, MM, RK, EK, FR)

Besides the specific electrification measures in the **CliMobCity scenario**, MoT is busy with the general electrification of road vehicles.
The municipal *Electric Vehicle Charging Infrastructure Plan* (MoT, 2021) has the target for 2030 of 37% of cars being electric ones. This target goes beyond that of:

- the *National Energy and Climate Plan* (Hellenic Republic Ministry of the Environment and Energy, 2019) aiming for 30% of cars to be electric ones by 2030;
- the *National Climate Law* stating that ⅓ of private cars ought to be electric ones by 2030.
- the levels EU reference scenario according to which post-fossil fuel cars have a share of 1.5% in 2030;
- the levels of the Tech scenario according to which 11% of the cars in 2030 will be post-fossil fuel ones (see following table).

As the municipal policy has been formulated after the start of the project and is more ambitious than former projections, it has been included in the CliMobCity measure package.

	EU reference					Tech			
	% BEV cars	% Hydrogen cars	% Together	% Fossil fuel remainder		% BEV cars	% Hydrogen cars	% Together	% Fossil fuel remainder
Thessaloniki, 2018	0,2	0	0,2	99,8	Thessaloniki, 2018	0,2	0	0,2	99,8
Thessaloniki, 2030	1,3	0,2	1,5	98,5	Thessaloniki, 2030	8	3	11	89
Thessaloniki, 2050	25	11	36	64	Thessaloniki, 2050	52	22	74	26

4.3 Expected change of mobility in the city (PA, MM, MCH, RK, EK, AvB)

4.3.1 Approach

For the prediction of the change of mobility the 4-step multimodal model VISUM of CERTH/HIT was applied. It includes the modes road (car and taxi), public transport (bus, new metro), bicycling and walking. Freight is derived by splitting predicted road values.
The model after inserting the changes in the infrastructure and service networks and their attributes, the social-economic input (population, work places and other attractions) and mobility preferences of travellers predicts the change of mobility demand and pattern and corresponding traffic flows.
For the prediction of the demand of electric shared mobility in the Municipality of Thessaloniki, car sharing supply and demand models were applied, developed in the MOMENTUM project.

The transport demand for public transport busses – assumed to be the same for diesel as for electric busses – was modelled applying the transport model. The replacement of diesel by electric public busses in the CliMobCity scenario and the general electrification of cars is taken along in the carbon modelling of PIK after the mobility modelling.

The effects of micromobility are not sufficiently known yet, let stand well incorporated into transport modelling. The shift to post-fossil fuel vehicles is taken along in the analysis of the reduction of CO_2e emissions. Fleet scenario testing for the electrification of the bus lines run through CERTH/HIT model VISUM as part of Thessaloniki's Bus Fleet Renewal Action Plan.

The description of current and future mobility in the following sections focusses with regard to trips on the flows in, from and to the city, and with regard to vehicle-kms and passenger-kms on all flows (including trips through the municipality), in both cases only on the trip parts taking place in the municipal area.

4.3.2 Outcomes of the mobility forecast: BAU and 2050 CliMobCity

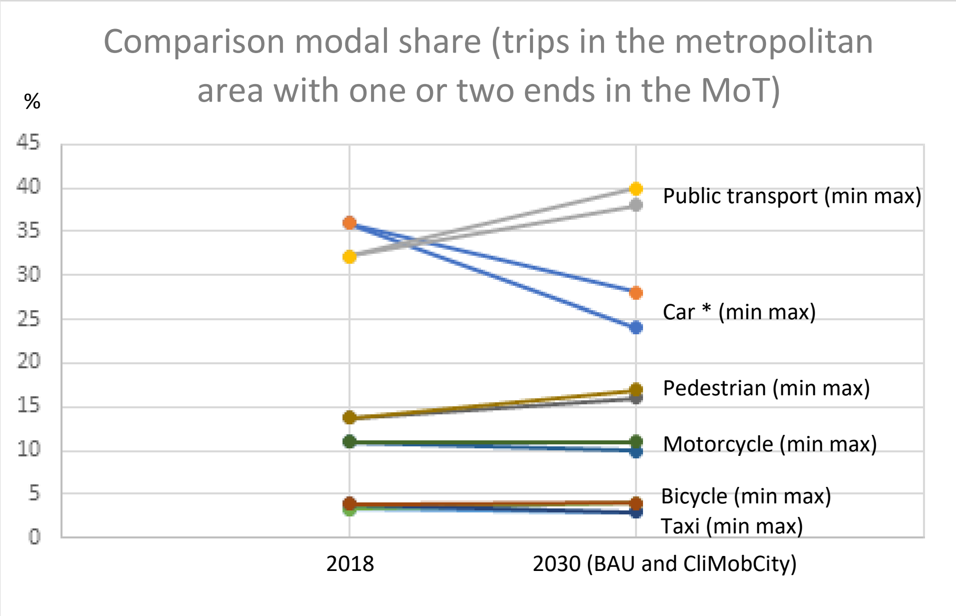
(**Daily Trips** in the metropolitan area in, from and to the MoT, regarding the metropolitan area)

- In both scenarios (**SUMP 2030** and **CliMobCity in 2030**) the number of trips increases by 9% (all modes) which is more than the population growth (6%).
- The number of public transport trips increases by 30%, the response to the inauguration of the metro system, the suburban railway and the maritime line.
- Car trips decline by 15%.
- Taxi trips decline by 11%.
- Pedestrian trips increase by 8% and bicycle trips by 26%.

(**Modal share** of trips in, from and to the MoT, regarding the metropolitan area)

- Despite of the relative high level in the base year, the share of public transport is predicted to increase significantly by 2030. The share of public transport will then pass the share of car mobility and reach a level of 38-40%, under less to more fortunate conditions.
- This increase is accompanied by a shift within public transport. About 25% of rides[50] in 2030 is expected to go by metro, 2% by rail and 1% using the maritime line, the rest by bus.
- The share of car trips declines from 36% in 2018 to 24-28% in 2030.
- The improvement of pedestrian infrastructure echoes in the modal share, moving up from 14% to 16-17%.

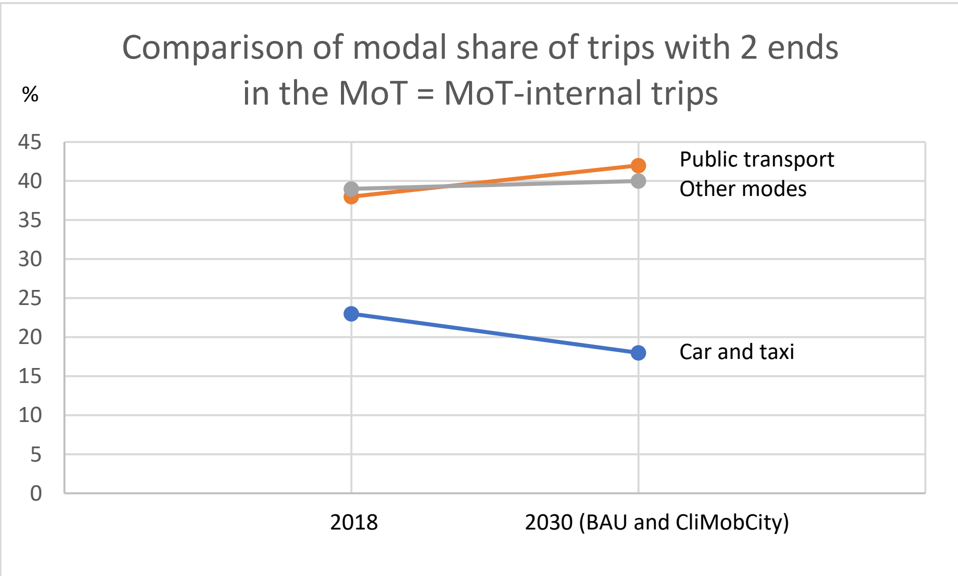
[50] Trip data were not present for this distinction. A public transport trip can consist of several (public transport) rides with a transfer in between. The ride/trip-ratio in 2018 was 1.04 and is expected to become 1.2 in 2030, as many passengers will haven bus-metro transfers v.v.



* Private and – in 2030 – also shared electric car.
Source data: *Appendix-Thessaloniki-report*, Table 7.

(**Modal share** of trips *within the MoT; 2 ends of the trip in the municipality*)

- The direction of the modal shift is similar for MoT-internal trips, but the magnitudes differ. The share of public transport was larger than of car/taxi already in the base year (PT 38% versus car 23%), the gap between both becoming larger in 2030 (PT 42% versus car 18%; see following figure).
- Shared electric car trips represent 3% (hourly) to 4% (daily) of internal car trips in 2030 (*Appendix-Thessaloniki-Report*).



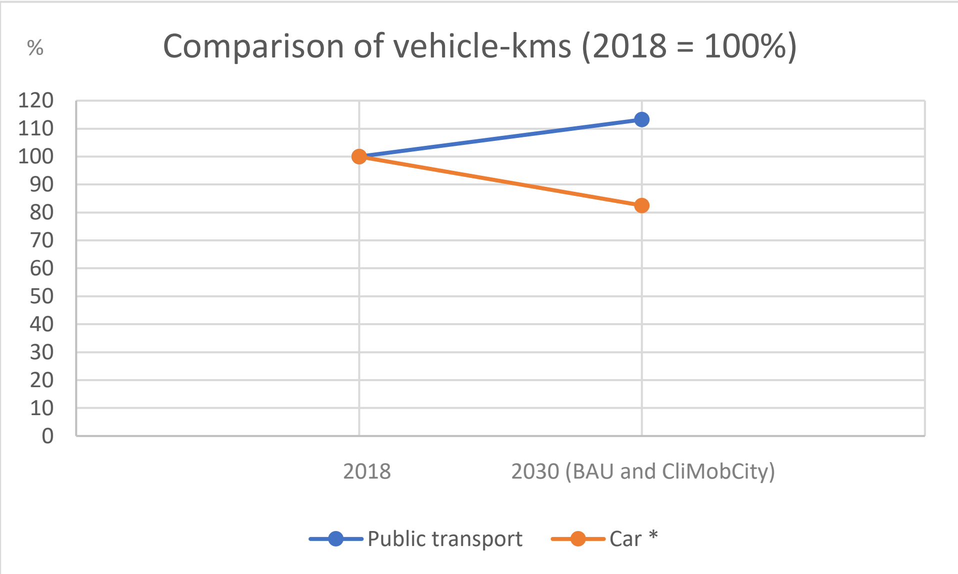
(**Average distance**)

- The average distance of cars declines from 8,1km (2018) to 7,8km (2030), with minor differences in 2030 between in the **BAU** scenario and the **CliMobCity** scenario.

- The average distance of public transport increases from 7km (2018) to 10km (2030). Evidently there is more modal shift of car to public transport in the longer distance than the shorter distance.
- The average distance of the shared electric car is expected to be shorter than of the private fossil fuel car.

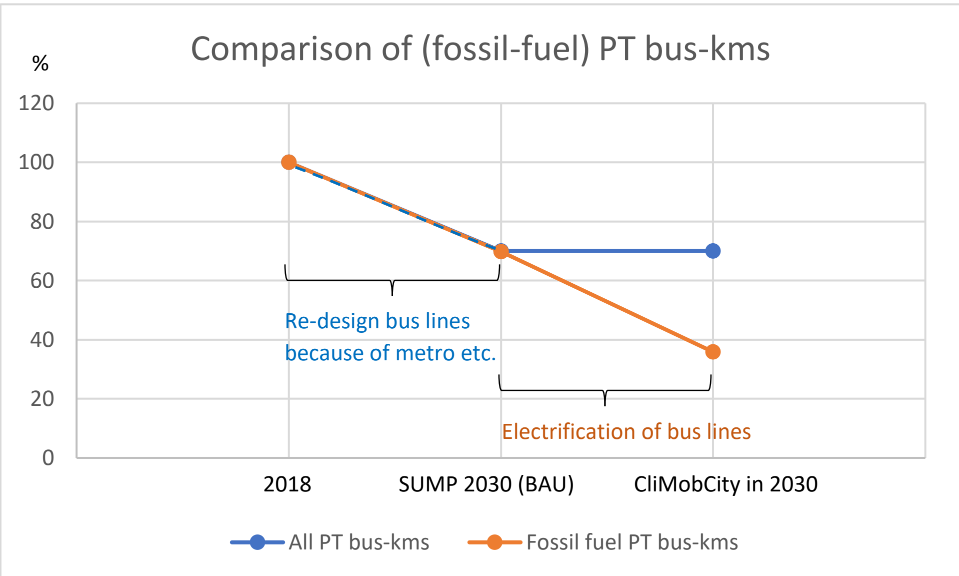
(**Vehicle-kms** of all trips in, from, to and through the MoT [Always only the kms within the MoT are included. The trips from/to the MoT are the ones from/to the entire metropolitan area]).

- The number of car-kms (private cars including electric cars and taxis) declines by 18% (see following figure).
- The number of vehicle-kms in public transport (metro, bus, regional train, maritime line) increases by 13%, despite of the decline of bus-kms by 30%.



(**Vehicle-kms** of trips in Thessaloniki [2 ends of the trip in the municipality])

- The shorter distance of shared electric car trips (a measure in the **CliMobCity** scenario) implicate that the 3% hourly trip share only provides a 1% share of car-kms in 2030 (*Appendix-Thessaloniki-Report*).
- Daily bus-kms are expected to decline by 30% in the **BAU** scenario, meaning 30% less **diesel** bus-kms (see following figure).



(**Traffic impacts**; **BAU** and **CliMobCity** scenario)

- The throughgoing traffic in Tsimiski road is reduced from 25% to 5%. It partly moves to Egnatia street, where, while its number of functional lanes for cars is reduced, the percentage of throughgoing traffic increases (31->51% eastbound; 35->42% westbound), at the dispense of centre visitors, which partly shift to the metro. Also Agiou Dimitrou Street absorbs more traffic, as its share of throughgoing traffic increases (31->34%). The *Appendix-Thessaloniki-Report* observes on the basis of the transport modelling and the prediction of traffic flows (p. 32): "The results of the interventions to reduce the capacity of the road network, are mainly reflected in the increase of vehicle hours between base year and 2030, but also in the reduction of the average network speed of the collection roads." This, however, does not influence total traffic flow in the MoT. Averagely, traffic flows are reported to improve slightly.

(**Electrification**)

- The mentioned intra-municipal shared electric car trips in the **CliMobCity** scenario largely substitute fossil-fuel car trips.
- Of the daily bus-kms remaining after the redesign of the public bus network (70% of the bus-kms in 2018), about half will have become electrified by 2030 in the **CliMobCity** scenario (*Appendix-Thessaloniki-Report*). Together this implies a reduction of diesel bus-kms to the level of 36% (see following figure).

A rough interpretation of the results (BAU and CliMobCity, unless mentioned differently)

- The **BAU** scenario leads to spectacular changes of mobility. The supplementary mobility changes of **CliMobCity** measures are rather small. However, their CO_2e reduction effects still are substantial (see following section).
- The striking modal shift includes a 30% increase of public transport trips with one and/or two ends in the MoT accompanied by a decrease of 15% of private car trips. The overall increase of trips is 9%.
- Travel distance of public transport trips is increasing, letting the average distance of car trips decline.
- While passenger-kilometrage in public transport is increasing, private car-kms are reduced by 18%.
- The measure to substitute private fossil fuel car trips and vehicle-kms by the shared electric car trips (**CliMobCity** scenario) has the magnitude of a niche market (based on 100-200 shared cars to be implemented). However, the type of measure could evolve to a mainstream configuration and could so reduce fossil fuel kilometres on a substantial scale. Additional benefits of shared electric cars are, although not discussed by the MoT, the reduction of car parking demand, and an induced modal shift to other modes.
- Diesel public bus-kms decline by 64%, almost half of which is due to the redesign of the bus network following the inauguration of e.g. the metro system (**BAU**), the other half due to the electrification of part of the remaining bus lines (**CliMobCity**).
- The freight logistic measures of the **CliMobCity** measures have not been elaborated in the *Appendix-Thessaloniki-Report*, but instead are the subject of one of the four actions of the Mot in the framework of this project. The action is to outline the approach in this policy field.
- Although not elaborated in the *Appendix-Thessaloniki-Report*, it seems evident that the success of the metro in terms of transport demand is also based on the high and partly increasing building densities in the centre and the accessed residential areas.
- The metro has clearly contributed to strengthening the compact city, the corresponding modal shift allowing to downgrade the car capacity of two boulevards through the city centre while keeping road traffic flow satisfactory.

4.4 Analysed reduction of CO_2e emissions[51] (FR, EK, AvB)

The inauguration of the metro system is, as described above, the main factor for the decline of car-kms (18%) between 2018 and **SUMP 2030 (BAU)**. Amongst the remaining private car-kms there is only little electrification (from 0.2% in 2018 to still only 1.5% in 2030) and hence only little additional CO_2e reduction. In the MoT the metro inauguration is accompanied by a reduction of public transport bus-kms of 30%. These are 30% less diesel kilometres. The metro is electricity powered. However, the electricity production is far from green meaning that the shift from bus to metro does not yet completely unfold its CO_2e reduction potential. All these changes plus the development of CO_2e emissions in the freight sector together provide an overall CO_2e reduction of only 8% (blue line in the following figure).

In the **CliMobCity scenario**, which adds measures to the BAU scenario, CO_2e emissions can be reduced by another 6% (total reduction now is 14%; still blue line). The 6% reduction is the result of including the general electrification ambition of the MoT for 2030, of the replacement of diesel by electric public busses, and to a small extent of introducing the shared electric car scheme.

The MoT electrification aim for 2030 is higher than the post-fossil powertrain share in the Tech scenario, for which reason the **CliMobCity** dot on the blue line (following figure) lies lower than the **BAU** dot on the orange line. The small differences between both lines are due to differences in the cleanness of fossil fuel cars.

One can also reflect on the effectiveness of SUMP 2030 (BAU) and CliMobCity measure packages in the light of green electricity production which is not realistic for 2030, but perhaps useful for considering which contribution to carbon reduction local measures should make. Only in this scenario the modal shift to metro and electrification of public transport busses and shared electric cars pilot unfold all their benefits. The total carbon reduction in the CliMobCity scenario now is 21% (grey line). What remains is an emission level of (100-21=) 79% in comparison to 2018.

The project then raised the question what more could be done to achieve additional reductions. Such measures have been explored conducting **forecasting lever exercises** in the carbon model (= what-if exercises). These were based on overall scenario 3 (CliMobCity, Tech, green energy):

- (overall scenario 4) reduce the share of cars by 10 %-points and conduct corresponding increases of public transport use and active travel;
- (overall scenario 5) 10% less time spent because of less road vehicle-kms,
- (overall scenario 6) increase the share of post-fossil cars by 10 %-points,
- (overall scenario 7) combinations of these.

The result is respectively 1%, 1%, 2%, and 4% CO_2e reduction.
The total reduction including the lever exercises is 24% of the emissions of 2018, the remaining CO_2e emissions having the level of 76%.

