2050 CliMobCity
Interreg Europe

2050 Climate-friendly mobility in cities

Appendix-PIK-Report

Analysis of CO_2e emissions

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Attachment-PIK-Report

This report, the Attachment-PIK-Report is a background report to the Project Summary.

The 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.

This report for the CO_2e analysis goes more in depth when explaining the carbon modelling process, the output and also by presenting more background tables.

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2050 CliMobCity Appendix-PIK-Report

Introduction

This report describes the process and results of analysing the CO_2e emissions and reduction of mobility of the four partner cities (Bydgoszcz, Plymouth, Thessaloniki and Leipzig) in the framework of the European (Interreg Europe) project 2050 CliMobCity, and of the model used for the analysis. The latter we for formulation ease in this report call the **carbon model**.

The CO_2e emission[1] modelling approach was inspired by the family of so-called 2050 Calculators and especially by the European Calculator (http://tool.european-calculator.eu/intro) which were spearheaded by the call for more transparent approaches to address the challenge of reducing carbon emissions. A key feature of this model family is the use of so-called levers that show potential changes towards decarbonisation, each of which can be set to different ambitions [Pestiaux et al., 2019]. The European calculator analysed CO_2e emissions of different sectors on the level of countries and Europe, including the transport sector.

A part of the European Calculator, namely the transport module, was transformed into a simulation model to analyse CO_2e emissions of urban mobility with focus on climate and social dimensions of the low-carbon transition. Calibrated to 4 European cities, the model is used to explore alternative scenarios of low-carbon mobility and the respective impacts in economic, climate and social spheres. The model is built to test a variety of low carbon trajectories or scenarios and to understand their key implications for policy planning. Those scenarios should support policy making by giving an indication of the required evolution of key indicators to reach the CO_2e reductions: scenarios explore the impact of switching certain groups of parameters on/off so as to better understand the impact of certain choices (energy efficiency and lifestyle changes, technological options, etc.).

The lever settings and levels combined describe the scenario for the respective urban base year (like 2021) and target year (like 2050) for both behaviour (e.g. time spent in transport every day) and technologies (e.g. fuel mix in passenger and freight transport).

Managing the transition to low-carbon mobility in cities needs to consider multiple aspects of infrastructure, technologies, climate protection, costs, social and health implications. Every aspect should deserve the same level of consideration in order to help cities evaluate the implication of specific actions. Current models used by cities for the purposes of energy planning capture well the technology/infrastructure and costs but are not holistic enough to incorporate climate protection and social implications.

The carbon model analyses the CO_2e emissions in different years and for different scenarios. Comparing the results shows the change of emissions, reduction or increase, or the difference between two alternative scenarios for the future. The change of emissions results from the change of mobility, predicted by the partner cities. However, the change of mobility is not the only input. Also the change of powertrains (technologies), more precisely the shift from fossil fuel vehicles (like gasoline or diesel vehicles) to post-fossil fuel ones (like electric or hydrogen vehicles) is an important factor and – with reference to electric vehicles – the energy mix of electricity production. It was

[1] In addition to CO_2, the greenhouse gases N_2O and CH_4 are also taken into account by means of CO_2-equivalents (CO_2e).

assumed that the hydrogen was only produced from renewable energies (green hydrogen). In the following, the model logic and the structure are described.

Logic and output of the carbon model

The carbon model follows a bottom-up approach to compute energy consumption and CO_2e emissions from the transport sector. The CO_2e calculation is based on mobility projections until the target year, formulated by the cities. The **carbon model** is a **what-if model**. One can mimic a specific future mobility configuration by setting so-called “levers” (= choosing certain values of different mobility variables) in the model (see Table 1). The available levers focus on measures that are important for CO_2e reduction, such as:

- a modal shift lever, pointing out a change of e.g. bicycle, tram or bus use at the dispense of car use (from traffic model);
- the average distance, represented by a “time-spent” lever (from traffic model);
- a powertrain lever (called T(technology)-share lever), describing the expected penetration of electric and hydrogen cars and the remaining use of gasoline and diesel cars responding to different emission standards (from EUCalculator).