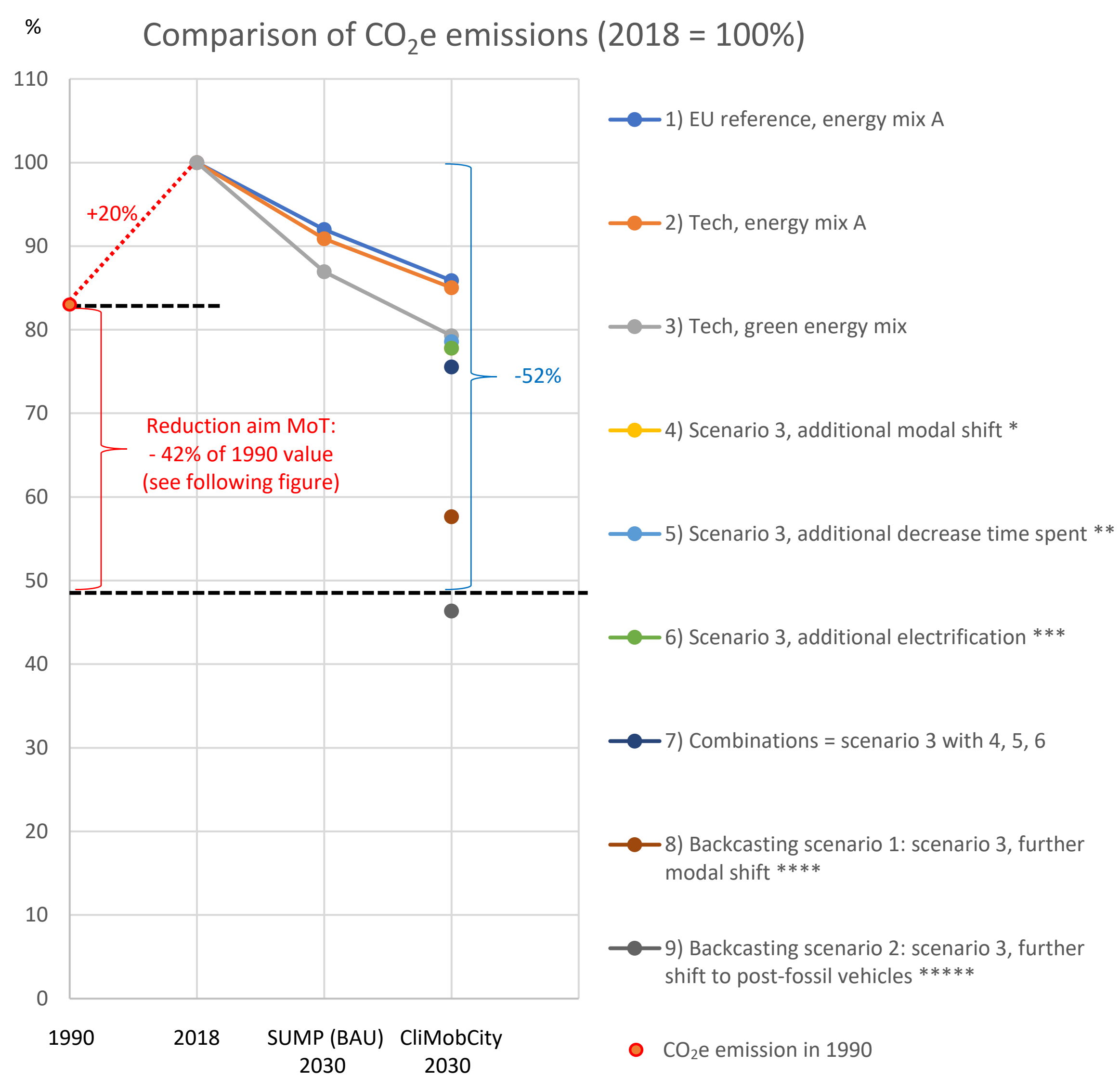
The mentioned lever exercises were forecasting ones. One can instead conduct **backcasting lever exercises** in which the CO_2e reduction to be achieved is the starting point to search for measures that provide sufficient reduction. Two such exercises have been carried out, again starting from overall scenario 3:

- (overall scenario 8): the share of LDVs (including cars) declines by 26 %-points, that of 2-wheelers by 5 %-points. In return the shares of bus (much of which is electric), metro (all electric), rail, walk and bicycle increase. The achieved CO_2e reduction is 46%, hence despite of the backcasting intention not sufficient. But more car shift is not possible.

[51] For a more detailed description of the results and approach of the CO_2e analysis see the Appendix-PIK-report.

- (overall scenario 9) a powerful shift to post-fossil fuel LDVs (including cars): The share of BEVs increases by 61 %-points, that of diesel and gasoline vehicles shrinks by respectively 15 and 46 %-points. The achieved CO_2e reduction is 54%, hence sufficient because more than the required 52%. The **remaining** emissions is mainly caused by HGVs (trucks, non-public transport busses), also by public transport busses (1/3 of them still has diesel propulsion) and by 2-wheelers.

Such measures in the envisaged time frame (2018-2030) are not realistic. But the exercises provide orientation.



*	Share of cars and other LDVs: -10 %-points; of public transport busses and active travel: each +5%-points.
**	10% less time spent, because of less road vehicle-kms and/or more fluent traffic flow.
***	Share of post-fossil fuel vehicles: +10 %-points at the dispense of the share of fossil fuel vehicles.
****	Share of cars and other LDVs: -26 %-points; of 2W -5 %-points, of bus +8 %-points, of metro +8 %-points, of rail +3 %-points, of walking +3 %-points, of bicycle +9 %-points.
*****	Share of BEV: + 61 %-points; of diesel: -15 %-points, of gasoline: -46 %-points.

This type of presentation supports understanding of the relation between different results (dots).
But be aware of that:

- lines between the 1990, 2018 and BAU dots represent (alternative) developments in time;
- lines between BAU and CliMobCity dots serve the comparison, but don't represent developments in time.

In the last chapter (6) of this report we reflect on types measures that could lead to more reduction than MoT in the 2050 CliMobCity demonstration has taken into consideration.

As already indicated, the transport modelling does not show the effects of measures entailing new types of micro-mobility services and corresponding hub nodes on future mobility, while these may have the potential to reduce CO_2e emissions of mobility in substantial amounts. But whether this is likely, is not sufficiently validated by research yet and certainly depends on the context of implemented concepts. Also this we briefly discuss this in the last chapter of this report.

Thessaloniki's population is growing. The CO_2e reduction per capita is 2-5 %-points higher than the total reduction, dependent on the scenario (not shown in the figure).

4.5 Feedback from the municipal reflection on the CO_2e reduction (PA, MM, GP)

The MoT set a challenging target for 2030, that of reaching 42% less emissions than in 1990, according to the National Climate and Energy Plan of 2019. In the framework of 2050 CliMobCity Project, MoT adopted this target for the urban mobility sector. According to the analysis described above, the challenges that accompany this target are that apart from the need to undertake, in a more sustainable and environmentally friendly way, the estimated (9%) increase of the overall trips that start and/or end within MoT between 2018-2030, the target also implies the phasing out of a significant increase of 20% of CO_2e that is assumed/approximated for the period 1990-2018. Starting from a "burdened" situation when compared to 1990, the MoT has set its strategic planning for sustainable and low-/zero-carbon mobility through its SUMP (2018-2021), leveraging on the significant impacts of the inauguration of the metro system in the end of 2023-beginning of 2024. SUMP 2030 (BAU) measures are wrapped around the new era of the multimodal public transport system, redefining the role of the areas, and supporting a polycentric development. With the implementation of the SUMP package of measures, a modal shift from private cars to public transport and active modes of transport will be achieved, pushing down CO_2e emissions, nonetheless, not reaching the desirable target. A further modal shift could be possible through suggested local measure packages (see section above), but eventually a modal shift that could alone bring the CO_2e emission target would assume a non-realistic modal share of conventional private cars within the borders of the Municipality. A fossil fuel-free scenario can be proposed, though, for the city centre of MoT, building upon relevant SUMP proposed measures for the partial exclusion of the city centre, such as the exclusion of fossil fuel cars from part of Tsimiski street.

Efforts should be, also, placed on the BEV's penetration (through private and sharing schemes) and the greening of energy (although this might be seen more at a national level). Already, electrification scenarios of the public bus fleet and model testing for electric car-sharing schemes indicate their potential. The same applies for scenario testing expressing a greener energy mix of electricity production.

The following, though should be considered for MoT:

- The MoT is located at the heart of Thessaloniki's metropolitan area and is also highly burdened by through traffic. A common vision shared by all Municipalities of the metropolitan area for providing connected and unfractionated zero emission transport services is of outmost importance. Targeted actions should be placed in this direction (i.e., establishing electric-car sharing schemes that serve trips between MoT and other Municipalities).
- On the opposite side of the positive effects of greener share of powertrains rests the low rates of BEV and Hydrogen car penetration for Thessaloniki (as this estimated from both the EU reference and Tech scenarios). However, the implementation of measures to promote the use of BEV and Hydrogen vehicles should cover both the provision of the needed infrastructure (e.g. charging stations) and the mindset change (through financial supporting and awareness campaigns), or

even less popular measure such as the prohibition of non-green vehicles to access the broad city centre, which implies a strong political commitment.

Incentives to reduce the travel demand (i.e., increase teleworking) might also prove successful. Commitment of the business sector is needed, but reaching out to big employers in the city could be seen as a good starting point.

It is important to note that in April 2022, while 2050 CliMobCity was reaching the end of Phase 1, MoT was selected to the EU Mission for Climate neutral and Smart Cities with the ultimate goal to achieve climate neutrality by 2030. The central feature of the Cities Mission is the Climate City Contract (CCC) which includes an Action Plan for the city to achieve climate neutrality by 2030 and an Investment Plan. MoT is in progress of developing the CCC in collaboration with the local stakeholders and the citizens and it is going to be officially signed by the Mayor in October 2023.
In the context of the Mission, climate neutrality is defined as “achieving net zero GHG emissions, to be realized mainly by cutting emissions, investing in green technologies and protecting/enhancing the natural environment.” Achieving climate neutrality requires a Mission City to reduce the GHG emissions from all sectors and sources within the city’s boundary to net zero by 2030. MoT’s Action Plan within the CCC includes the following sectors for the city within its geographic boundary: emissions from all buildings and facilities within the boundaries of MoT (municipal, residential, commercial) and the transport sector. The Action Plan also includes emissions that are indirect (due to consumption of grid-supplied electricity) and out-of-boundary (emissions from treatment of waste produced within the geographic boundary). Nevertheless, while cities are required to reduce all sources of GHG emissions to the extent feasible, it is acknowledged that depending on local circumstances there may be certain emission sources which cannot be fully mitigated by 2030 due to technological or financial constraints. Subsequently, compensating for any ‘residual emissions’ will be possible, to an extent, to account for those emissions sources which cannot be fully eliminated (e.g. through carbon sinks and carbon credits). As mentioned in a previous chapter, the target is impossible to be achieved solely for the field of mobility, so excessive CO_2e emissions will need to be absorbed.

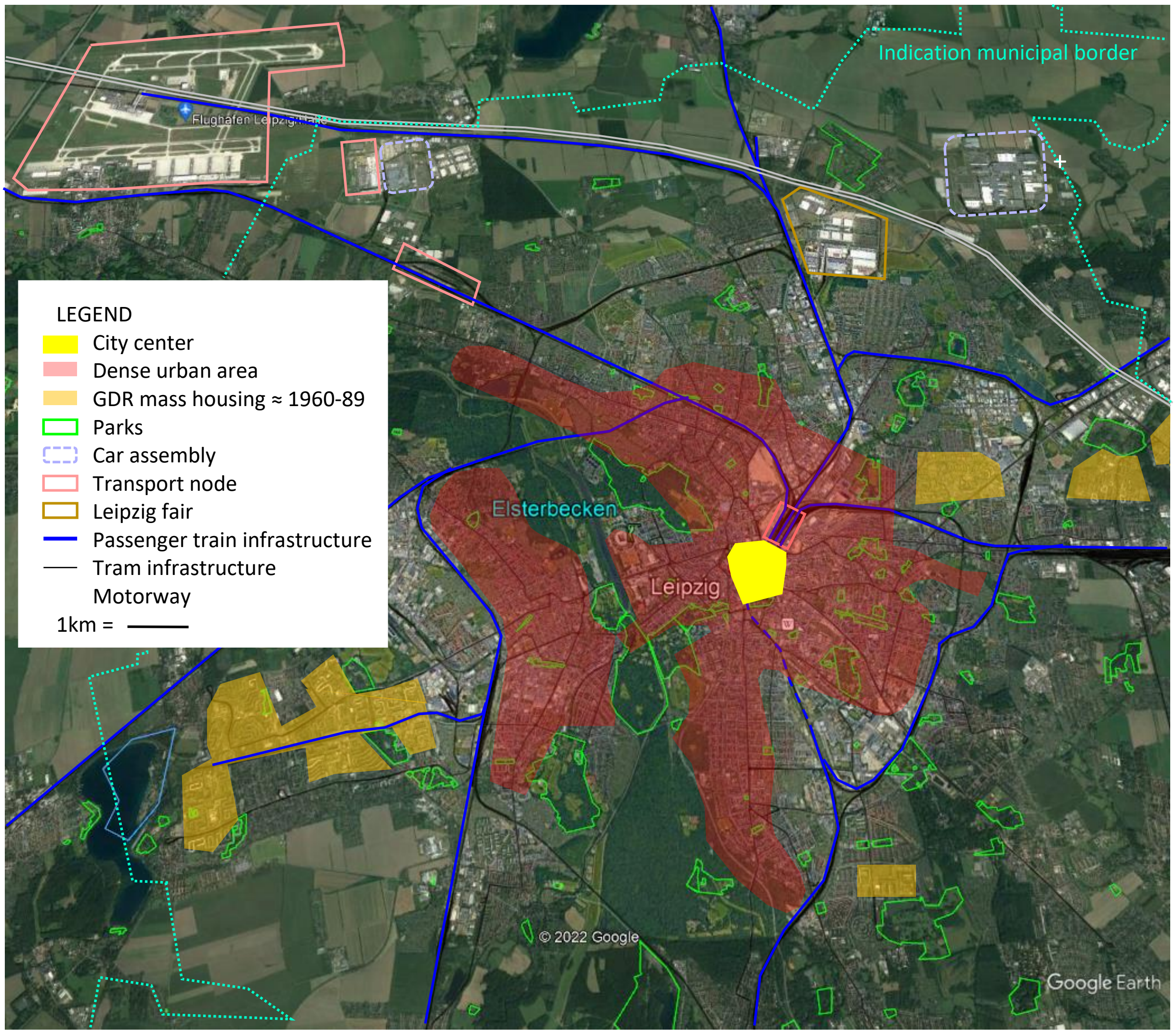
Taking all the above into consideration, MoT’s climate aim has changed to reach climate neutrality by 2030, but the actions to achieve this goal include all sectors that are described above and the possible residual emissions can be mitigated through technology and nature based solutions.

5 LEIPZIG: Measure packages, change of mobility and of CO_2e emissions

(MoL = Municipality of Leipzig)

5.1 Current situation and backgrounds (JB, EK, AvB)

Leipzig is the largest city (about 600,000 inhabitants) behind Berlin in the eastern part of Germany. It was an important trade, production and cultural town already centuries ago. The Leipzig fair dates back to medieval times and today is accommodated in a large complex of exhibition and conference halls. Leipzig until 1945 had a large publishing and editing sector, some of which is still flourishing. Due to the large-scale industrialisation in the 19th century Leipzig has a substantive dense residential belt around the city centre (both, the centre and the belt have about 3500 inhabitants per km^2), outside of which the densities gradually decrease, ending in single house areas in the city's fringes. The fringe, however, also includes a number of suburbs hosting large housing complexes, stomped out of the ground during the GDR-period (1945-1989). These areas have a density comparable with the belt.
The city is divided by a green corridor, today hosting recreational functions in a forest and along a small river.
The industrial activities of some large parts of the 19th century industrial areas have moved to other places in the world, but their many buildings have been or are being repurposed giving home to young enterprises, housing and culture. After the unification of West and East Germany there have



been substantial investments by large employers in transport and logistics (airport, DHL freight hub) and car assembly factories (BMW, Porsche) along the northern edge of the city.
Leipzig has the largest train station building in Germany, part of which still accommodates national and regional trains. The local public transport network includes a dense network of rather fast tramlines which access the dense residential areas and also go beyond these. Quite some Leipzig residential areas including the mass housing on the westside of the city are accessed by regional train.
In 2015 of all trips in, from and to Leipzig 17% went by public transport, 45% by car, the rest being active travel.[52] Within public transport 58% of public transport trips in, from and to Leipzig took place by tram, 25% by bus, and 17% by regional train.[53]

Leipzig, photo impressions

5.2 Policies (JB, EK, AvB)

5.2.1 Climate mitigation aim

Leipzig's climate policies have become increasingly ambitious. After the Climate emergency decree (MoL, October 2019) the city's climate aim was climate neutrality in 2050. The *Energy and Climate Protection Programme 2040* (*EKSP 2040*; MoL, autumn 2022) aims for climate neutrality by 2040. This has become and remained Leipzig's climate aim for the project, although Leipzig in the meantime has joined the EU Mission to deliver 100 climate neutral and smart cities in 2030. On the basis of interpolation between 2015 and 2040 the reduction to be achieved in 2035 is 80% of the

52 From the "Planfall 2035" modelling spreadsheet.
53 *PTV (2018)*. The corresponding figures for all trips (including throughgoing ones) are 14% (public transport) 58% (car).

emission in the base year. This is a challenge, also in the light of the expected population growth. The municipal activities (offices, logistics etc.) are to become climate neutral by 2030.[54]

5.2.2 Overview of mobility measure packages

The exploration horizon in Leipzig's demonstration in the project is 2035.

- Regarding **BAU policies** for strategic mobility planning, the central planning documents are the *Integrated City Development Concept Leipzig 2030 (INSEK 2030)*[55]), a multi-sectoral planning outlining future measures also in the field of mobility, and the *Mobility strategy 2030* (MoL, 2018) which concretises INSEK's measure package for mobility. After the launch of these documents it showed that the projected growth of population needed to be adjusted downwards. The result is shown in the third bullet (below). For describing the mobility effects of the BAU measures, given the lower population growth, the project consulted the results of a PTV modelling run called *Planfall 2035*.[56]
  Two newer planning documents, the *Climate Emergency Action Programme 2020* (MoL, 2020)[57] and the draft *Energy and Climate Protection Program 2030* (MoL, 2022) elaborate measure packages, referring to the *Mobility Strategy 2030* and *INSEK 2030*.
  Then there are specific areas within mobility policies, which very much depend on the cooperation of firms, and which are more the working field of Leipzig's department for Economic affairs: vehicle electrification and development towards other post-fossil powertrains, car sharing, micro-mobility, passenger or freight mobility hubs. The implementation frameworks for these areas are the subject of the city's documents *Leipzig – City of Smart Mobility*[58] and the *Charging Infrastructure Concept Leipzig 2020*.[59]
- The **2050 CliMobCity scenario** for Leipzig focusses on the mobility policy areas *Leipzig - City of Smart Mobility* which is currently being updated[60], the time horizon shifting from 2020 to 2025-40. This and the draft *Charging Infrastructure Concept Leipzig 2030*,[61] the follow-up of the *Charging Infrastructure Concept Leipzig 2020*, relate to the *Mobility strategy 2030* and are by far more ambitious than the preceding documents, aiming for significantly higher levels of post-fossil powertrains. These updated documents are the centre of the **CliMobCity scenario**.
  As in the **CliMobCity scenario** the infrastructure and services influencing the mobility pattern are expected to be similar to those in BAU, and as the mobility changes due to mobility hubs and shared vehicles still are difficult to model, the project has declared the *Planfall 2035* mobility results (e.g. trips and vehicle-kms) also to be valid for the **CliMobCity scenario**.[62] Therefore the difference between the **BAU** and the **CliMobCity scenario** is hardly the change of mobility, but of powertrains in the road sector and their facilitation by mobility hubs.
- A central feature of the Leipzig demographic planning is the reduction of the projected population growth in comparison to former forecasts Mobility Strategy 2030. This is from 583,000 (2015) to 657,000 (2035) inhabitants ≈ 13% (0.6% per year).[63]

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[54] Per inhabitant the total (all sectors) CO_2e emissions in 2019 were 5.3t. Leipzig now aims for 1.9t in 2030 and 0.25t in 2040. For mobility the corresponding emissions are 1.35t per inhabitant in 2019 and 0.71t in 2035 (no value mentioned for 2050). (Source: MoL, 2022, *EKGS 2040)*.

[55] *Integriertes Stadtentwicklungskonzept 2030 (INSEK)* (MoL, 2018).

[56] It strictly speaking predicts the change of mobility for the period 2018-2035 instead of 2015-2030.