In addition to the input from the traffic models, data for certain levers was also needed from other sources. Intensive literature research was carried out for this purpose, and the findings were collected in the so-called inventory. This is a collection of city, social, economic and mobility data pointing out the relation between societal activities (like working, shopping) and mobility (like number of trips, modal split, travel distances) in dependency of type and size of cities. The data are found in publications, hence by literature study, and then structured.

In the CliMobCity project the carbon model for its mobility input mainly relies in the transport modelling outputs. This is a big advantage as the granularity of the information is finer and as the data are more city-specific, the output therefore reflecting the spatial characteristics of a specific city rather well. The data from the inventory have less spatial fineness, as they often refer to other cities, or to types of cities, the average city or even only to a larger spatial entity like a region or country. But the inventory can be used to supplement or check the plausibility of the transport modelling output. The other way around, the transport modelling output is used to feed the inventory of new data.

For the technological data like powertrain performances and shares or the energy mix for electricity production, all input to the carbon model origins from the inventory.

As indicated, the carbon model was not developed from scrap. Instead it was initially designed to determine transport activities itself and calculate emissions without an upstream transport model. Therefore the type of input was one that could perhaps be answered by experts, like time spent per person, day and mode. This together with speed per mode and the share of mobile population (from local plans or other local sources) would then lead to the transport demand, expressed in passenger-kms. Finally the modal share information was needed to weight the passenger-kms per mode. In the project 2050 CliMobCity the same input is used, but it comes directly from the transport models. The passenger-kms are delivered per mode/activity: LDV (e.g. car), motorised 2-wheeler, bus, tram, metro, rail, bicycling and walking. With additional information as vehicle occupancy and distribution of road mobility across different types of roads the carbon model now disposes of vehicle-kms. Vehicle-kms of LDVs, 2-wheelers, busses, trams, metro, train, and bicycle, running on different types of infrastructure.[2]

[2] If no traffic model is available, further steps are necessary, which are explained in the annex.

Next to the mobility, which is the output of the transport modelling done by the cities, the calculation of the energy requires the following input parameters:

- the technology share for each mode (in %) (EUCalculator, 2019);
- the energy consumption of each technology in each mode [MJ/vkm, MJ/pkm or MJ/tkm] (EuCalculator; Höltl, 2017; Ambel et al., 2017), these are aggregated values which take into account different types of roads;
- vehicle efficiency [MJ/km] (EUCalculator).

The main outputs of the carbon model are:

- the energy demand from transport;
- the direct CO_2e emissions from transport including the emission from the production of fuels (well-to-wheel emissions) are calculated, using the emission intensity of each type of fuel used in the various technologies [t CO_2e/GWh].

The calculation logic adopted here follows the logic described in Figure 1:

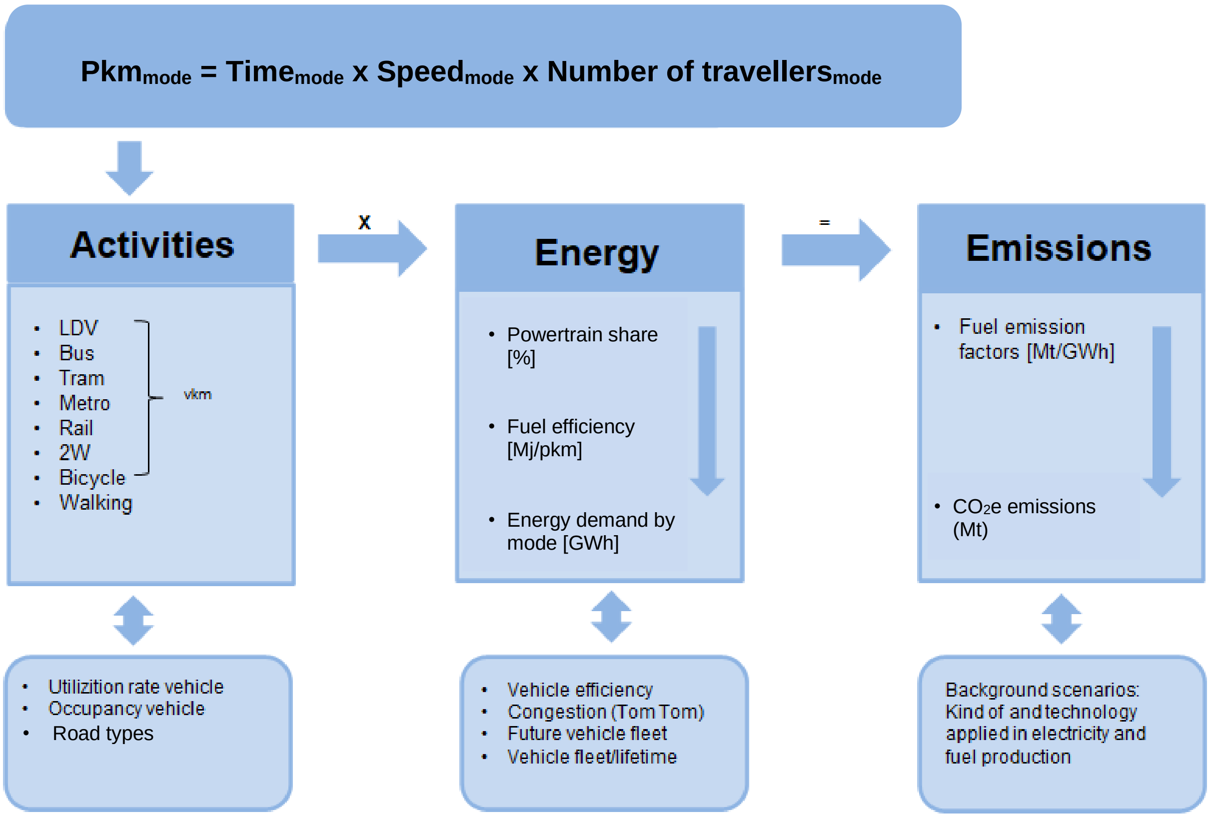


Figure 1 Overview of the structure adapted for the transport emission model

Passenger transport, input, levers, output and calculation trees

For passenger transport, the model is able to represent all modes shown in Figure 2. For the partner cities where no metro or tram is in operation, these modes were not taken into account. This allows the model to be specifically adapted to local conditions. For the assessment of the environmental impact of these transport modes, it is crucial to know which propulsion or technology the modes are predominantly equipped with. The model offers a range of the most current technologies for each transport mode. Subsequently, the model specifies the type of fuels with which these technologies are powered. Some fuels can be used in different technologies. For instance, diesel is primarily used as a fuel for Internal Combustion Engines (ICE) vehicles, but is also used as a fuel for Plug-in Hybrid Electric Vehicles (PHEV). The data for the percentage share of the respective technologies is mainly based on national data (see chapter Scenario). Finally, three energy vectors are mapped: those of the conventional fossil fuels and, in order to map current discussions dealing with the significance of biofuels and e-fuels, these two fuels were formed as extra vectors.

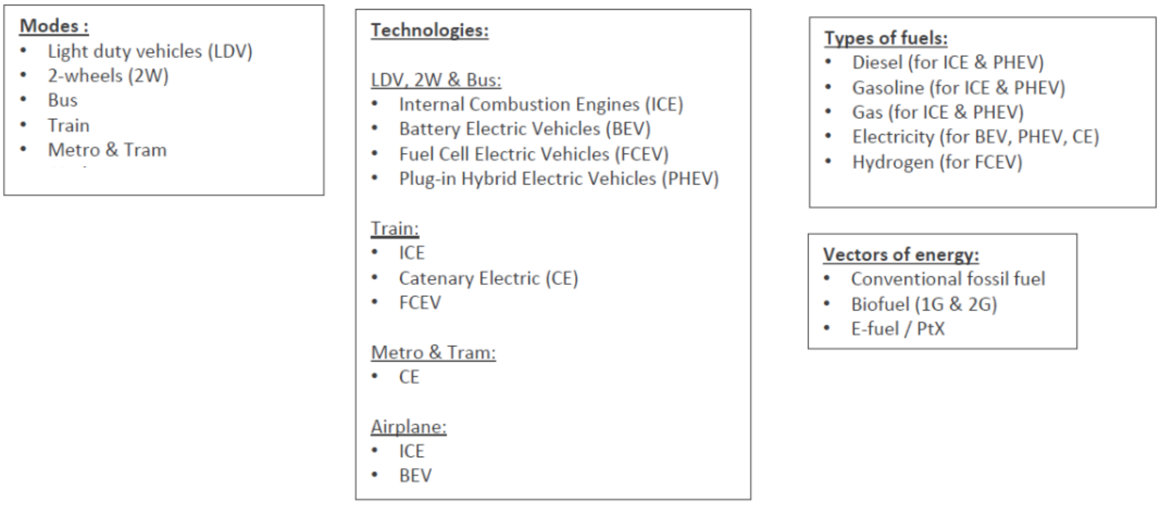


Figure 2 Scope definition of the passenger transport module: modes, types of vehicles , Taylor et al.,2019
(1G = first generation, 2G = second generation, PtX = power-to-X)