[57] *Sofortmassnahmenprogramme zum Klimanotstand 2020* (MoL, 2020), and *Energie- und Klimaschutzprogramm 2030* (MoL, 2022).

[58] *Leipzig – Stadt der intelligenten Mobilität* (MoL, 2017).

[59] *Ladeinfrastrukturkonzept Leipzig 2020* (MoL, 2020).

[60] The process, results and status are described in the *Appendix-Leipzig-Report*.

[61] *Ladeinfrastrukturkonzept Leipzig 2030* (MoL, draft in development).

[62] This seems justified also in the light of the fact that the mobility impacts of measures like hub implementation, car sharing or micro-mobility still are difficult to model. It may be expected, that Leipzig's mobility modelling would lead only to limited differences for the **BAU** (*Planfall*) and the **CliMobCity scenario** in 2035.

[63] The population development and projections witness some dynamic. Before 1945 Leipzig had more than 700,000 inhabitants. From 1940, during the GDR-period and during the first decade after the unification the population declined

5.2.3 Content of the BAU measure package

The *Mobility Strategy 2030* describes decisions regarding future transport infrastructure and services, traffic management, land use and pricing measures. The following map gives an overview of the most important public transport and road infrastructure measures, park and ride or mobility hub locations, and also of land reservations for infrastructure to be implemented on the rather long term, like for the future tram line through the Kurt Eisener Strasse connecting two parts of the city (see purple oval in the map).

The measures/policies of the Mobility Strategy 2030 are translated into input for the transport model. For the modelling scenario *Planfall 2035* (essentially reflecting on Mobility Strategy 2030 measures, but projecting a smaller increase of population) the input consists of the base year infrastructure and services, to be changed by[64]:

- about 20 road infrastructure measures of Leipzig and surrounding municipalities (new links and a bridge, a few including tram infrastructure, widening of roads, other use of lanes),
- about 10 measures with reference to the regional train system: new stops, frequency increase for a few lines,
- more than 15 tram measures (several new lines, several line extensions, frequency increases for a few lines, change of routes),
- more than 20 bus measures (several new lines, several line extensions one of which using part of an old line, a few shortening of lines, frequency increases for a few lines)
- many new tram or bus stops, refurbishment of many tram or bus stops.

5.2.4 Content of the CliMobCity measure package

The measure package in the new draft *Leipzig - City of Smart Mobility policy* and corresponding with the draft *Infrastructure Charging Concept Leipzig 2030*, consists of more and an accelerated implementation of existing types of measures, and of some new types of measures. Most important are:

- expanding the network of vehicle charging points corresponding with the aim of 30% electric vehicles by 2030 (see section *Towards post-fossil fuel vehicle policies* below);
- 100% electrification of all public transport vehicles by 2030;
- targeting passenger mobility: creating new public mobility stations where one can park and pick up shared vehicles (bikes, cars), charge e-vehicles, shared or not (cars) and park private bicycles;
- expanding private electric car charging and sharing nodes or making such accessible to other users);
- more on-demand transport networks to supplement public transport services where the transport demand is too small to provide tram or bus services;
- increasing and improving multimodal services in new business models like ride sharing;
- targeting freight transport:

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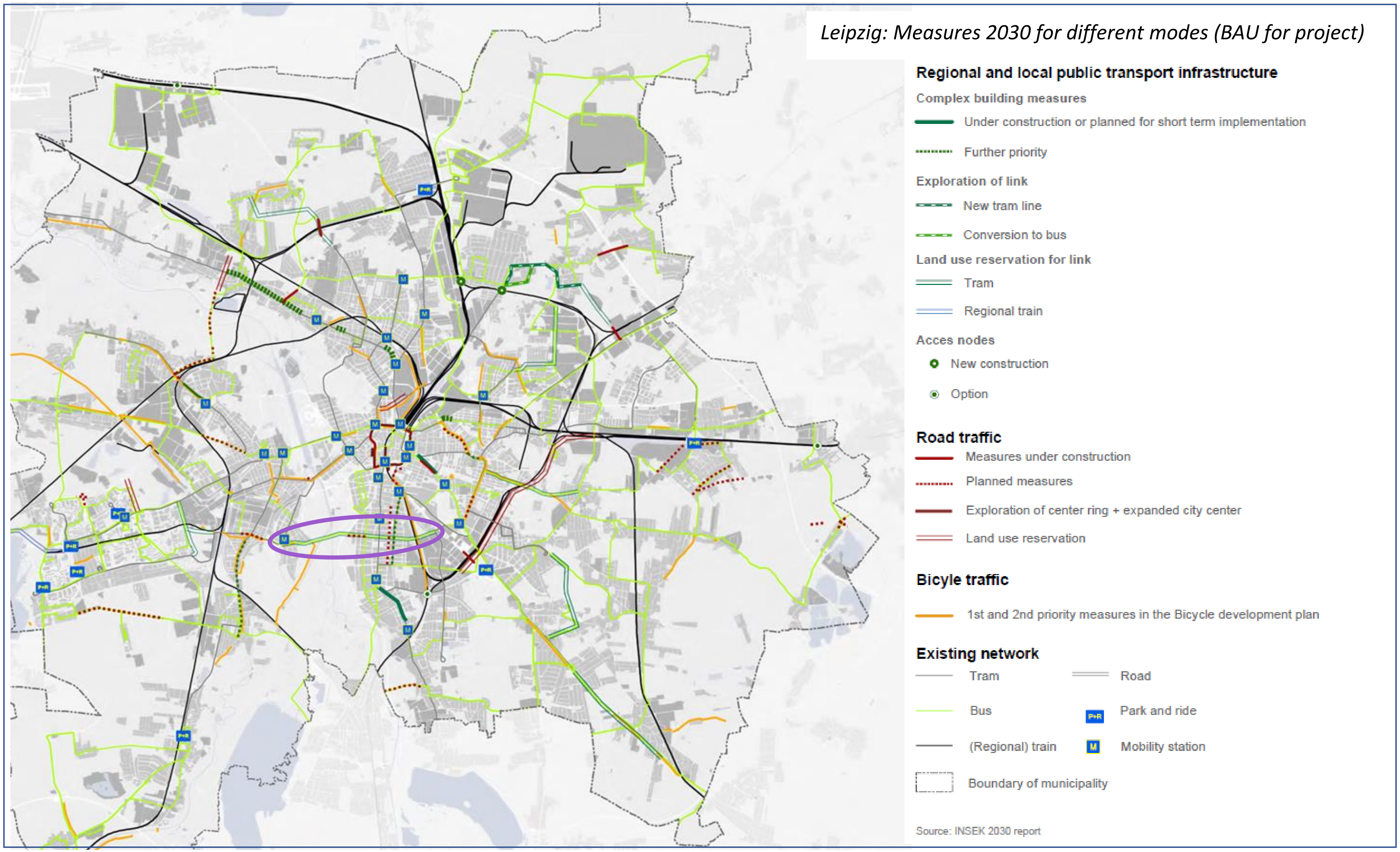
to 440,000 inhabitants. Then a growth phase began, migration from former West-Germany being a main factor. This gave reason for assuming large growth rates in the forecasts accompanying the *Mobility Strategy 2030*. In the meantime the population growth has slowed down and the forecast rates in the transport model have been adjusted downwards, still remaining positive.

64 Sum of measures of Planfall 2030, Nullfull 2030 and Planfall 2035.


Leipzig: Measures 2030 for different modes (BAU for project)
Regional and local public transport infrastructure
Complex building measures
Under construction or planned for short term implementation
Further priority
Exploration of link
New tram line
Conversion to bus
Land use reservation for link
Tram
Regional train
Acces nodes
New construction
Option
Road traffic
Measures under construction
Planned measures
Exploration of center ring + expanded city center
Land use reservation
Bicyle traffic
1st and 2nd priority measures in the Bicycle development plan
Existing network
Tram
Road
Bus
Park and ride
(Regional) train
Mobility station
Boundary of municipality
Source: INSEK 2030 report

- implementing urban hubs enabling to use larger trucks in parts of the transport chain or and small vehicles including cargo bikes in other parts. There are plans for central hubs (inner cities), hubs in neighbourhoods as well as large hubs at the city borders;
- ideas to use the tram for freight transport will probably not be further developed, because tram capacity is already limited.

Mobility station with sharing-bikes parking and charging lots for shared e-cars

Source: *MoL*.

5.2.5 Towards post-fossil fuel vehicles (JB, EK, FR)

The draft *Charging Infrastructure Concept Leipzig 2030* strives for:

- near to 30% electrification of road vehicles (cars, trucks) in 2035. In the preceding document, the *Charging Infrastructure Concept Leipzig 2020*, this was 9% in 2025;
- 100% electrification of all public transport vehicles by 2030.

As mentioned before, all municipal activities (e.g. logistics etc.) are to become climate neutral by 2030.

With post-fossil fuel cars and trucks having a share of 30% in 2030, the draft *Charging Infrastructure Concept Leipzig 2030* is more ambitious than the EU reference scenario (post-fossil fuel share is 17%) and less than the Tech scenario (51%).

	EU reference					Tech			
	% BEV cars	% Hydrogen cars	% Together	% Fossil fuel remainder		% BEV cars	% Hydrogen cars	% Together	% Fossil fuel remainder
Leipzig, 2015	1	0	1	99	Leipzig, 2015	1	0	1	99
Leipzig, 2035	12	5	17	83	Leipzig, 2035	36	15	51	49
Leipzig, 2050	31	13	44	56	Leipzig, 2050	65	28	93	7

5.3 Expected change of mobility in the city (JB, EK, AvB)

5.3.1 Approach

The impression of future mobility changes due to the measure packages is based on the results of a former run of the *PTV VISUM – IVLM model*. This is a four-stage multimodal model including the modes road, public transport, bicycling, walking and freight.[65] The mobility effects of substituting private by shared cars are not modelled. The transport modelling does not show the effects of measures entailing electric mobility, shared cars and corresponding nodes on future mobility. The

65 Freight is calculated along a simplified modelling approach (derived from results for road transport).

effects of shared cars and micro-mobility are not sufficiently known yet, let stand well incorporated into transport modelling. The shift to post-fossil fuel vehicles is taken along in the analysis of the reduction of CO_2e emissions.
The description of mobility in the following sections refers to all trips (in, from, to, through). When it comes to passenger-kms or vehicle-kms, only the trip part taking place in the municipal area is included.

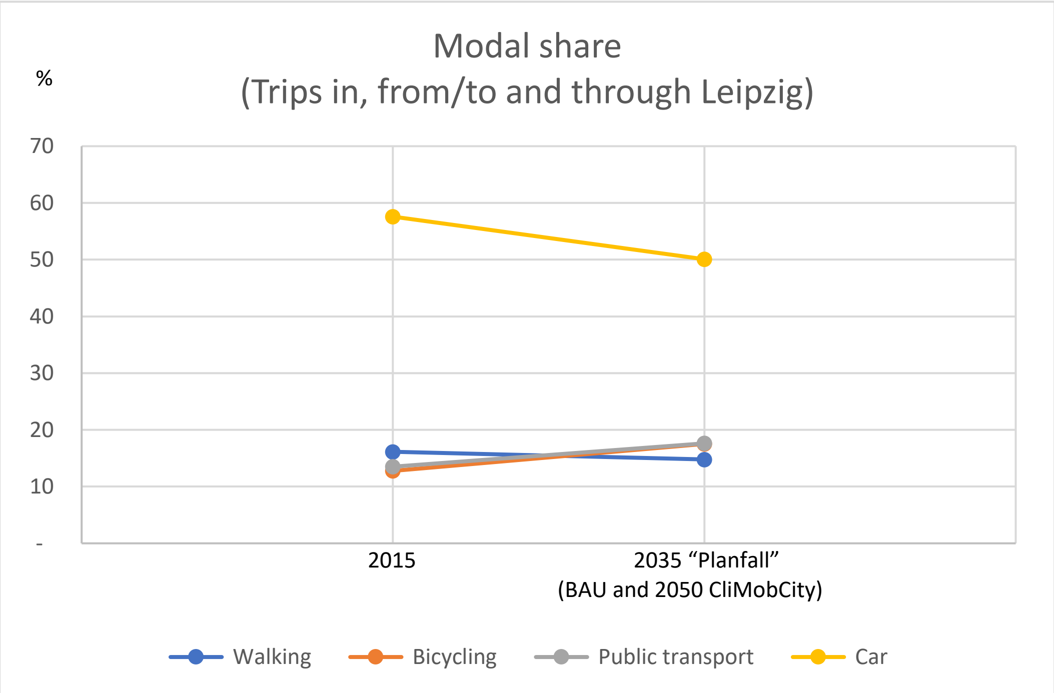
5.3.2 Outcomes of the mobility forecast: BAU and CliMobCity

The estimated change of mobility between 2015 and 2035 ("Planfall") caused by the described measures are in short:
(**Trips in, from, to and through Leipzig, all modes**)

- The total number of daily person trips increases by +10% (0.5% per year) being less than of the population growth.
- The number of daily person trips within the city[66] (share 58%) increases by 15%, that of trips from/to Leipzig[67] (share 16% in 2015) by 13%, and that of throughgoing trips[68] (share 26% in 2015) declines by 4%.
- The largest flows (trips, all modes) are present within the area consisting of the centre, the 19th century belt and the GDR post-war sections. Rather large are also the flows from and to the north western municipal area (large employers) and the southwestern region outside of the municipality.

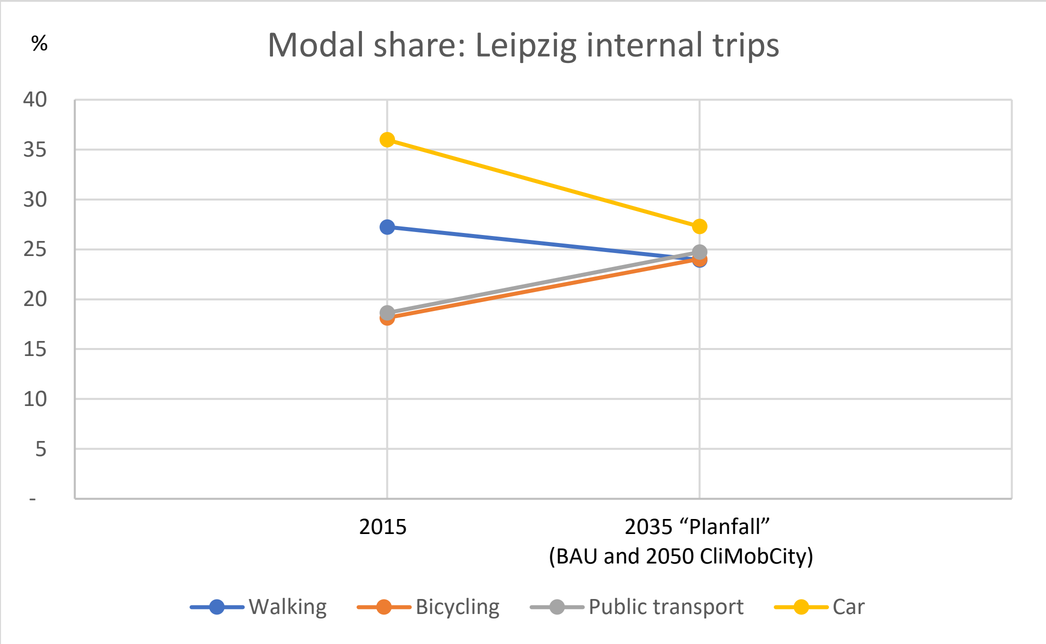
(**Trips per mode and modal share in, from, to and through Leipzig**)

- The number of daily person trips by car (share [also] 58% in 2015) declines by 5%; this is the net result of the following changes: -13% (internal trips), +8% (trips from and to Leipzig) and -4% (throughgoing trips).
- The number of daily public transport trips (share 14% in 2015) increases by 43%; this is the net result of the following changes: +52% (internal trips), +14% (trips from and to Leipzig) and -18% (throughgoing trips).
- The number of bicycle trips (share 13% in 2015) increases by 50%.



66 Two ends of the trip in the municipal area.
67 One end of the trip in the municipal area.
68 No end of the trip in the municipal area.

- For the modal share (see following figure) this implies a decline of car share of 8 %-points (from 58% to 50%), and an increase bicycling share of 5 %-points (from 13% to 18%) and of 4 %-points for public transport (from 14% to 18%). While the volume of walking trips is increasing a little bit, its share is declining by 1 %-point (from 16% to 15%).
- Regarding only Leipzig-*internal* flows, the shares of public transport and active travel shifts are larger and of car smaller than of all Leipzig flows. Also, the increase of shares of walking, bicycling and public transport and decrease of car shares is larger for internal flows than for all flows (see following figure): public transport share increases by 6 %-points (from 19% to 25%), bicycling share by 6 %-points (from 18% to 24%) car share declines by 9 %-points (from 36% to 27%).

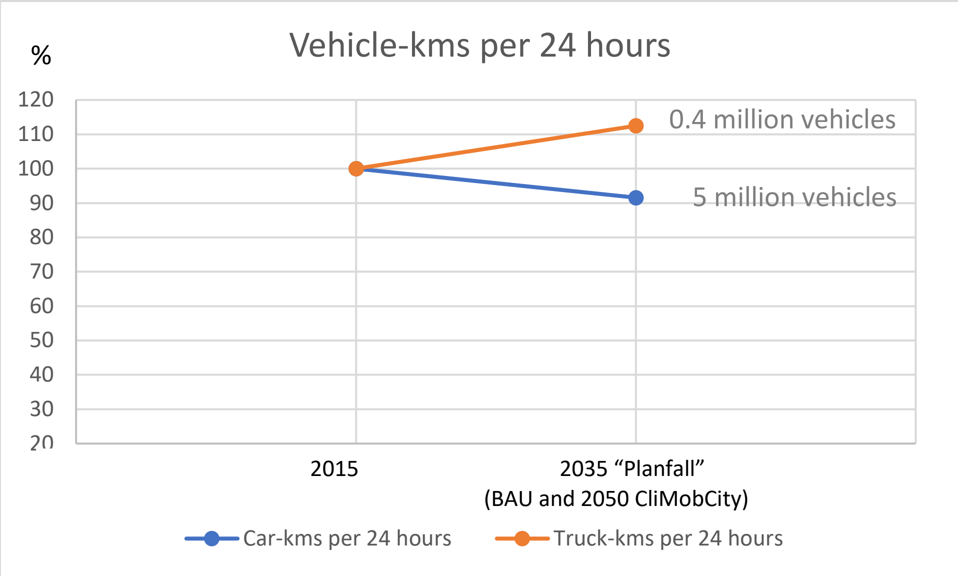


(Average distance)

- The average travel distances in, from and to Leipzig are increasing for car from 6.5 to 7 km and decreasing for public transport from 8.2 to 7.3 km.
- The average distances of walking in, from or to Leipzig are modelled to be about 1 km and slightly declining. For bicycling the average distance is about 5km and hardly changing.

(**Vehicle-kms and public transport passenger-kms in, from, to and through Leipzig within the municipal boundaries**)

- The combination of decreasing number of person trips by car, increasing average distance of car trips and change of car occupation leads to a decrease of daily car-kms of 8% (see following figure).
- The number of daily truck-kms increases by 12%. But the number of trucks is small in comparison to cars (0.4 million versus about 5 million cars).
- The planned public transport measures lead to the following increase of vehicle-kms (regional train +27%, tram +35%, bus +15%).
- This has repercussions in increasing passenger-kms: regional train +24%, tram +38% and bus +21%. For tram and bus these values are higher than of vehicle-kms, indicating that their average occupation is increasing.



(**Traffic impacts**)
The change of passenger and traffic flows has led to a reduction of the number of road vehicles between 2015 and the "Planfall 2035" (**BAU** and **CliMobCity**) on most roads. Major exceptions are the national highways and some roads in the periphery giving access/egress to the highways. This all can be seen when considering the sum of changes in the maps Road 1 and 2 below (green = decrease, red = increase), both presented on the same scale.[69]
The public transport lines mainly witness an increase of passenger flows. This is visible when summing the flow changes in the maps Public transport 1 and 2 below (green = decrease, red = increase), both being presented on the same scale.[70] In the "Planfall 2035" the service network changes lead to decreases on a few routes in comparison to the Zero scenario 2035, but also in this comparison there is more growth than decline.
Both, the road and public transport flow changes, indicate that the general growth of mobility can spatially easily be absorbed in the city, the public transport requiring less space per passenger than the road mobility. Reconstructions of road profiles and public space will be required at different places.

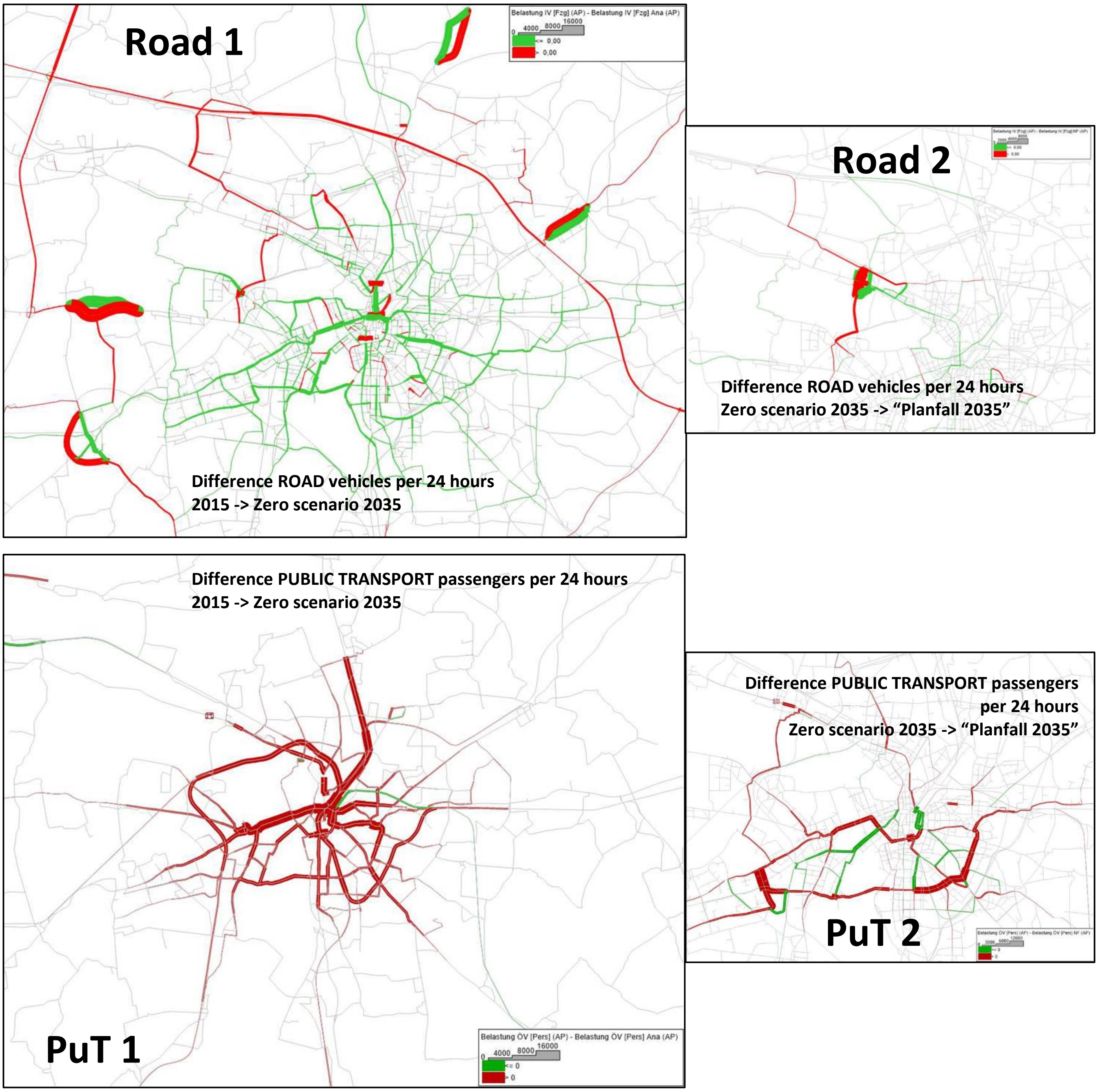
A rough interpretation of the results

- Expected modal shift policy in the *Mobility Strategy 2030* (**BAU**) appears to be very effective in Leipzig, despite of the already existing rather high quality of the public transport network, the consequence of matching pull and push measures, and partly also due to the relative high residential densities in the central areas of the city: many public transport improvements reach a relative big group of inhabitants.
- The large increase of number of public transport trips (43%) and bicycling trips (50%) goes hand in hand with a "small" decrease of number of car trips (5%), a consequence of the large share of car trips (58% in 2015 and 50% in 2035).
- The modal shift efforts provide a decline of daily internal car trips of 13% (the internal trips representing roughly 60% of all trips in, from/to and through Leipzig). This keeps the demand for road infrastructure caused by population growth (also 13%) in balance which is a favourable

69 Map Road 1 shows the change of traffic intensities between 2015 and a former (before CliMobCity) first package of measures. Map Road 2 shows the additional change of traffic intensities, starting from the intensities in map Road 1, and caused by the "Planfall 2035" measures.

70 Map PT 1 shows the change of PT passenger traffic intensities between 2015 and a former (before CliMobCity) first package of measures. Map PT 2 shows the additional change of passenger intensities, starting from the intensities in map PT 1, and caused by the "Planfall 2035" measures.

circumstance for compact city policies. The increase of number of trips from and to Leipzig will not change this result significantly, as much of that traffic is directed towards large employment concentrations along the city edge.



Green = decrease or no change, red = increase
Source: *PTV, 2020*

- The overall decline of daily car trips by 5% takes place despite of an increase of daily car trips from and to Leipzig of 8%. The latter on its turn is less than the 14% increase of public transport trips from and to Leipzig. This indicates that modal shift is taking place successfully also for trips from and to Leipzig. However, the car and PT mobility together also indicate that suburbanisation is at stake.

- The share of all daily passenger trips by car declines by 8 %-points. For city-internal mobility this is 9 %-points. Both are close to the reduction aim of 10 %-points postulated in the *Mobility strategy 2030*. Geographically the decline of car trips is the largest where the residential densities are high and the tram or train network accesses the areas well.
- The shift to public transport is the consequence of a significant increase of public transport services as foreseen in the BAU and CliMobCity scenarios (and thus assumed in the modelling input). The implementation of such amount of additional public transport services in such short period is/will be very challenging.
- As already indicated, the transport modelling does not show the effects of measures entailing shared cars and corresponding hub nodes on future mobility.

5.4 Analysed reduction of CO_2e emissions[71] (FR, EK, AvB)

The climate aim of Leipzig until 2022 was climate neutrality in 2040. This implies a reduction of CO_2e emissions of 80% by 2035 in comparison to the base year 2015. This aim has stayed the focus of the project's CO_2e analysis, despite of the city recently joining the EU Mission of 100 climate neutral and smart cities in 2030.

In the **BAU scenario** modal shift and change of average distance, cumulate in the mentioned declines of vehicle-kms, most prominently the decline of car-kms by 8% and an increase of truck-kms by 12% between 2015 and 2035. These mobility changes in combination with an increasing share of post-fossil powertrains for the remaining car-kms (as expected in the EU reference scenario), induce a carbon reduction of 25% (see blue line in the following figure). The number of public transport vehicle-kms is increasing, but these in 2035 all are electric vehicle-kms.
If for the BAU calculation not the EU reference share of post-fossil vehicles had been used for calculations, but the targeted share in the *Charging Infrastructure Concept Leipzig 2020*, the CO_2e reduction would be less.

In the **CliMobCity scenario** there is additional electrification: 100% of the public busses are electric ones in 2034. The general electrification is facilitated more strongly by an extended mobility station (passenger hub) policy according to the new (draft) Smart mobility policy. All municipal activities (e.g. logistics etc.) are to become climate neutral by 2030.
The CO_2e reduction of the CliMobCity scenario is 26%, just little bit more than of the BAU scenario (blue line). The actual difference, however, is larger because, not only is, as just mentioned, the BAU reduction actually less than shown in the figure, but also is the city's electrification ambition in the CliMobCity scenario higher[72] than in the EU reference scenario, leading to a dot between the blue and the orange line, as indicated by the red dot in the following figure.

In the Tech scenario having a larger replacement of fossil fuel vehicles, CliMobCity CO_2e emissions would decline by 34% (orange line) between 2015 and 2035. Would the electricity production also be green in 2035, the CliMobCity scenario would provide a CO_2e reduction of 41% (grey line).

These reductions do not meet the climate aims of Leipzig. Therefore a number of **forecasting lever exercises** have been conducted: What, in comparison to overall scenario 3 in the following figure:

- (overall scenario 4) if the share of cars and other LDVs would decline by 10%-points in favour of more busses and active travel?
- (overall scenario 5) if there would be 10% less "time spent" for travelling because of less road vehicle-kms?

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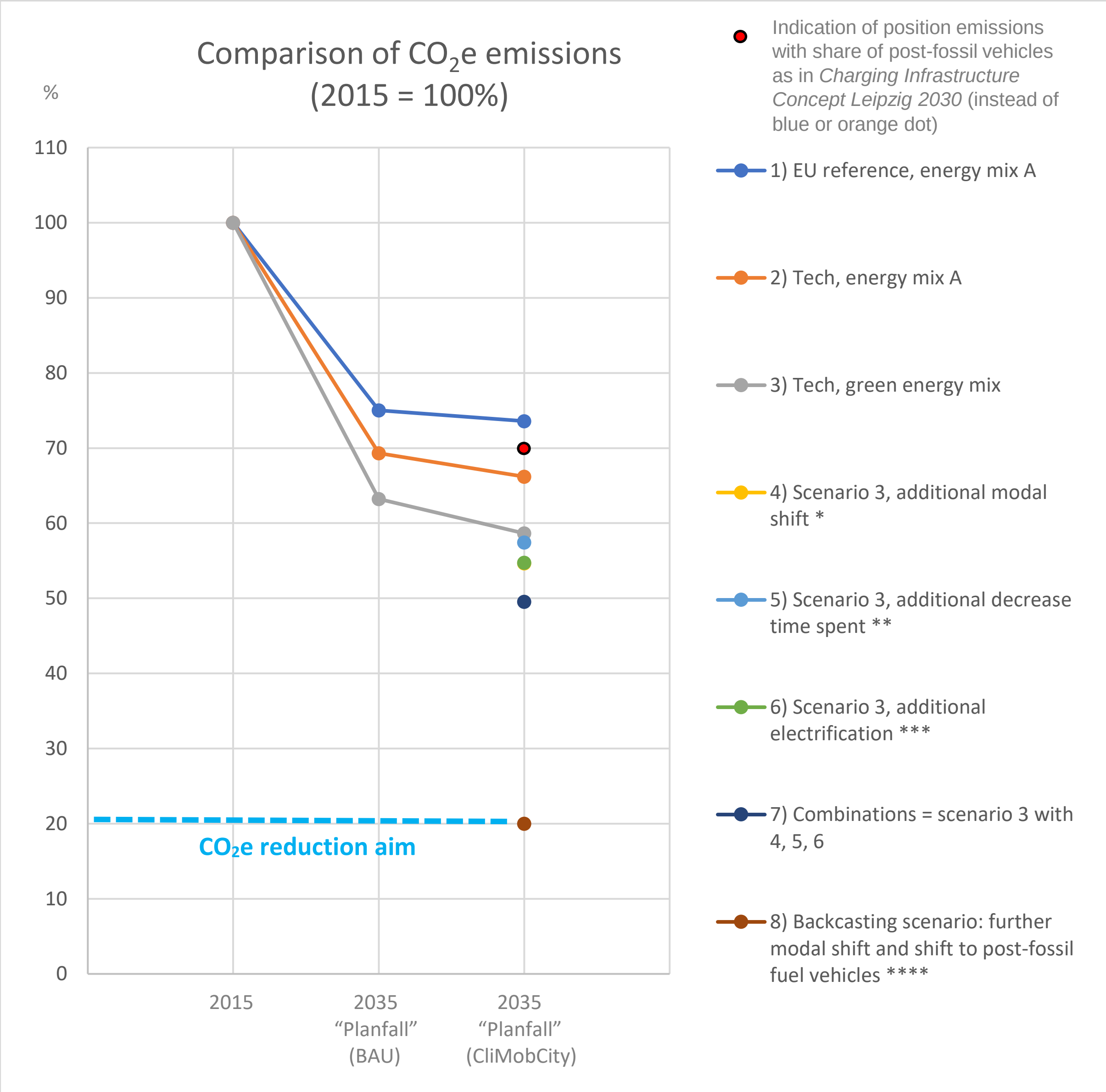
[71] For a more detailed description of the results and approach of the CO_2e analysis see the *Appendix-PIK-report*.

[72] Conform the draft *Charging Infrastructure Concept Leipzig 2030*.

- (overall scenario 6) if the share of post-fossil vehicles would be 10%-points larger?
- (overall scenario 7) if the three improvements were combined?

This would lead to total reductions in comparison to 2015 of respectively 45%, 43%, 45% or 50%, hence additional reductions of respectively 4%, 1%, 4% or 9%. Still the reduction is not sufficient, not for the aim of climate neutrality in 2040 (80% reduction in 2035), let stand of climate neutrality in 2030.



*	Share of cars and other LDVs: -10 %-points; share of public transport busses and active travel: each +5 %-points.
**	10% less time spent, because of less road vehicle-kms.
***	Share of post-fossil fuel vehicles: +10 %-points at the dispense of the share of fossil fuel vehicles.
****	Share of cars and other LDVs: -10 %-points; increasing share of post-fossil cars and other LDVs to the level of 86%, increasing share of post-fossil trucks and other HDVs to the level of 22%.

This type of presentation supports understanding of the relation between different results (dots).
But be aware of that:

- lines between the base year dot and BAU dots represent alternative developments in time;
- lines between BAU and CliMobCity dots serve the comparison, but don’t represent developments in time.

Therefore a **backcasting lever exercise** has been carried out. In such exercise one or more levers are moved into positions which lead to sufficient, namely 80% CO_2e reduction between 2015 and 2035. Also this backcasting is a what-if exercise, to be validated by demand considerations.
It shows that a near to 80% reduction could be achieved if – in comparison to overall scenario 7 – there was:

- additional reduction of the modal share of LDVs (cars etc.) in passenger mobility by another 10 %-points;
- additional electrification: thereafter 86% of the LDVs (cars etc.) would be electrified;
- additional electrification of HDVs (mainly freight) by 20% leading. Thereafter 22% of all HDVs would be post-fossil fuel ones.

These changes are the content of overall scenario 8 in the figure above (= overall scenario 10 in the overview table of *Annex 1*).

The CO_2e reductions per capita are, regarding all overall scenarios, 2-8 %-points higher than the total CO_2e reductions.

Concluding, in the overall scenarios 1 and 2 the increasing share of public transport has a positive impact for the change of CO_2e emissions. The reduction potential can be unfolded by the greening of the electricity production. In BAU the CO_2e reduction due to the change of mobility is supplemented by the shift to post-fossil fuel vehicles amongst the remaining car-kms. In CliMobCity there is additional reduction due to the electrification of all public transport vehicles and to further electrification of road vehicles. All of these reductions take place despite of population growth and increase of number of total trips and the increase of average travel distance by car.

As already indicated, the transport modelling does not show the effects of measures entailing micro-mobility services and corresponding hub nodes on future mobility, while these may have the potential to reduce CO_2e emissions of mobility in substantial amounts. But whether this is likely, is not sufficiently validated by research yet and certainly depends on the context of implemented concepts. Also this we briefly discuss this in the last chapter of this report.

5.5 Feedback from the municipal reflection on the CO_2e reduction (JB)

The first point to reflect on is the potential of CO_2e reduction in both scenarios. Both scenarios, the BAU scenario as well as the CliMobCity scenario, show how much reduction of CO_2e emissions are possible, if all measures will be implemented. Each scenario has a reduction potential of about 25% referring to the EU reference electrification share. With a more ambitious electrification share (Tech scenario) in the future and also a green energy mix for electricity production, the CO_2e reduction potential reaches up to about 40%. With mobility changes going beyond the Mobility Strategy 2030 and electrification measures going beyond the Infrastructure Charging Concept 2030, more CO_2e reduction can be achieved.

This leads to mainly two conclusions. The first one is, that there is a need for renewable energies as fast as possible and as much as possible. In our opinion the future of mobility is driven by electrification, individual mobility as well as public transport. This should be the way to operate vehicles climate neutral. The second conclusion is that all measures should be speeded up to reach the goals as soon as possible. This is why the City of Leipzig takes part in the EU Mission of 100 climate neutral and smart cities in 2030.

All potential which is shown in the table above, is not enough to get to climate neutral mobility. So, the lesson learned can only be to do even more, to develop new measures, to encourage people even more to use public transport and other climate friendly modes of mobility.

But in the end the truth is also that a city cannot influence all factors. A lot of factors are decided on the national or EU level, such as the extension of renewable ore the development and application of E-fuels. So, both levels need to do more to make a climate neutral mobility possible.

But there are also concerns on the city level. Public transport is very expensive. So, measures like new trams ore busses, like expanding the tram network depend very much on tax income of the city. The city of Leipzig doesn’t have such a strong tax income as other German cities. For example, Leipzig has only a third tax income from companies like the City of Nuremberg, although Leipzig is bigger. But the economic structure in the eastern parts of Germany is 30 years after the reunification still weaker than in the western parts.

Besides the financial concerns there are concerns referring directly to the measures themselves. For example, it is quite easy to buy new trams with bigger capacity compared to the planning process of establishing a new tram line. Such a planning process will last several years. So, it takes a lot of time which, as the results of the potential modelling show, we don’t have. But not only big measures like new tram lines are challenges. For more electrification of private cars more charging infrastructure is needed. In a very dense city like Leipzig with a lot of quarters of multi-storey buildings there is often no private space to charge an electric car. So, the city needs to provide public space to enforce the extension of charging infrastructure. But public space is limited and there are even more demands for example like infrastructure for bikes, street lighting and trees.

Finally, there are a lot of things to do. On the EU and national level, the extension of renewable and E-fuels need to be enforced. On the city level the extension of public charging infrastructure and the efforts for more public transport need to be enforced.

6 Reflection by and recommendations from the advisory partners TU Delft and PIK to the partner cities

The estimated future reduction of CO_2e emissions from passenger and freight mobility in cities as a result of measure packages proposed by the partner cities and given the change of energy mix for electricity production is significant, also against the background of an expected growth in the urban population.

Nevertheless, the results are not sufficient to meet the cities' reduction targets. This is the central conclusion to start from in a critical reflection of the climate mitigation policies of the partner cities and the work of the 2050 CliMobCity project. What are the causes of the relative modest CO_2e reduction, where did it take place in more satisfactory magnitudes and where not? And what are the central angles to change policies in a more effective direction?

6.1 Reflection on climate aims in the light of insufficient CO_2e reduction (EK, AvB, FR)

Recalling the **climate targets** of the partner cities for the project, Bydgoszcz aims for climate neutrality in 2050, Leipzig in 2040 (or 80% CO_2e reduction in 2035), Plymouth in 2030 and Thessaloniki for a 42% reduction of the emissions between 1990 and 2030, being equivalent with 52% reduction between 2018 and 2030.[73]

The CliMobCity measure packages with a share of post-fossil vehicles corresponding with the Tech scenario or more (in Thessaloniki) and assuming the electricity production to be all green leads to CO_2e reductions of 19% (Bydgoszcz), 32% (Plymouth[74]), 21% (Thessaloniki, reference year being 2018) and 41%. **The gap with the cities' targets is then 81%** (Bydgoszcz)**, 68%** (Plymouth)**, (52%-21%=) 31%** (Thessaloniki with reference year 2018)**, and 39%** (Leipzig) respectively**.**

For this reason the project for each city explored the impact of further measures in what we call **forecasting lever exercises** (overall scenarios 4-7 in following table). These are described in Section 6.4. The mobility and/or powertrain improvements in these scenarios provide up to another 13% (Bydgoszcz, Plymouth), 9% (Leipzig) and 3% (Thessaloniki) reduction. **The gap now is respectively 68%** (Bydgoszcz), **55%** (Plymouth), **28%** (Thessaloniki) **and 30%** (Leipzig)**.**

For Thessaloniki and Leipzig, the two cities not already aiming for climate neutrality at the end of their planning period, also **backcasting lever exercises** were carried out. These indicate that with more powerful modal shift from car to other modes and shift from fossil fuel to post-fossil fuel cars the cities reduction aims can be achieved. The magnitude of these shifts, however, is far beyond the shift speeds envisaged in current ambitious measure packages.