The carbon model has eight levers (see Table 1). They reflect the different influences of the transport system and technology development and are crucial for the carbon modelling. Some levers relate to local decision-making (e.g. time spent bicycling), other levers to national/international decision-making (e.g. vehicle efficiency). One of the levers is **transport demand** in **passenger-kms**. It can be moved into different positions on its own, but typically is the result of three other variables provided by the cities and representing three further levers: the time spent/person/day/mode, the average speed/mode and the population. With these along, there are in total eleven levers. The most important input per city from the transport models is presented in the input tables of the Annex.

Not all levers are used in the 2050 CliMobCity project, for instance not the lever lifetime of vehicles, as this would expose the CO_2e emissions from producing, maintaining and recycling vehicles, but such emissions lie outside of the scope of the project.

	Lever	Short description
1.	Transport demand [pkm/capita]	The transport demand is expressed as passenger km/capita per year. *[Transport models]*
2.	Occupancy [passenger/vehicle]	Occupancy is expressed as number of passengers per vehicle and has only an impact on road vehicles. *[Transport models and TRACCS, 2013]*
3.	Utilization rates [km/vehicle/year]	The utilization rate is the number of kilometres travelled by a vehicle yearly. *[TRACCS, 2013]*
4.	Lifetime of vehicles [total km/vehicle]	The lifetime of vehicles is expressed in total kilometres that can be travelled by a vehicle before being discarded. It will be translated in years depending on the utilization rate. *[ACEA, 2018]*
5.	Modal share [%/mode]	The modal share lever describes how passengers are travelling: by car, bus, train, etc. *[Transport models]*
6.	Vehicle efficiency [MJ/km] or [MJ/pkm]	This lever describes how the efficiency of new vehicles evolves. The vehicle efficiency is expressed in MJ/km for road vehicles and in MJ/pkm for rail and aviation. *[Höltl, 2017; Ambel et al., 2017]*
7.	Low Emission Technology development [% of new vehicles/technology]	This lever described the level of adoption of low emission technologies. *[ACEA, 2018; Eurostat, 2018; TRACCS, 2013]*
8.	Fuel mix [%/fuel type]	This lever described the fuel mix, taking into account biofuels and e-fuels (electricity is linked to the technology lever). *[USDA, 2017; Eurostat, 2017; Eurostat, 2018]*

Table 1 Lever list passenger transport adapted from Taylor et al., 2019

Zooming into the boxes `energy' and `emissions' of Figure 1, and connecting these to the levers of Table 1 leads to the calculation tree shown in Figure 3. It distinguishes external input (yellow) for the carbon model, lever input (green) and intermediate and final output of the carbon model (blue). For transport demand the difference between external input and lever input is subtill. The **transport demand** for the cities' BAU and CliMobCity scenarios comes from the cities' predictions/transport models and determines the position of the levers of the carbon model (yellow). However, this transport demand can also be varied, as is done in the what-if lever forecasting or backcasting exercises (green).

Other inputs are:

- **Technology share** in %, mainly based on national data, if local data are available, then usage of local data. A higher technology share of post-fossil fuel cars will therefore be translated to a higher number of vehicle-kilometers travelled by low-emissions technologies. Also includes shares of bio- and e-fuel. The percentage national values are based on analyses of the EU Calculator. There, different ambitious scenarios regarding post fossil fuel shares were calculated, two of these scenarios were also used for the CliMobCity project: the EU reference and the Technology Scenario (see section scenarios).
- **Emission factors per technology** [IPCC, 2006]. Dynamic future developments are also considered.