Given the magnitude of the gap the question arises whether the partner cities' climate aims are perhaps too ambitious. The answer is: no, very likely not too ambitious. Admittedly, according to the EU climate aims the CO_2e emissions are to be reduced by 55% in 2030 and all the way in 2050, which is less stringent than most partner cities' aims. But the EU climate aim relates to pathways that to some extent distract from the urgency, like the acceptance of "negative" emissions. This is allowing overshoot CO_2e emissions to occur (positive emissions) and in return assuming that the CO_2e overshoot emissions will be removed again (negative emissions).[75] The urgency is therefore perhaps

[73] Leipzig and Thessaloniki have in 2022 joined the EU Mission for 100 climate neutral and smart cities in 2030, implying a sharpening of their reduction aims. The project sticked to the municipal aims before the EU mission.

[74] The mobility basis for this CO_2e result is to be validated by a multi-modal transport model, in which also all vehicle-kms outside of the municipal area are excluded.

[75] Meaning that the CO_2e overshoot is absorbed from the air and stored underground or processed into new products or that absorbing takes place biologically, for instance by planting new trees in addition to the normal stock of trees.

better expressed by the so-called carbon budgets. A carbon budget describes the maximal CO_2e emission still allowed in order to limit global warming to a certain amount without accepting negative emissions. It is a global quantity that can be decomposed to the level of continents, countries, regions or cities.[76] The carbon budget divided by the average annual emission provides the number of years left until no carbon may be emitted anymore, hence the year in which climate neutrality would need to be achieved. Statements referring to this carbon budget angle and regarding the year in which climate neutrality would need to be achieved, include:

- For max +1.5°C the world needs to achieve climate neutrality not much later than 2035, under the condition that the reduction would start immediately and take place in a linear fashion, and otherwise earlier (United Nations Environment Programme, 2021, p. 35; PBL Netherlands National Assessment Agency, 2021, p. 46).
- Or as IPCC (2023a; underlining by authors) puts it: "If the annual CO_2 emissions between 2020-2030 stayed, on average, at the same level as 2019, the resulting cumulative emissions would almost exhaust the remaining carbon budget for 1.5°C …". Hence climate neutrality would need to be achieved by 2030.
- An example of decomposition of the world carbon budget to the city level is The Hague. The conclusion of CE Delft (Shilling et al., 2017, p. 7)[77] was that if the city endorses the 1.5°C target, it would need to become climate neutral before 2030.

If climate neutrality can't be achieved on time, meaning that there is an overshoot of CO_2e emissions, concepts to after all respond to the climate aims are 'net zero emissions' or 'Carbon Dioxide *Removal*' (CDR). Both are about achieving climate neutrality on time by compensating overshoot (= part of the positive) emissions by negative emissions. The difference between both approaches is that "net zero CO_2 emissions is generally applied to emissions and *removals* **under direct control or territorial responsibility of the reporting entity**, while carbon neutrality generally includes emissions and *removals* within **and beyond** the direct control or territorial responsibility of the reporting entity" (IPCC, 2023b; highlighting by authors). In both concepts, mobility overshoot emissions would be compensated by negative emissions in other sectors (for optional directions see footnote 75), but in case of net zero emission aims the actor like the municipality itself would be responsible for such compensation. A city then must answer the question which municipally organised measure(s) could provide sufficient negative emissions. We in this report do not elaborate negative emission options.

6.2 Developments and CO_2e emissions in the BAU scenarios (EK, AvB, FR)

We recall the main factors of the change of CO_2e emissions of mobility. These are the **vehicle-kms** per mode and in different network parts of a mode, the share of different **powertrains** per mode, in particular the share of post-fossil fuel road vehicles, and the energy mix for **electricity production** (e.g. how green?). The first two factors determine the energy consumption, the three factors together determine the CO_2e emissions. A shift from car to e.g. (electric) public transport or a shift from carbon to e.g. electric road vehicles will not substantially reduce CO_2e emissions if the share of green electricity production is low. And only a combination of substantial mobility, powertrain structure and energy mix changes can result in sufficient reduction of CO_2e emissions. The challenge is to find relevant combinations of mobility and powertrain changes, given a certain energy mix. The Interregional learning in the project was to and has helped in this search process.
In **Bydgoszcz** there is a change of population of -3.5% (-0.1%/y), a small increase of total number of trips, an 8% increase of car trips[78] and a near to 25% increase of average travel distance (car and

[76] The consequence of the world carbon budget is not completely the same for all countries/continents: the specific impact will depend on the current carbon and future footprints and on whether the developed countries are expected to decarbonise faster in favour of allowing developing countries decarbonising slower.

[77] Starting from the carbon budget concluded (Van Vuuren et al. 2016; a PBL report) for the Netherlands after the Paris agreement.

[78] At the expense of other modes, in particular public transport (-2% trips despite of a substantial expansion of the tram network).

public transport). This is the net result of suburbanisation and substantial investments into the extension of the road and tram networks. All cumulates in an increase of car-kms by 38%. Apparently the comparative attractiveness of public transport on all mobility relations is insufficient. Nevertheless, because of the expected shift to post-fossil fuel cars and also some greening of the energy mix for electricity production, in BAU there is only little increase of CO_2e emissions (+1% in the period 2021-2050; EU reference powertrain scenario; see *Reflection Table 1*).

In **Plymouth** the population is projected to increase by 13% (0.7%/y), the number of car trips in BAU changes correspondingly[79] (also 13%), there is an increasing average travel distance, and car-kms change by +19%.[80] This all is a result of a relative car-oriented measure package and some suburbanisation. Given some shift to post-fossil fuel vehicles the CO_2e emissions change by -5%.

The population of the municipality of **Thessaloniki** is expected to grow by 6% (0.5%/y), and the total number of trips increases by 9%, but the number of car trips nevertheless declines by 14%. While the average distance of public transport is increasing that of cars is changing by -4%. All cumulates in a change of car-kms of -18%. The major background to this quite spectacular decline is the inauguration of the metro system with 2 lines and of the suburban railway line, the presence of high urban densities and the redistribution of public space in some main boulevards through the city centre in favour of active travel and bus lanes, made possible by the grace of metro access. However, the change of CO_2e emission is only -8% [81] (see *Reflection Table 1*), as there is little shift from fossil fuel to post-fossil fuel vehicles in the remaining car-kms, little innovation in the freight sector, still quite some 2-wheeler traffic, and as the carbon benefit of electric metro use is limited because of the energy mix for electricity production.

The projections for **Leipzig**'s population development come down to 13% (0.6%/y). The number of trips increases by 10%, that of car trips changes by -5%. Average car distance shows a minor increase. All together leads to a change of LDV-kms (including car-kms) of -8%. This all is caused by substantial investments into the public transport network next to redistributing public space in favour of public transport and active travel, and in the context of relative high urban densities. The decline of CO_2e emissions because of less car-kms is supplemented by CO_2e reduction by a substantial shift to post-fossil vehicles amongst the remaining car-kms. Together CO_2e emissions change by -25%. Would instead of the EU reference scenario Leipzig's BAU electrification rate apply, the CO_2e reduction in BAU would be less.

Reflection Table 1 illustrates the relevance all factors of CO_2e reduction. Take the last two cities: in Thessaloniki -18% car-kms relate to -8% CO_2e emissions, in Leipzig -8% car-kms to -25% CO_2e emissions. Both cities have little innovation in the freight transport sector and a limited greening of the electricity production (see *Reflection Table 3*). But there is a big difference in shift from fossil fuel to post-fossil fuel cars: being substantial in Leipzig and very small in BAU Thessaloniki (see *Reflection Table 2*). This affects the CO_2e emission amongst the remaining car-kms. In Leipzig this powertrain shift supplements the CO_2e reduction caused by the change of mobility and some greening of the electricity production, in Thessaloniki's BAU scenario there is little supplementing.

[79] The modal shares are as in the base year.
[80] This for trips from/to Plymouth includes the trip lengths outside of the municipality, as trip lengths only referring to the part inside Plymouth could not be provided.
[81] From the viewpoint that Thessaloniki's climate aim is actually defined as reduction of 1990 and not 2018 CO_2e emissions which lie approximately 20% higher, the same absolute reduction represents an emission increase of 10%.

Reflection Table 1
*Change of car-kms, share of post-fossil fuel cars, and CO_2e emissions in **overall scenario 1a** in comparison to the base year*
*(**BAU,** powertrain shares according to EU reference scenario; energy mix A for the future year)*

	Planning period	Change of car-kms (%) from base year to BAU	Change of share of post-fossil fuel cars (%-points) from base year to EU reference scenario * (off-rounded)	Change of CO_2e (%) from base year to BAU **
Bydgoszcz	**2021-2050**	+38%	+23 %-points	+1%
Plymouth	**2015-2034**	+19%	+17 %-points	-5%
Thessaloniki	**2018-2030**	-18%	+1 %-point	-8%
Leipzig	**2015-2035**	-8%	+16 %-points	-25% ***

* See *Reflection Table 2*. Source: *Appendix-PIK-Report (PIK, 2023)* on the basis of *Taylor et al. (2019)*.
** As in overall scenario 1a in the overview table of *Annex 1*.
*** = Less reduction if not EU reference shares (*Reflection Table 2*), but concrete Leipzig BAU electrification target shares are taken into account.

Reflection Table 2
Share of post-fossil fuel cars in the EU Reference and the Tech scenario

	Share (%) of post-fossil fuel cars in base year	Share (%) of post-fossil fuel cars in future year (EU reference scenario) *	Share (%) of post-fossil fuel cars in future year (Tech scenario) **
Bydgoszcz (2021-2050)	**0.2**	**23**	**43**
Plymouth 2015 (2015-2034)	**1**	**18**	**56**
Thessaloniki (2018-2030)	**0.2**	**1.5** used for BAU. For CliMobCity use of local aim: 37	**11** used for BAU. For CliMobCity 37 plus used
Leipzig (2015-2035)	**1**	**17**	**51**

* = Used for BAU and CliMobCity (blue line in cities' CO_2e figure).
** = Used for BAU and CliMobCity (orange line in cities' CO_2e figure).

Reflection Table 3
Share of fossil electricity production (Source: Annex 2)

	Share (%) fossil electricity production in base year	Reduction of share (%-points) from base energy mix to energy mix A (future)	Share (%) fossil electricity production in energy mix A (future year = reduction still needed to achieve fully green electricity production) *
Poland (2021-2050)	**88**	**44**	**44**
UK (2015-2034)	**55**	**35**	**20**
Greece (2018-2030)	**70**	**25**	**45**
Germany (2015-2035)	**60**	**9**	**51**

* = Used for all future scenarios (BAU, CliMobCity, EU reference and Tech)

6.3 Developments and CO_2e emissions in the CliMobCity scenarios (EK, AvB, FR)

Plymouth, Thessaloniki and Leipzig have each developed one **CliMobCity scenario**, Bydgoszcz two **CliMobCity scenarios** (W1 and W2) plus **two sensitivity-analysis scenarios** (W1+ and W2+).
Plymouth's CliMobCity measure package is clearly modal shift directed, supporting active travel, extending regional rail and investing into public bus infrastructure. The bus service development, although currently lying largely outside of the municipal and regional public decision competence, is via the measure "bus back to better" assumed to be substantially improvable again.
The CliMobCity measure packages of **Thessaloniki** and **Leipzig** focus on the electrification of municipal and public transport vehicles, and on promoting shared mobility, which supplements the powerful modal shift measures in their BAU packages. Of course electrification is also an objective in Bydgoszcz and Plymouth, and all cities are busy with parking regulation, shared vehicle and mobility hub development.
Bydgoszcz in CliMobCity focusses on the change of mobility and land use. In its first main CliMobCity scenario (W1) the areal coverage of public transport is extended in comparison to BAU, following the land use development (suburbanisation) of the BAU scenario, and the road network is extended, just as in BAU. Furthermore, in the central city parts private car traffic is limited. The second CliMobCity scenario (W2) focusses on – in comparison with BAU and W1 – of reurbanisation (1/3 of peripheral BAU housing is moved to the central city part), an increase of public transport service frequencies in the central area, a stricter regime of limiting road traffic in the central city part, and a reduction of road investments. The sensitivity scenarios are explained further on.

The main result of the CliMobCity measures (overall scenario 1) is shown in *Reflection Table 4*.

- the CliMobCity W1 **car-kms in Bydgoszcz** increase in similar magnitudes as in BAU (38%), or less, namely 31% (CliMobCity W2). The improved development in W2 is due to the better balance of push and pull measures and the reurbanisation. Still, the increase of road vehicle-kms is substantial. In both cases the shift to post-fossil fuel vehicles and to some extent also the greening of electricity production (*Reflection Table 3)* slightly decreases **CO_2e emissions** from +1% (BAU) to -1% (W2);
- the **car-kms in Plymouth** increase "only" by 5% (CliMobCity), a consequence of modal shift. This together with the shift to post-fossil fuel cars and the greening of electricity production (*Reflection Table 3)* provides a change of **CO_2e emission** of -9%.[82]
- the **car-kms in Thessaloniki** are roughly the same in BAU and CliMobCity. There is, however, the electrification of municipal vehicles, the shared electric car program and the additional electrification of cars, their share being 37 %-points higher than in the base year.[83] Together with some greening of electricity production (*Reflection Table 3)* this leads to an **CO_2e emission** change of -14% (CliMobCity);
- the **car-kms in Leipzig** are the same in BAU and CliMobCity. The electrification of PT busses and cars together with the greening of electricity production (*Reflection Table 3)* provide 1% less overall **CO_2e emissions** than in BAU. Would one, however, not consider the EU reference powertrain structure for 2035, but the concrete Leipzig electrification target shares relevant for BAU and CliMobCity,[84] the difference of CO_2e emissions between overall scenario 1a (BAU) and 1 (CliMobCity) would be larger.

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[82] The modal shift leading to the reduction of car-kms is not modelled in Plymouth, but based on experts' estimation and has yet to be validated. The travel distances and vehicle-kms for journeys from/to Plymouth include the journey parts outside of the municipal area. Concluding, the estimated change of performances in Plymouth requires some validation using a more advanced transport model

[83] Due to the city's *Charging Infrastructure Plan* (MoT, 2021). In the first half of the project not yet decided. Therefore considered to be the domain of the CliMobCity scenario.

[84] According to the existing *Charging Infrastructure Concept Leipzig 2020* (lower than in the EU reference scenario) for the BAU scenario, and according to the draft *Charging Infrastructure Concept Leipzig 2030* (higher than in the EU reference scenario).

Reflection Table 4
*Change of car-kms, share of post-fossil fuel cars, and CO_2e emissions in **overall scenario 1** in comparison to the base year*
*(CliMobCity**,** powertrain shares according to EU reference scenario; energy mix A for the future year)*

	Planning period	Change of car-kms (%) from base year to CliMobCity	Change of share of post-fossil fuel cars (%-points) from base year to EU reference scenario * (off-rounded)	Change of CO_2e (%) from base year to CliMobCity with EU Reference scenario **
Bydgoszcz	**2021-2050**	+31% (W2) to +20 (W2+)	+23 %-points	-1% (W2) to -2% (W2+)
Plymouth	**2015-2034**	+5%	+17 %-points	-9%
Thessaloniki	**2018-2030**	-18%	+37 %-points ***	-14%
Leipzig	**2015-2035**	-8%	+16 %-points	-26% ****

* See *Reflection Table 2*. Source: *Appendix-PIK-Report (PIK, 2023)* on the basis of *Taylor et al. (2019)*.
** As in overall scenario 1 in the overview table of *Annex 1*.
*** Not according to the EU reference scenario but to the announced municipal electrification aim.
**** = More reduction if not EU reference shares, but concrete Leipzig BAU electrification target shares are taken into account.

Bydgoszcz had, as indicated above, next to its CliMobCity scenarios (W1 and W2) defined so-called **CliMobCity PLUS [“+”] scenarios** (W1+ and W2+), meant to explore the imaginable effects of **changing mobility preferences** of people. Imaginable because of the long period envisaged: 2021-2050. Adjusted preferences means that more people would choose other ways of mobility, even if the transport supply remains the same. In the spirit of climate-friendly mobility this could mean that more people prefer to travel shorter distances or less people prefer to travel by private car in favour of more public transport and active travel. The change of mobility preferences would be the consequence of changing awareness of benefits, disadvantages and urgencies, for instance understanding better and having more affinity with the climate challenge. In Bydgoszcz’ PLUS scenario W2+ the change of mobility has led to a smaller increase of car-kms (+20%) than in W2 (+31%), the corresponding reduction of CO_2e emission being respectively 2% instead of 1%. Also in W1+ there are less car-kms and CO_2e emissions than in W1.

Future research will need to validate the adjusted mobility preferences in the PLUS scenarios, the resulting mobility changes and additional CO_2e reduction. However, on the very long term, like 2050, the planning horizon for the explorations of Bydgoszcz in the project, a change of preferences is likely to take place, and the direction of the change is likely to be “more sustainability”, given the societal challenges and given the direction of awareness raising actions being clearly directed towards more sustainability. This expectation is at odds with the current practice in transport models which typically assumes the current mobility preferences to remain constant in the future. The reasoning of this practice is not that there would be no change of preferences, but simply that there is little knowledge and apparently little research about such change. We address awareness raising further on in this chapter.

The results presented up to here were based on the powertrain shares according to the EU reference scenario. Instead one can imagine the transition to post-fossil fuel vehicles to be faster, namely according to the **Tech scenario**, and correspondingly CO_2e emissions to decline more (*Reflection Table 5*). The achieved changes of CO_2e emissions then are estimated to lie between -6% and -34%.

Reflection Table 5
*Change of car-kms, share of post-fossil fuel cars, and CO_2e emissions in **overall scenario 2** in comparison to the base year*
(CliMobCity, powertrain shares according to Tech scenario; energy mix A for the future year)

	Planning period	Change of car-kms (%) from base year to CliMobCity	Change of share of post-fossil fuel cars (%-points) from base year to Tech scenario * (off-rounded)	Change of CO_2e (%) from base year to CliMobCity with Tech scenario **
Bydgoszcz	**2021-2050**	+31% (W2) to +20 (W2+)	+43 %-points	-6% (W2) to -7% (W2+)
Plymouth	**2015-2034**	+5%	+55 %-points	-24%
Thessaloniki	**2018-2030**	-18%	+37 %-points ***	-15%
Leipzig	**2015-2035**	-8%	+50 %-points	-34%

* See *Reflection Table 2*. Source: *Appendix-PIK-Report (PIK, 2023)* on the basis of *Taylor et al. (2019)*.
** As in overall scenario 2 in the overview table of *Annex 1*.
*** Not according to the Tech reference scenario but to the announced municipal electrification aim.

The results presented up to here were all based on the current energy mix for electricity production in the base year and energy mix A in the future year. If instead the **energy mix** would be **green** in the future year (100% green instead of fossil fuel shares still being 44% [Bydgoszcz], 20% [Plymouth], 45% [Thessaloniki], 51% [Leipzig]; see *Reflection Table 3*) the achieved changes of CO_2e emissions would lie between -19 and -41% (*Reflection Table 6*).

Reflection Table 6
*Change of car-kms, share of post-fossil fuel cars, and CO_2e emissions in **overall scenario 3** in comparison to the base year*
(CliMobCity, powertrain shares according to Tech scenario; green energy mix for electricity production in the future year)

Green energy mix for electricity production	Planning period	Change of car-kms (%) from base year to CliMobCity	Change of share of post-fossil fuel cars (%-points) from base year to Tech scenario (off-rounded) *	Change of CO_2e (%) from base year to CliMobCity with Tech scenario and green electricity production **
Bydgoszcz	**2021-2050**	+31% (W2) to +20 (W2+)	+43%	-19% (W2) to -20% (W2+)
Plymouth	**2015-2034**	+5%	+55%	-32%
Thessaloniki	**2018-2030**	-18%	+37%	-21%
Leipzig	**2015-2035**	-8%	+50%	-41%

* See *Reflection Table 2*. Source: *Appendix-PIK-Report (PIK, 2023)* on the basis of *Taylor et al. (2019)*.
** As in overall scenario 3 in the overview table of *Annex 1*.

Reflection Table 7a gives an overview of the CO_2e reductions achieved in the different scenarios as presented in the *Reflection Tables 1, 4, 5* and *6*. The design of the carbon analysis in the project does not allow to draw elaborated conclusions concerning the contribution of single factors to the CO_2e reduction. But summarising the former findings leads to the following statements. In Bydgoszcz and Plymouth the mobility measures in both, BAU and CliMobCity, do not lead to a reduction of car-kms. The favourable change of CO_2e emissions, that can nevertheless be achieved, is mainly due to the

Reflection Table 7a
*Overview of change of CO_2e emissions in **overall scenarios 1a, 1, 2** and **3** in comparison to the base year*

	Planning period	**Overall scenario 1a (BAU, EU reference, future energy mix A)** (from *Reflection Table 1*)	**Overall scenario 1, (CliMobCity, EU reference, future energy mix A)** (from *Reflection Table 4*)	**Overall scenario 2, (CliMobCity, Tech scenario, future energy mix A)** (from *Reflection Table 5*)	**Overall scenario 3, (CliMobCity, Tech scenario, future green energy mix)** (from *Reflection Table 6*)
Bydgoszcz	**2021-2050**	+1%	-1% (W2) to -2% (W2+)	-6% (W2) to -7% (W2+)	-19% (W2) to -20% (W2+)
Plymouth	**2015-2034**	-5%	-9%	-24%	-32%
Thessaloniki	**2018-2030**	-8%	-14% *	-15%	-21%
Leipzig	**2015-2035**	-25% **	-26% ***	-34%	-41%

* Including announced municipal private road vehicle electrification target shares.
** = Less reduction if not EU reference shares, but concrete Leipzig BAU electrification target shares are taken into consideration.
*** = More reduction if not EU reference shares, but concrete Leipzig BAU electrification target shares are taken into consideration.

Reflection Table 7b
Main types of measures (mobility, electrification etc.) and energy backgrounds leading to the CO_2e reductions mentioned in Reflection Table 7a

1	2	3	4	5	6
	Planning period	**Overall scenario 1a (BAU, EU reference, future energy mix A)**	**Overall scenario 1, (CliMobCity, EU reference, future energy mix A)**	**Overall scenario 2, (CliMobCity, Tech scenario, future energy mix A)**	**Overall scenario 3, (CliMobCity, Tech scenario, future green energy mix)**
		Focus measures and backgrounds additional to the base year	Focus measures and backgrounds additional to column 3	Focus measures and backgrounds additional to column 4	Focus measures and backgrounds additional to column 5
Bydgoszcz	**2021-2050**	• Powertrain • Energy mix A	• Mobility • Zero emission bus fleet	• Powertrain	• Green energy mix
Plymouth	**2015-2034**	• Powertrain • Energy mix A	• Mobility	• Powertrain	• Green energy mix
Thessaloniki	**2018-2030**	• Mobility • Energy mix A	• Powertrain • Shared electric cars • Electrification of many bus lines	• Powertrain	• Green energy mix
Leipzig	**2015-2035**	• Mobility • Powertrain	• Powertrain • All busses electric	• Powertrain	• Green energy mix

* Mobility = about e.g. modal shift and change of travel distances, cumulating in the change (e.g. reduction) of car-kms.
** Powertrain = mainly about shift from fossil fuel **cars** (e.g. gasoline, diesel) to post-fossil fuel **cars** (e.g. electric or hydrogen cars).

electrification of cars and – in Bydgoszcz – especially the greening of the electricity production (*Reflection Table 7b*). In Thessaloniki, comparing the columns, the largest reduction is achieved in overall scenario 1a. In that scenario there is hardly any shift to electric cars while also the greening of the energy mix for electricity production is modest. The change of mobility there is the largest contributor to the CO_2e reduction. In Leipzig it is the combination of mobility and car electrification in BAU (the greening of electricity production is limited; see *Reflection Table 3*) providing the largest contribution to the CO_2e reduction (25%; *Reflection Table 7a*), as the greening of the energy mix until 2035 is rather modest.

The lowest and highest CO_2e emission of the four cities per overall scenario in *Reflection Table 7a* are summarised in *Reflection Table 8*. The analysed CO_2e reductions are not sufficient to meet the cities' CO_2e reduction targets, even of the energy mix for electricity production was entirely green.

Reflection Table 8
Minimum and maximum change of CO_2e emission within the four cities per overall scenario (1a, 1, 2 and 3) in Reflection Table 7a
(scenario names and table colours correspond with the overview table in Annex 1)

	Change of CO_2e emission (%) in comparison to the base year	
	Lowest value of the 4 cities	**Highest value of the 4 cities**
Overall scenario 1a (BAU, EU Reference, energy mix A)	+1	-25
Overall scenario 1 (CliMobCity, EU Reference, energy mix A)	-1	-26
Overall scenario 2 (CliMobCity, Tech, energy mix A)	-6	-34
Overall scenario 3 (CliMobCity, Tech, green energy mix)	-19	-41

6.4 Additional CO_2e reduction by additional measures (EK, AvB, FR)

Given the gap between targeted and achieved CO_2e reduction, as indicated in Sections 6.1 to 6.3, the project was interested to explore the CO_2e reduction of additional mobility and/or powertrain measures. This took place by means of so-called **lever exercises** with the carbon model (EUCalc). The project first defined core mobility changes[85] in comparison to overall scenario 3 (CliMobCity measure packages, Tech powertrain shares, green energy mix for electricity production) and considering additional measures. These were:

- (overall scenario 4) an additional modal shift: the share of LDVs is reduced by another -10 %-points in change for a higher share of active travel and public transport (+ 5 %-points each);
- (overall scenario 5) 10% less road time spent (road vehicle-kms);
- (overall scenario 6) 10 %-points additional share of post-fossil LDVs at the dispense of fossil fuel ones;
- (overall scenario 7) a combination of these measures (overall scenarios 3, 4, 5 and 6).

The performance improvements were modelled by moving the levers in the carbon model to corresponding positions, all in the what-if mode, as there was no preceding mobility modelling.

The results are shown in *Reflection Table 9* and the overview table in *Annex 1*: the total reduction in comparison to the base year ranges between 24% (min, Thessaloniki) and 50% (max, Leipzig). With reference to overall scenario 7 there is an additional CO_2e reduction of 3% (min, Thessaloniki) and 13% (max, Bydgoszcz and Plymouth). The remaining emissions still represent 28% (min, Thessaloniki, looking towards the aim of 52% reduction) to 68% (max, Bydgoszcz towards the aim of 100% reduction) of the base year CO_2e emissions. In other words, none of these reductions is sufficient to meet the CO_2e reduction aims of the partner cities.

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[85] The term core mobility change is explained in *Chapter 1*.

Reflection Table 9
*Minimum and maximum total change of CO_2e emission of the four cities in the **forecasting lever exercises***
(yellow; scenario names and table colours correspond with the overview table in Annex 1)

	Change of CO_2e emission (%) in comparison to the base year	
	Lowest value of the 4 cities	**Highest value of the 4 cities**
Overall scenario 3 (CliMobCity, Tech, green energy mix)	-19	-41
Overall scenario 4 (= overall scenario 3 plus additional modal shift)	-22	-45
Overall scenario 5 (= overall scenario 3 plus decrease time spent)	-21	-43
Overall scenario 6 (= overall scenario 3 plus additional shift to post-fossil fuel vehicles)	-22	-45
Overall scenario 7 (= overall scenario 3 plus combination of additional measures of overall scenarios 4, 5 and 6)	-24	-50

For Thessaloniki and Leipzig also **backcasting lever exercises** were carried out, again starting from overall scenario 3 and the cities' climate aims. Which additional (what-if) core mobility changes would be needed to achieve the needed CO_2e reduction? For Bydgoszcz and Plymouth such backcasting lever exercises were not conducted, as these two cities – contrary to Thessaloniki and Leipzig[86] – planned to be climate neutral at the end of the envisaged planning period, meaning that all their vehicles would need to be post-fossil fuel ones by then and therefore measure priorities (like first public transport development, then electrification or the other way around) are less relevant.

The additional measures in the backcasting scenarios in comparison to overall scenario 3 (= CliMobCity, Tech scenario, green energy mix) led to the following total CO_2e reduction between the base and future year: -54% in overall scenario 9 (Thessaloniki) and -80% in overall scenario 10 (Leipzig), both being sufficient in the light of the cities' reduction aims (*Reflection Table 10*; the footnotes in the table summarise the content of additional measures).

Reflection Table 10
Total change of CO_2e emission in the backcasting lever exercises for Thessaloniki and Leipzig
(scenario names and table colours correspond with the overview table in Annex 1)

Name scenario	Ingredients of the scenario	**Change of CO_2e emission**	
		%	**Comparison to reduction aim**
Overall scenario 3 Thessaloniki	**Tech, green energy mix**	-21	
Overall scenario 8 = Backcasting Thessaloniki 1	**Overall scenario 3 plus further modal shift ***	-42	
Overall scenario 9 = Backcasting Thessaloniki 2	**Overall scenario 3 plus further shift to post-fossil fuel vehicles ****	-54	Sufficient
Overall scenario 3 Leipzig	**Tech, green energy mix**	-41	
Overall scenario 10 = Backcasting Leipzig	**Overall scenario 3 plus further modal shift and shift to post-fossil fuel vehicles *****	-80	Sufficient

* **Thessaloniki**: Mode share: -26 %-points LDV (e.g. cars), -5 %-points 2W, +8 %-points bus, +8 %-points metro, +3 %-points rail, +3 %-points walk, +9 %-points bike.
** **Thessaloniki**: Powertrain share: + 61% BEV; -15% diesel, -46% gasoline.
*** **Leipzig**: Share of modes: -10 %-points LDV (e.g. cars), increase of post-fossil fuel cars and other LDVs to the level of 86%, increase of post-fossil trucks and other HDVs to the level of 22%.

[86] Before these in 2022 became part of the EU initiative of 100 climate neutral cities by 2030.

At the end of these explorations we should add that the mentioned changes of CO_2e emissions take place although Plymouth, Thessaloniki and Leipzig witness population growth, in Bydgoszcz partly as a result of population decline. The reduction of **CO_2e emissions *per capita*** in Plymouth, Thessaloniki and Leipzig is roughly 2-13%-points higher than of *total* CO_2e emissions.

6.5 Main conclusions from the demonstrations (EK, AvB)

6.5.1 Regarding the relation between change of mobility and shift to post-fossil fuel vehicles

What the project demonstrations show is that given well-chosen policies and under favourable conditions there can be a substantial decrease of CO_2e emissions. Some **main conclusions** from the demonstrations are as follows.

- The **reduction of car-kms because of shift to public transport** can be large, as in Thessaloniki, but contributes to low carbon mobility only to the extent that electricity production is green.
- CO_2e reduction due to the reduction of car-kms can be supplemented by the **shift from fossil fuel to post-fossil fuel (e.g. electric) cars amongst the remaining car-kms**. The supplement is small to large, dependant on magnitude of the shift to post-fossil fuel cars and on the magnitude of the shift to green electricity production.
- In Bydgoszcz the greening of electricity production is a very large contributor to CO_2e reduction, as the base year share of green electricity production is very small and the expected future share relative high.
- A substantial reduction of CO_2e emissions in the **car** sector can nevertheless only provide a limited **overall** CO_2e reduction, if there is little CO_2e reduction in **other road transport sectors, in particular the freight sector**. The volume of HGV-kms is predicted to increase substantially and each HGV-km has a relative large carbon footprint, also still in future years. We address freight transport further on in this chapter, but already mention it here in order not to overinterpret the mechanisms in passenger transport.
- Developing **bicycling and walking** infrastructure hardly reduces car-kms and CO_2e emissions because of the short travel distances involved, unless it improves the accessibility of public transport and shared cars. **E-bicycling** takes place for longer distances and in this regard is more effective for CO_2e reduction if it replaces passenger car mobility.
- CO_2e reduction by means of developing **public transport** tends to require **high investments**, increase operational costs and have **long preparation times**.
- CO_2e reduction by means of **electrifying road transport** or developing other post-fossil fuel options **also** tends to **take long**, as the EU reference and Tech scenarios show. Acceleration of the replacement of cars by financial incentives also represents a heavy **financial** burden for the public hand. In addition, the associated spatial impact which as we describe in the following section tends to hamper the development towards climate-friendly mobility.

As already mentioned before, the explorations in this project are not designed and suitable to draw detailed conclusions about the contribution of mobility or powertrain changes to CO_2e reduction. The comparisons nevertheless give some hints. A further example: in each of the forecasting lever exercises the additional CO_2e reduction always refers to only **one** change in comparison to overall scenario 3. By comparing the overall scenarios 4 and 6 with 3 in the upper Overview table of *Annex 1* one can see that reducing the share of cars in all modes by 10%-points in the four partner cities often leads to a similar CO_2e reduction as increasing the share of post-fossil cars in all cars by 10%-points.[87]

[87] The additional CO_2e reduction in comparison to overall scenario 3 is: in Bydgoszcz resp. 6 and 5 %-points, in Plymouth resp. 4 and 7 %-points, in Thessaloniki resp. 1 and 1 %-points, and in Leipzig resp. 4 and 4 %-points. Compare: Bydgoszcz: -19% with -25% or -24%. Plymouth: -32% with -36% or -39%. Thessaloniki: -21% with -22% or -22%; Leipzig: -41% with -45% or -45%.

Novel types of mobility as shared vehicles and their support by mobility hubs can, as outlined further on in this chapter, are likely to provide additional CO_2e reduction, but the reduction magnitudes are not very large, unless the novel types would evolve from a niche market, what they are now, to a mainstream market.

6.5.2 Regarding the spatial dimension of mobility

Measures like ones to achieve **mobility changes** as modal shift are important for the reduction of fossil fuel-kms. On the other side, in the climate neutral city **all vehicles will need to be post-fossil fuel ones**. Not one running vehicle may then still emit CO_2e anymore. From this angle mobility measures seem to be superfluous. Why then bother with mobility measures?

A major reason, already indicated in the Introduction chapter, is the **spatial argument** which is an impact on its own but also has repercussions for the climate-friendliness of mobility: public transport and active travel require less space per passenger-km than the car. This is important for compact cities with a relative high density which in many cases can't endlessly facilitate the expected future growth rates of mobility, especially car traffic. In the compact city the average travel distance is shorter, for which reason also more people choose for walking and bicycling (2 advantages for climate-friendly mobility). Even the use of scooters benefits from the shorter distances in the compact (high density) city (*Badia and Jenelius, 2021*). Last but not least the compact city provides more demand for high(er) frequency public transport and a higher cost coverage in metro, tram or bus systems.

In the cities' demonstrations the spatial dimension of mobility has only partly been elaborated, namely by clarifying the average distance travelled and by getting a rough picture of traffic intensities, of achieved average road speed and of congestion in the road network.

- The spatial dimension was most prominently addressed in the Bydgoszcz demonstration. The main finding was that the measures in CliMobCity scenario W2 (urban densification and frequency increase of public transport in the central city area together with a reduction or road investments in other city parts) lead to a smaller increase of the number of car trips and a higher share of walking than the measures in CliMobCity scenario W1 and to less increase of travel distances in public transport or car mobility. Corner stones of the W1 measure package were more suburbanisation on the local level, more PT coverage of all city, more road investments outside of the central city parts. This indicates the relevance of land use choices for sustainable mobility.
- Suburbanisation and related urban sprawl is an issue on two levels, the city and the regional one. Bydgoszcz in its demonstration especially addressed the city level. From the spatial flow matrix one for Plymouth can derive that spatial and transport measures lead to an increase of number of trips from and to the city, in this way to an increase of average travel distance by car, more in BAU than in CliMobCity. A subject deserving special attention is the development of urban satellites in combination with that of public transport connections, like the suburban railway line in Thessaloniki or the Tavistock rail connection in Plymouth. As far as the new PT connections induce modal shift amongst existing travel flows (which they are expected to do in both cities), they contribute to the reduction of CO_2e emissions by mobility. However, if these interventions seduce people to move from the city to the region,[88] the travel distance will increase which may increase CO_2e emissions.
- The relation between car use and lack of space in the city there was discussed in the sub-section "Traffic impacts" in each city chapter: **Thessaloniki** is a very densely populated city, not only in the project, but also in European comparison, and also not only in the (large) city centre, but throughout the municipality. At many places the main roads are not wide and already intensely

[88] In the world of modelling such could be predicted by a so-called land use and transport model, not by a transport model.

used, so there is no to very limited space for more road traffic. The shift from car to the new metro will be accompanied by a substantial decline of number of car trips and car-kms, which in the city centre is urgently needed as the city also wants to assign more public space to active travel. Relying mainly on e-mobility to reduce CO_2e from mobility would be no option in this city. In **Leipzig** a decline of car trips is expected, especially of city-internal ones and despite of an increase of trips from and to Leipzig, together providing a decline of car-kms. The big picture is that road traffic intensities are expected to decline throughout the city except for a larger number of road segments in the periphery of the city which give access/egress to/from the city. This pattern matches well with the city's structure: it would hardly be possible to facilitate much traffic growth in the large older parts of the city, given the relative high residential density and profile of main roads. **Plymouth** currently witnesses some road parts with congestion. In the CliMobCity different to the BAU scenario the number of car trips is stabilised to near the current situation while there also are road improvements. The city's density is relative low, also in the central city parts. The overall picture is a good traffic flow in a CliMobCity future. If in the project there is a city where a strong focus on the electrification of car transport could work spatially, this certainly is Plymouth. **Bydgoszcz** lies between Thessaloniki and Leipzig on the one side and Plymouth on the other side. While there is sufficient space for infrastructure development in most parts of the city, the space availability is rather limited in the central parts. Despite of the differences between Bydgoszcz' future scenarios, there is quite some traffic pressure on many roads in the central area in all scenarios, whether the total car-kms increase much (as in W0 or W1) or less (as in W2).

Summarizing on the basis of such brief observations of future developments, CO_2e reduction by mainly electrification of traffic perhaps is an option for Plymouth, given the spatial structure of the city, but difficult in Leipzig and to some extent in Bydgoszcz and merely impossible in Thessaloniki.

6.5.3 Regarding push and pull measure combinations

From the project's demonstration an old wisdom for mobility can be confirmed, which is the relevance of effective combinations of pull and push measures. **Pull measures** are directed to make public transport, active travel, electric vehicle use, shared car use etc. more attractive, by improving infrastructure, services and amenities, accelerating the implementation of electric charging points, (re)designing city structure in favour of shorter distances and public transport use, and redistributing public space in favour of the sustainable modes. **Push measures** are directed towards making (fossil fuel) road vehicle use and ownership less attractive. Examples of push measures are expanding or intensifying low- or zero-emission zones, stepping up car parking policies by regulation or pricing, reducing maximal road speeds, or introducing road and areal access fees, or reducing public space for cars. Road and area(-based) pricing were two specific urban access regulation instruments and a focal research area in the 2000s, being introduced in Stockholm, London and Milan and reducing road traffic by respectively 20%, 20% and 35% "thanks to a shift to public transport (+10% in London and 12,5% in Milan)" (*Burrieza, 2019*). Such shifts in the sustainable direction suggest to consider again such measures. Of course the acceptance of pricing deserves attention. In "Stockholm and Milan even a referendum was held. In each case, at the time of introduction citizens were not in favour, but after implementation the public opinion has turned." We address the social dimension of the pricing and acceptance, still deserving attention, further on.

Bydgoszcz' explorations have again underlined the relevance of pull push combinations. In W0 (BAU) and W1 (CliMobCity) there is a lot of pull, but too little push, together letting car-kms increase. In W2 (CliMobCity) there is, next to PT development and reurbanisation, more push pressure by less road development and more stringent rejection of car mobility through the centre next. This together with the reurbanisation leads to a significantly smaller increase of the car-kms.

Less explicitly analysed, but certainly present are push mechanisms also in **Thessaloniki**. Already the dense urban structure functions as such, as it makes it difficult for cars to through pass the city in short time. The redistribution of public space on major roads in the city centre in favour of bus lanes and active travel amplifies the push power, and is possible by preparing the access to the centre by alternative modes (metro, bus, bicycle, walking for the last mile).

6.5.4 Reflecting on the potential content of additional measures packages

From the lever exercises the following question arises: which concrete measures could provide the additional reduction of fossil fuel vehicle-kms and of CO_2e emissions? In principle one can think of more of the same types of measures and of new types in the packages. We here do not give an extensive overview of potential measures, but focus on some highlights and promising solutions, first focussing on passenger mobility, in that framework also taking a look at shared vehicle services, micromobility and mobility hubs, and at the end outlining policy options/perspectives for freight transport.

The first search direction may be more of the same types of measures, either in the same planning period (like up to 2030/35) or for the following strategic planning period, dependent on what is realistic next to ambitious. Potential examples of **"more of the same"** are extending the metro network into other high density areas (Thessaloniki), intensifying the (e-)bicycle network (all partner cities), or supplementing tram and bus lines by public transport taxi's for the last mile between homes in residential areas with low densities and the stops of bus or tram lines along the edges of those areas (as the FLEXA system in **Leipzig**). In Leipzig, FLEXA has been analysed to increase the use of some public transport bus lines by 6-12% and of some tram lines by 3-4% (*2050 CliMobCity, 2022, Newsletter 3*).[89]

Another area of "more of the same' is the co-development of city and public transport, also referred to as **transit-oriented development (TOD)**. Examples include stamping both out of the ground (as in the Amsterdam **IJburg** case, visited at the project's kick-off meeting), or intensifying both in the same area (as in the CliMobCity scenario W2 in **Bydgoszcz**) or accessing existing settlements by new public transport (as is the case for the **Thessaloniki** metro or proposed in the **Plymouth** Tavistock case), or building or densifying a settlement around a rail station (what is taking place around the main station of **Leipzig** and for which there still is plenty of space) or along a metro, tram or bus line. **Plymouth**'s *JLP 2034* (BAU plan) also mentions a residential search area for a new rail station much closer to the centre. The aspiration to reopen a rail station at Plympton, a larger rather centrally located residential area, is real and ongoing.
TOD measures are meant to produce synergetic effects between city and transport. The co-development includes finding the right scale in both systems. For instance, certain spatial settings (size of feeding area, number of and distance between stops) fit better to light rail instead of heavy rail.

Another area of "more of the same" are park-and-ride nodes in the city's periphery to convert part of trips from and to a city from private car to a multimodal trip like car-bus (e.g. Plymouth), car-tram (e.g. Leipzig and Bydgoszcz), car-metro (e.g. Thessaloniki), or car-bicycle (all partner cities).

There may also be new measure combinations going beyond "more of the same" like promising **new combinations of push and pull measures** or, taking account of new technological developments, or **new combinations of behavioural and technological measures**. An example of a measure combination might be the more consequent development of a network of P+R nodes at the city edge where electric charging of cars takes place, and from where travellers transfer to public transport, (shared of private) bicycle or scooter to the destinations in town, amongst which perhaps zero emission zones. The transfer between modes could be supported by attractive pricing for and performance of e.g. public transport and bicycling amenities and discouraging pricing and capacity of

89 The additional public transport is sustainable, if it mainly reduces car-kms and hardly induces new mobility.

road and parking infrastructure. As far as shared cars are used to reach a P+R node other travellers can use them after their deposal there.

Pricing measures should become more effective by making them more **climate-friendly** and more **equal/inclusive**. The first is to say that the pricing of for instance car parking or road use or areal access is related to the amount of (CO_2e) emissions. Indirectly such already exists, like parking fees in city centres designed to support modal shift, or like road-pricing or area-based pricing as far as they are designed to make users pay for the externalities of their mobility. But the instruments are rather air-pollution and congestion oriented (Burrieza, J., 2019) than energy and climate oriented, and they are – except for parking fees – not widespread. The more equal/inclusive quality of pricing measures is about pricing car parking or road use in ways that encourage and discourage travellers in socially more honest, equal and inclusive, and therefore expectantly more effective ways, like (more) income-dependent. In the past such financial design would technically not have been feasible, but this has changed in the age of smart information organisation. The equality dimension of measures has the last years entered the policy arena (think of the income-dependent traffic penalties in Norway or Finland) and is increasingly drawing attention: for instance, the recent report "Sharp aims, sharp choices" launched in the Netherlands by the national governmental platform *Interministerial Policy Review* (*IBO, 2023, p.90*)[90] and addressing national climate policies in 2030 and 2050 states: "Those with more income and assets should carry a larger part of costs". The conversion of such concepts into daily practice of course will require much policy work, largely on a supra-local level.

In some cities, like Leipzig and Bydgoszcz, there is the challenge of **accessing large employers or industrial sites outside of the city centre**. Given the involved trip volumes, alternatives to private car mobility could contribute to relevant CO_2e reductions. However, the monofunctional character of such nodes and the dominance of work shifts leading to trip concentrations in time make it difficult to access such nodes by standard public transportation. Either other innovative transport means would need to be introduced (like Leipzig's pilot of a robotised shuttle bus connecting a PT stop with a car manufacturer's plant; Pietzsch, 2019) or the monofunctional character of the node would need to be changed, on a relevant scale. As some of such solutions aren't financially viable under current financial frameworks, one might consider to adjust the frameworks for special cases, allowing to develop more climate-friendly mobility because of focussing less on short-term cost-benefit thresholds, but instead taking more into consideration long-term savings from avoided climate damage or avoided climate adapting investments.

Novel instruments touch other policy areas, like:

- that a municipality, perhaps together with its region, disposes over the needed **legal competences** to plan and implement certain types of measures. An example where such is not present, is the bus network in Plymouth which since the liberalisation of public transport in the UK outside of London is developed mainly according to the commercial benefits of the private bus operator. The municipality can hardly influence service development, like increasing service frequencies, as the bus firm is neither public nor working in the framework of a franchising system like in many other European countries. Another example seems to be the competence of a German city to reassign public space used by cars to the bicycling, as explained during a project seminar (see the "Bicycle network improvement – Berlin case" in *2050 CliMobCity, 2021, Newsletter 2*). But safety arguments in German road legislation make such transformation difficult;
- that some principles need to be legally programmed in a climate-friendly direction. A study of the German Institute for Urbanism (*DIFU, 2022*) gives the example that parking in public space in Switzerland has to be paid by the parking car user, unless the city says the contrary. In Germany

[90] Adapting the fore principles for social justice from the scientific council for government policy (WRR).

the system works the other way around: parking in public space is free, unless the city decides the opposite.

- that supra-local legislation changes where such circumstances are not present.

Another direction of solutions for climate-friendly mobility is that of **smart mobility**. In a case study for Warsaw (*Zawieska and Pieriegud, 2018*) the authors on the basis of a literature study in the field of ITS applications for 13 measure fields (e.g. traffic management, parking, logistics, public transport, autonomous driving) estimate that the assumption of a cumulative CO_2e reduction of 30% on top of the measure package for Warsaw in the Tech scenario may be assumed to be realistic. The authors, however, give no further reasoning for this conclusion.

6.5.5 Freight transport

Freight transport and logistics is a dynamic sector, following economic growth and changing international labour division, changing sales and retail channels, facing increasingly strict (inter)national sustainability frameworks and municipal liveability frameworks, subject to internet as a game changer and continuously busy with increasing the scale of transport (e.g. larger trucks and warehouses), at least outside of the city. Inside the city liveability frameworks and consumers preferences tend to limit scale increase.

The central challenge in climate-friendly freight transport and logistics, namely to reduce fossil fuel truck-kms, has two frontiers, namely:

1) to use freight vehicles more efficiently (-> higher average loading degrees -> may require other bundling of flows to truckloads), and
2) the replacement of fossil-fuel by post-fossil fuel freight vehicles. This requires the implementation of truck charging or other post-fossil fuel infrastructure in a network of relevant locations.

For both frontiers, local policies can foster changes and performance improvements by introducing climate-friendly conditions for areal access of freight vehicles.

Both frontiers will also be dealing with a reorganisation of existing or the implementation of **new types of decoupling nodes**. Regarding frontier 1, this concerns nodes to resort the goods from trucks from different European regions to trucks to certain city destinations v.v., and/or to change the transport scale from large trucks outside of the city to smaller ones inside the city v.v.

Regarding frontier 2, much will depend on the powertrain and technology future of trucks: **in the city**, the battery electric truck may became a mainstream vehicle, because its operational distances are short and recharging would be possible at many (un)loading locations. However, corresponding locations then need to prepare for appropriate charging facilities.

Outside of the city the question is which type of powertrain has the future. In this framework the debate between the German Federal Sustainability Agency (UBA) and the German Ministry of Technology gives an outline of possible mainstream futures of inter-city road transport: the first organisation advocates electric catenaries above the federal highways, the second hydrogen powered trucks. In the first case decoupling points at the city edges will be required unless the trucks have supplementary propulsion for in the city. Potentially synergy can be developed between the nodes for bundling and resorting, and the nodes for powertrain decoupling.

In all cases the electrification of vans and other small freight vehicles in the city can be a quick win, as these have the largest CO_2e emissions per ton-km.

Thessaloniki has devoted one action in its Action plan for the project to freight transport and logistics, namely to write “technical Specifications for the elaboration of the "Sustainable Urban Logistics Plan (SULP)".

The reduction of fossil fuel truck- and van-kms is a very important task **in all four cities**, as freight transport is a major source of CO_2e emissions still remaining after "implementing" the CliMobCity measures packages and after having realised all projected powertrain and energy mix shifts. The challenge for a municipality will be to recognise and understand the ongoing and expected changes and their meaning for CO_2e emissions and develop framework or facilitating concepts in which the enterprises' initiatives can move towards climate-friendly future.

6.5.6 Shared vehicles, micromobility and mobility hubs (EK, AvB, FTK and NvO[91])

All cities are preparing for large(r) scale implementation of **mobility hub** networks encouraging **shared car use, electric vehicle use, micromobility**, public transport use and intermodal mobility, but such **novel mobility forms** have hardly been incorporated in the mobility modelling. Only indirectly in Plymouth[92] and only regarding shared electric cars in Thessaloniki, which however in 2030 still represent a niche market (3-4% of all city-internal car trips are electric shared car trips; city-internal car trips together with taxi's have a share of 18%). One reason for not modelling is, as already addressed in the Introduction chapter, that there is not yet sufficient empirical evidence about the functioning and attractiveness of the novel mobility forms, despite of a growing body of surveys and analyses in this field.
For the project the question arises whether the surveys and analyses that do exist, contain indications of the magnitude of mobility changes and derived reductions of CO_2e emissions, allowing to draw conclusions about to which extent these novel forms of mobility could cover the shown gap between CO_2e reduction aims and reduction.

The main aim of all **shared vehicle and hub use** is to make private car use decline and also to accelerate the **shift to post-fossil fuel vehicles**. Other aims can be to have more travellers **shift to active travel and public transport use**, while avoiding that too many travellers move from active travel or public transport to car mobility, and that too much new mobility emerges. Background to these aims is the expectation that shared car users produce **less car-kms** because of fewer car trips (essentially modal shift) and shorter car distances, and that **shared cars are more efficient** and emit less CO_2e as they are used more intensely and therefore replaced more frequently. Next, there is the expectation that in the shared car system **fewer cars are needed per driven km** than in the private car system. Then also less cars need to be produced and recycled, hence less CO_2e is emitted for the production and recycling of cars. In the city the smaller number of needed cars would also reduce the space requirement for car parking, a change accompanied by multiple benefits (lower costs, lower CO_2e emissions for paving and recycling pavements, more space for climate adaptation green). For other types of shared vehicles than cars the expectations are similar: at least, the shift from private car to shared micromobility would reduce the number of car-kms driven.

What is the evidence of these advantages occurring? One comes from the 2050 CliMobCity project itself. In Thessaloniki the introduction of 150 **electric shared cars** in the municipality would[93] not so much reduce the number of car-trips, but would **reduce the number of car-kms** resulting in a 13% reduction of the CO_2e emitted as compared to the base year, 2018 (see *Appendix-Thessaloniki-Report* [MoT, 2022]), **being 1 %-point more reduction than the reduction achieved by all measures without the shared electric car**. In addition, the shared car-kms are electric ones. One may expect that more reduction could be achieved, if the shared electric cars were displayed on a larger scale.

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91 This section has been written parallel to the literature review being conducted by Fatemeh Torabi Kachousangi (FTK) in the framework of her PhD research at the Delft University of Technology and accompanied by Niels van Oort (NvO), EK and AvB. The section has used insights from (accompanying) the FTK literature review and from other review activities.

92 By assuming this to be a factor of the artificially (= not led by demand functions) adjusted pattern of passenger flows in, from and to the city.

93 According to the *Appendix-Thessaloniki-Report*, p. 30.

In general there is consensus about the reduction of car-kms when shifting from a private to a **shared car**, whether this shift refers to the first, second or third private car in a household. An indication comes from a country-wide stated reference survey amongst car sharers in the **Netherlands** (*Nijland and Meerkerk, 2017*): for each car-driving person joining the car sharing system, the reduction of CO_2e emissions (inside and outside of cities) is analysed to be about 13-15% (see *Reflection Table 11*). The corresponding absolute reduction of CO_2e emissions -279 kg CO_2e/y.
But this was not the only effect that occurred. Shared car use also replaced trips of "environmentally more friendly transport modes" increasing the CO_2e emissions by 8% to 9%. Balancing between less emissions because of shifting from private to shared car (-13% to -15%) and of more emissions because of shifting from more sustainable modes (+8% to +9%), **the net CO_2e effect of using shared cars is -5% to -6% per person joining the car sharing system**.
The authors also analyse the CO_2e effects of the replacement of privately owned and shared cars. This leads to additional -7% to -13% CO_2e emissions. But this additional reduction can't be compared with the CO_2e values in the cities' demonstrations, as it doesn't refer to car use, but to emissions for car production, maintenance and recycling.

Concluding, **the 5-6% CO_2e reduction per person joining the car sharing system is what could be seen as an additional reduction, on top the reduction analysed by the project. But such amount only refers to users of shared cars, hence to a small fraction of all travellers. If all travellers join the shared car system, such percentage applies and otherwise will be less.**

Interesting backgrounds to these CO_2e results are that car sharers drive 15%-20% fewer car-kms, of which the authors state that it is not clear whether they simply drive less of instead use other modes. The abolishment of a car or to refrain from the plan to buy one together implies a reduction from 1.12 to 0.72 private cars per household. Interesting is also the modal shift. 34% of all shared car passenger-kms come from the private car, 41% from the train, 4% from bus, tram and rapid transit. Shared cars also induce new mobility which would otherwise not have taken place. Certain patterns of replacements, namely more car by train more than by urban public transport, fit to the fact that the survey was not city-specific, but included the countryside where distances are long.

Reflection Table 11
Change of CO_2e emissions amongst Dutch shared car users

	From	To	
Change in car kilometres	-15	-13	%
Change in mode of transport	9	8	%
Change in car ownership	-7	-13	%
Total	-13	-18	%

Source: *Nijland and Meerkerk (2018)*. Percentages except for "total" calculated by authors.

Another indication comes from **Würzburg**, where a survey (*Pfertner, 2017*) amongst the users of **shared cars** provided at Würzburg's 9 new mobility stations hubs and 10 Scouter stations (= existing shared car stations). The author explains that the CO_2e reductions comes from 1) lower CO_2e emissions per vehicle-km (smaller and more modern cars) and 2) a reduced number of (private) vehicle-kms. A third change, but negative factor for CO_2e reduction, was some modal shift from more public transport and active travel to the shared car.
Pfertner calculates the total (net) CO_2e reduction of shared cars from car stations and mobility stations in Würzburg to be 650t (*Reflection Table 12*). About[94] 103% of the net reduction is caused by

[94] The sum does not exactly add up to 100%. In general the calculation approach is not unambiguously described in all points.

fewer car-kms and 1.5% to more efficient vehicles. At the same time the shift from other modes to car adds CO_2e emissions in the magnitude of about 5% of the 650t.

Reflection Table 12
Change of CO_2e emissions amongst shared car users at Mobility stations and (Scouter) Car stations and in Würzburg, Germany

More efficient vehicles -9.6 t	-9.6	t
Additional car trips +30.7 t	30.7	t
Reduction of (private) car use -628.8 t	-628.8	t
Total saved	-649.9 *	t

* Equal to 1% of Würzburg's total transport CO_2e emissions
Source: *Pfertner (2017)*. Brackets around "private" added by authors.

Roughly 90% of the users of shared cars live in Würzburg. Would one relate the reduction of 650t to all CO_2e emissions of all local transportation in Würzburg, as the author suggests, **the reduction due to shared car use at the 9 new mobility hubs would represent 1%. This 1% is what could be considered to be the additional CO_2e reduction on top of the reduction analysed in the project. Would the car sharing evolve to a mainstream configuration, the reduction percentage would increase.**
The conclusion for Würzburg is that the shared car system nowadays still represents a niche market. A corresponding observation is that the city's car sharing involves some hundred (station-based) shared cars on a total of 50.000 registered cars in the city. This ratio underlines the idea of a niche market.
The Würzburg study has also explored the mobility changes due to **shared bicycle** systems and corresponding nodes in the city, but they were not subject of the CO_2e analysis. Nevertheless the modal shift found is interesting. The shared bicycle replaces public transport in 46% of the trips, walking in 27% and the private bike in 18% of all trips.

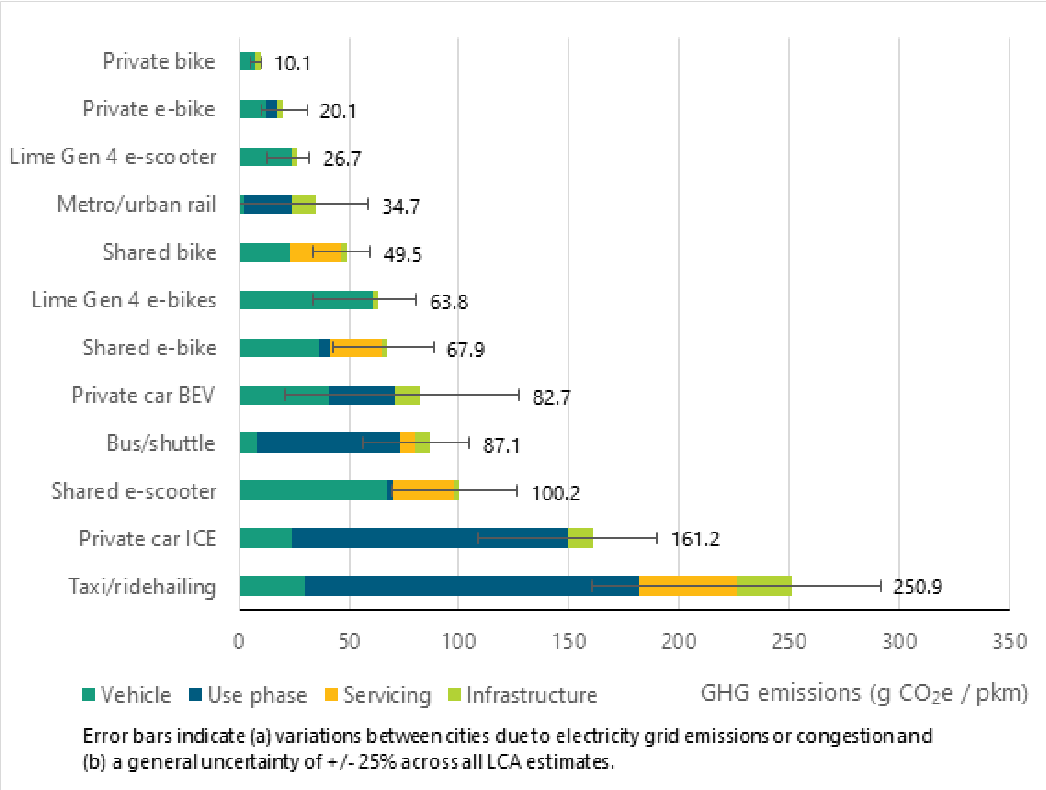
The same study also analyses the number smaller number of cars involved in the sharing than in the private car system, partly referring to the Federal Union for Car Sharing (Bundesverband CarSharing, 2016): "… studies estimate replacement ratios (1 shared car replaces x private cars) ranging from 1:2 to 1:20 for station-based carsharing and 1:1 to 1:3.6 for free floating systems."

As mentioned above, less cars imply less CO_2e emissions for the production, maintenance and recycling of cars, which however does not fall within the scope of 2050 CliMobCity. Fewer cars also require less space for parking. This supports the concept of the compact city with the climate advantages outlined above.

Another study analyses the mobility changes and their CO_2e impact of micromobility, more precisely of shared e-scooters and shared e-bicycles, in Berlin, Düsseldorf, Paris and Stockholm, one American and one Australian city. Krauss et al. (2021) analyse the average lifecycle (LCA) CO_2e emissions of these cities (*Reflection figure 11*), distinguishing between use, vehicle, infrastructure and servicing emissions. The *use* CO_2e emissions, marked blue, are well-to-wheel emissions, hence comparable with the project CO_2e values. They are smaller for bicycles and scooters than for public transport than for cars, smaller for fossil fuel than for e-vehicles, and smaller for private than for shared vehicles. The relative large use emissions for e-modes (e.g. metro/urban rail) are due to "coal-driven electricity generation in Australia and partly in North America". What the figure also shows is the change of ranking of modes taking place when including the other emissions than those of only vehicle use. The most striking examples are the shared bicycle, shared e-bicycle or shared e-scooter which have small emissions from using them, but high ones if the other lifecycle emissions are included. In that case **the shared (e) bicycle emits more than the metro/urban rail, and the shared scooter more the shared the bus/shuttle**. This is because of vehicle lifecycle emissions and service emissions. The first ones are the consequence of short vehicle lifecycles compared to the corresponding private modes. An example of a service emission is that of repositioning dockless shared bicycles or scooters.

Reflection Figure 13

Average LCA CO_2e emissions for selected combined modes by life cycle components in g CO_2e per passenger-km



Source: *Krauss et al., 2021*.

Whether implementing or expanding a shared e-bicycle or e-scooter system in a city will reduce CO_2e emissions or not, depends on then already existing modal share in that city. The study concluded that the implementation of shared e-bicycles is beneficial in all six cities except for Berlin. The reason is that in Berlin the share of taxi or ride hailing, two modes with large CO_2e emissions, is small. Let us not forget, that although very relevant, the study results are not directly suitable to answer our question about additional CO_2e reduction, as the reduction figures also refer to the emissions from the vehicle production etc. which is not in the scope of 2050 CliMobCity.

Interesting is the modal shift taking place in the four European cities. 40-50% of **shared e-scooter** trips replace walking, 26-39% public transport, 4-9% taxi or ride hailing, 3-7% private or shared car, truck motorcycle or moped, and 5-8% shared or private bicycle, e-bicycle, pedelec or e-scooter. For the **shared e-bicycle** this is (without Stockholm): 25-29% of shared e-bicycle trips replace walking, 33-39% public transport, 6-11% taxi or ride hailing, 9-19% private or shared car, truck motorcycle or moped, and 5-8% shared or private bicycle, e-bicycle, pedelec or e-scooter.

Modal shift from sustainable modes to **shared e-scooters** was analysed also for Rotterdam (*Faber, 2021*). 54% of shared e-scooter trips would have otherwise been walking or bicycling ones, 37% public transport ones, and about 11% car, taxi or private scooter ones. These replacement values resemble those of the study in the four European cities. Contrary to shared cars, the shared scooter in Rotterdam seems to be more appreciated as an unimodal travel mode (24%) than in combination with public transport (22%); and more for social, recreational and sport destinations (54%) than for any other motive.

Hiselius and Svensson (*2017*) explored another corner of micromobility, namely the use of **private e-bicycles** (of the pedelec type) and how this changes mobility in urban and rural areas. On the basis of a survey amongst private e-bike users in south and northern Sweden they analysed modal shift and the reduction of CO_2e emissions. Again there is the shift between modes. As in Sweden 80% of car trips has a distance of 4-5km “there is great potential for e-bikes to replace cars in these journeys” or to replace other forms of travel. The authors conclude that per person there would be an average decline of CO_2e emissions of 14 to 20%, and that the changes are not very different in urban and rural areas. The emissions of e-bike production and recycling were not taken into consideration.
The modal shift is interesting as background to the CO_2e analysis. The e-bicycle for work, school and purchase of groceries would replace (off-rounded) the private car in 50-60% of the cases, public transport in 10-20% and the conventional bike in 25-30% of the cases.

Indicative conclusions from these few sources are as follows.
(Shared cars)
- Shared car services can provide rather small additional (WTW) CO_2e reductions: 1% or more (Würzburg) or up to 5% (Netherlands) dependent on how much the shared car sector moves out of the niche market becoming a main stream market. If such results also apply for other cities, these percentages can be added to the results of the project’s demonstrations.
- The indicated reduction does not include the CO_2e reduction related to the production, maintenance and recycling of vehicles, expected when shifting from fossil fuel to post-fossil fuel cars.
- The CO_2e reduction by shifting from private to shared car use occurs despite of the shift from public transport and active travel to the shared car which takes place in parallel and is substantial.
- Shared car use can strengthen public transport use wherever public transport is used for the last mile, for instance between home and a mobility hub that is located near to a public transport stop.
- The WTW CO_2e reduction takes place because of less car-kms and despite of the shift from public transport, bicycle and walking.
- The exact cause of fewer car-kms is not known or hardly addressed in the studies.
- The shift from private to shared car ownership is stated to go hand in hand with a substantial reduction of parking demand (like 35% less in the Dutch case, at least half in Germany) wherever the shared car gets a foothold. The spatial gains remain small, as long as the shared car mobility remains a niche market.
- The studies do not explore the additional (parking) space demand due to the modal shift from bicycle or public transport to the shared car.

(Micromobility)
- *Private* e-bicycles and private e-scooters promise to reduce WTW CO_2e emissions substantially as compared to cars (see *Reflection figure 13* about four European cities). In Sweden the switch from car to private e-bicycle would reduce CO_2e emissions by 14%-20% per person involved. Its potential is large given the average car trip distance of 4-5km in the country.
- The use of *shared* e-bicycles would reduce WTW CO_2e emissions in the same way. However their vehicle lifecycle and vehicle servicing emissions are much larger than for private e-bicycles and

scooters. The lifecycle is short because of bad treatment by users. The servicing emissions are substantial, also because of repositioning operations.
- The lifecycle CO_2e emissions of the shared e-bicycle are, as mentioned, substantial, but can nevertheless be less than of the existing mode mix in cities with a high taxi and ride hailing share, as the latter two have a large carbon footprint. Such was – in one study – the case in some European cities, but not for Berlin.
- It deserves consideration by which measures one could perhaps improve the CO_2e performance of shared e-bicycles and shared e-scooters: by behavioural and building measures increasing their lifespan; or perhaps by abolishing dockless systems in order to reduce servicing emissions; or perhaps by electrifying the repositioning operations.
- Otherwise one perhaps should give more priority in facilitating *private* micromobility, like building private bicycle and scooter parking on a larger scale at mobility hubs and especially ones attached to public transport stops and stations.
- The shared (e) bicycle or shared e scooter replace public transport and walking in substantial amounts.

6.6 Awareness raising and other travel preferences (EK, AvB, FR)

For climate mitigation the **municipality** is regarded to be an **important policy level**, as most people of a country live in cities, most employment is present and many activities take place in cities. It is a focal point in designing a joint future for all, but the success of such design highly depends on the cooperation of the actors within and together with the municipality, and on a good coordination of bottom-up initiatives and top-down planning. For both, the **willingness of residents, firms and other organisations to change travel and investment preferences and habits** is a key factor for achieving a climate-friendly future.

The threat is that too many people and organisations think that not much will really need to change in the course of following decades. Such thinking hampers energy, climate and mobility transition. Where reluctance to change is present, one might first check the performance and attractiveness of the (innovative) transport services that are proposed. In a survey (mentioned in MoL, 2019) amongst Leipzig residents 75% of the questioned people states that they could not imagine a life without private car. Lacking quality of alternatives like that of bicycle infrastructure, crowded public transport vehicles etc. are mentioned as reason. Comparable: ”encouraging mode shift from cars to micromobility … requires a multifaceted approach, including reliable intermodal travel information, safe and secure infrastructures and alleviating the barrier of availability of shared micromobility” (*Krauss et al., 2022*).

Despite of critical remarks there are numerous statements signalling willingness to change. From the mentioned Leipzig survey one could also conclude that apparently a substantial group, namely up to 25% of the residents, can imagine a life **without** a private car. In the Würzburg survey each of the following questions harvested the following responses from users, city non-users, regional non-users of shared car or bicycle services: “A life without a private car is desirable, but not realistic” (one to three quarter of respondents disagrees). “I don't like sharing items” (less than the half agrees). “Future mobility consists more of using than of owning” (**more than half to three quarter agrees**). “I am reluctant to the idea of sharing my private vehicle” (less than half to more than three quarter agrees). So everywhere, there seems to be at least a substantial minority willing to change. Liao et al. (2018) regarding shared car use in the Netherlands distinguish three groups. The largest one (more than 50%) “demonstrates an extremely low interest in using car sharing both under one-way and roundtrip car sharing” and is own-car oriented. The car sharing-enthusiasts are the smallest group (less than 21%) which still is substantial.

Where an (innovative) transport service is functioning well, but nevertheless the willingness to adopt it needs a push, awareness raising and personal change support can help. Municipalities and other public actors are important entities to conduct such actions. Many cities are active in this area, directly or via mobility management of large employers in the city. ***Plymouth***'s Plymotion activities are a very good example: this city's long-term and branded sustainable initiative provides information and opportunities to overcome barriers and enable people to make more journeys by bike, on foot and by bus. ***Thessaloniki*** has devoted one action in its project Action plan to awareness raising, namely signing a Memorandum of Understanding with universities for targeted awareness raising campaigns towards students regarding mode choice and information about its impact in the environment, the city and the individuals. The introduction of well- or better-performing transport services in combination with awareness raising and change support was also the subject of ***Bydgoszcz*** when simulating the effects of changing of mobility preferences. In **Leipzig** the climate department in its presentation on the project's Final Dissemination Event drew attention to the need awareness raising and multiple actions in this field. All essentially serves to change peoples' mobility preferences, as such is considered to be necessary for the long term and the climate challenge.[95]

6.7 Wrap-up (EK, AvB)

All cities are increasingly aware of the urgency of climate mitigation, witnessed by their climate aims which were sharp and in the run of the project have become sharper and by the increasing volume of activities to reach the aims.

The partner cities have discovered that their BAU and CliMobCity measure packages do not sufficiently contribute to the municipal CO_2e reduction aims. Still, the project work showed that strong municipal interventions lead to relevant mobility changes and CO_2e reductions, and it has provided findings and improved understanding relevant for developing more climate-friendly strategic plans in the field of mobility, land use/spatial development, and energy policies, all the fields potentially contributing to effective CO_2e reduction of mobility in the cities. The cities were able to mutually learn what the potential benefits are of different approaches and measure packages, some with a stronger focus on behavioural/mobility change and others with a stronger technological/powertrain change, and of thinking differently and boldly.

Not reaching the climate aims on time should not lead to (municipal) climate cynicism or climate laisser-faire. The challenge for the cities is to keep on or intensify planning transparently and working hard to achieve climate neutrality as soon as possible by deciding effective measure packages in their strategic plans and implementing these, in parallel by seeking maximal cooperation of residents and organisations in the municipality, and also in parallel by communicating to higher policy echelons needed changes of policy frameworks. The project partners found this challenge description appropriate during the discussion on the last Partner meeting of the project, in June 2023. Always should the planning of climate-friendly mobility also focus on other sustainability (like air quality) and liveability to create synergies
Valorisation of the project work will hopefully help to improve future municipal policies.

[95] There are interesting statements in this regard like from the UK Department of Transport (2020) that the climate "target will only be credible if policy measures ramp up significantly and urgently …. We agree and do not underestimate the challenge of delivering what will be fundamental changes to the way people and goods move around. This will require changes to people's behaviours, including encouraging more active travel and the use of public transport, alongside increasing the uptake of zero emission vehicles and new technologies."

Annex 1 Overview of CO_2e reduction of the partner cities (EK, AvB, FR)

(The tables do not include the values for the combinations BAU with EU reference, Tech or Tech/green scenario, as shown in the cities' CO_2e figures)

Reduction CO_2e emissions

								Base year = 2018		Base year = 1990				
City →	Bydgoszcz					Plymouth		Thessaloniki		Thessaloniki			Leipzig	
Mobility scenario →	W0	W1	W2	W1+	W2+	JLP 2034	UK max	SUMP 2030	Shared elec.	2018	SUMP 2030	Shared elec.	Mob. Str.	Int. Mob.
↓ Techology and energy scenario	BAU	CliMobCity	CliMobCity	CliMobCity	CliMobCity	BAU	CliMobCity	BAU	CliMobCity		BAU	CliMobCity	BAU	CliMobCity
Scenario 1a (BAU, EU reference, expected future energy mix)	1					-5		-8		20	10		-25	
Scenario 1 (CliMobCity, EU reference, expected future energy mix)		0	-1	-1	-2		-9		-14			3		-26
Scenario 2 (CliMobCity, Tech, expected future energy mix)		-5	-6	-6	-7		-24		-15			2		-34
Scenario 3 (CliMobCity, Tech, green energy mix)		-18	-19	-19	-20		-32		-21			-5		-41
Scenario 4 (= scenario 3, additional modal shift *)			-25				-36		-22			-7		-45
Scenario 5 (= scenario 3, decrease time spent **)			-22				-34		-21			-6		-43
Scenario 6 (= scenario 3, additional electrification ***)			-24				-39		-22			-7		-45
Scenario 7 (= combinations of scenario 3, 4, 5 and 6)			-32				-45		-24			-9		-50
Scenario 8) Backcasting scenario 1: scenario 3, further modal shift ****									-42			-31		
Scenario 9) Backcasting scenario 2: scenario 3, further shift to post-fossil fuel vehicles *****									-54			-44		
Scenario 10) Backcasting scenario 3: further modal shift and shift to post-fossil fuel vehicles ******														-80

* Share: -10 %-points LDVs (e.g. cars), +5 %-points public transport busses, +5 %-points active travel.
** 10% less time spent, because of less road vehicle-kms and/or more fluent traffic flow.
*** Share: 10 %-points extra shift to post-fossil fuel vehicles.
**** Thessaloniki: Share: -26 %-points LDV (e.g. cars), -5 %-points 2W, +8 %-points bus, +8 %-points metro, +3 %-points rail, +3 %-points walk, +9 %-points bike
***** Thessaloniki: Share: + 61 %-points BEV; -15 %-points diesel, -46 %-points gasoline
****** Leibzig: Share of modes: -25 %-points cars and other LDV, +15 %-points public transport busses, +10 %-points active travel. Share of powertrains: +32 %-points post-fossil vehicles (BEV), -20 %-points gasoline, -12 %-points diesel.

Remaining CO_2e emissions

								Base year = 2018		Base year = 1990				
CO_2e reduction aimed for in target year (%) →	100	100	100	100	100	100	100	52	52	42	42	42	80	80
City →	Bydgoszcz					Plymouth		Thessaloniki		Thessaloniki			Leipzig	
Mobility scenario →	W0	W1	W2	W1+	W2+	JLP 2034	UK max	SUMP 2030	Shared elec.	2018	SUMP 2030	Shared elec.	Mob. Str.	Int. Mob.
↓ Techology and energy scenario	BAU	CliMobCity	CliMobCity	CliMobCity	CliMobCity	BAU	CliMobCity	BAU	CliMobCity		BAU	CliMobCity	BAU	CliMobCity
Scenario 1a (BAU, EU reference, expected future energy mix)	101					95		44		62	52		55	
Scenario 1 (CliMobCity, EU reference, expected future energy mix)		100	99	99	98		91		38			45		54
Scenario 2 (CliMobCity, Tech, expected future energy mix)		95	94	94	93		76		37			44		46
Scenario 3 (CliMobCity, Tech, green energy mix)		82	81	81	80		68		31			37		39
Scenario 4 (= scenario 3, additional modal shift *)			75				64		30			35		35
Scenario 5 (= scenario 3, decrease time spent **)			78				66		31			36		37
Scenario 6 (= scenario 3, additional electrification ***)			76				61		30			35		35
Scenario 7 (= combinations of scenario 3, 4, 5 and 6)			68				55		28			33		30
Scenario 8) Backcasting scenario 1: scenario 3, further modal shift ****									10			11		
Scenario 9) Backcasting scenario 2: scenario 3, further shift to post-fossil fuel vehicles *****									-2			-2		
Scenario 10) Backcasting scenario 3: further modal shift and shift to post-fossil fuel vehicles ******														0

* Share: -10 %-points LDVs (e.g. cars), +5 %-points public transport busses, +5 %-points active travel.
** 10% less time spent, because of less road vehicle-kms and/or more fluent traffic flow.
*** Share: 10 %-points extra shift to post-fossil fuel vehicles.
**** Thessaloniki: Share: -26 %-points LDV (e.g. cars), -5 %-points 2W, +8 %-points bus, +8 %-points metro, +3 %-points rail, +3 %-points walk, +9 %-points bike
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Annex 2 Expected energy mix for electricity production in the base year and year of planning horizon

(Source: *Appendix-PIK-Report* [PIK, 2023])

	1	2	3	4	5	6	7	8	9 = Sum 1-8	10	11	12	13 = Sum 10-12	14
Country	Electricity by geo-thermal	Electricity by hydro-power	Electricity by marine power	Electricity by CSP	Electricity by PV	Electricity by offshore wind	Electricity by onshore wind	Electricity by biomass	GREEN ENERGY	Electricity by coal	Electricity by gas	Electricity by oil	FOSSIL FUELS	Electricity by nuclear power
Poland (base)		1%			0%	0%	7%	3%	12%	82%	6%	0%	88%	0
Poland (2050)		2%			2%	3%	16%	8%	31%	33%	11%	0	44%	22%
Germany (base)	0%	3%	0	0%	7%	2%	12%	2%	26%	42%	17%	0%	60%	15%
Germany (2035)	0%	4%	0%	0%	15%	8%	21%	5%	52%	13%	38%	0	51%	0
Greece (base)	0%	12%	0%	0%	7%	0%	10%	0%	30%	44%	16%	10%	70%	0%
Greece (2030)	0%	17%	0%	0%	13%	0%	25%	0%	55%	25%	17%	3%	45%	0%
UK (base)	0%	2%	0%	0%	3%	6%	8%	5%	24%	23%	32%	0%	55%	21%
UK (2034)	0%	2%	0%	0%	4%	12%	14%	15%	46%	0%	20%	0%	20%	34%

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