- **National developments** in electricity production must also be taken into account here. The higher the share of renewable energies in electricity production, the lower the emission impact of the electricity.

Also here the external input can be substituted by what-if input, meaning that one or more levers are set into a different position. An example is that the technology lever is not set according to the powertrain shares of the EU reference or Tech scenario, but to an explorative other value, as has been carried out in the forecasting and backcasting lever exercises, serving exploration.

There are three outputs of different types (Figure 3, blue):

- Transport demand per technology (powertrain), which is calculated by combining the transport demand per mode and the technology share.
- Energy consumption per technology, in which the average energy consumption of the vehicle fleet per technology and a specific vector mix is considered.
- Emission intensity per technology.

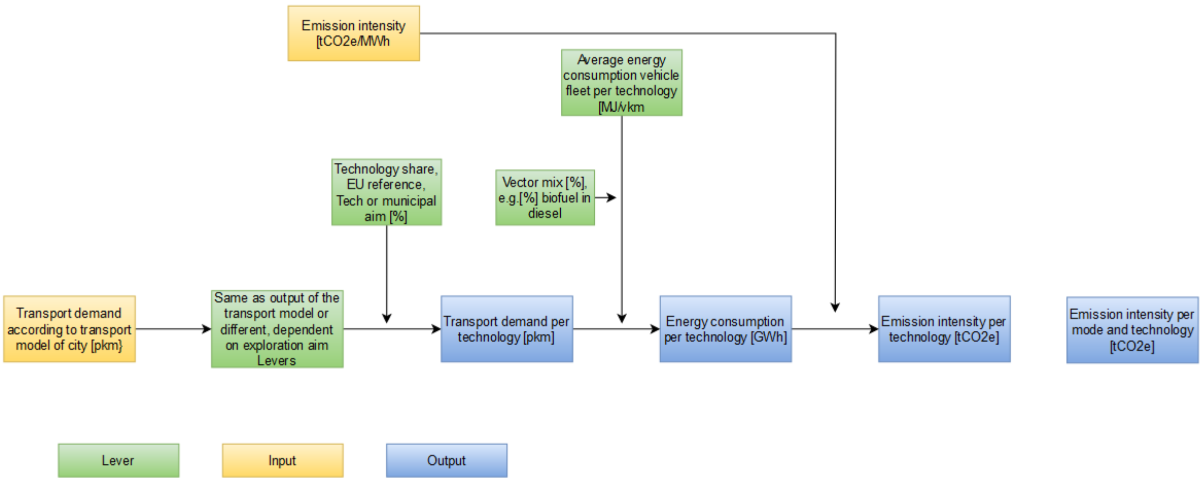


Figure 3 Calculation tree transport demand, technology share and emission intensity

Freight Transport, input, levers, output and calculation trees

A finding of the project was that the focus of the cities is on passenger transport and less on freight transport. This made the calculation for delivery traffic much more difficult due to the lack of data. Therefore, freight transport was compressed to road delivery traffic. A distinction could be made between heavy goods vehicle (HGV) and light good vehicle/van (LGV). Table 2 shows all the relevant levers for freight transport.

Lever	Brief description
Transport demand [tkm]	The transport demand is expressed as Vkm. In this module, aviation, land transport and shipping are considered together. [Transport models]
Vehicle efficiency [MJ/km] or [MJ/pkm]	This lever describes how the efficiency of new vehicles evolves. The vehicle efficiency is expressed in MJ/km for road vehicles and in MJ/tkm for rail, boat and aviation. [ICCT, 2012; TRACCS, 2013]
Low Emission Technology development [% of new vehicles/technology]	This lever described the level of adoption of low emission technologies. [ACEA, 2018; Eurostat,2018; TRACCS, 2013]
Fuel mix [%/fuel type]	This lever described the fuel mix, taking into account biofuels and e-fuels (electricity is linked to the technology lever). [USDA, 2017; Eurostat,2017; Eurostat,2018]

Table 2 List of levers freight transport

As with passenger transport, the traffic activity served as the basis for calculating the emissions. Bydgoszcz, Plymouth and Leipzig provided absolute values (e.g. vehicle-kms). Thessaloniki was able to determine approximately the percentage share of total road delivery traffic in the total transport network. The emissions were calculated in a similar way to passenger transport (Figure 3). The transport activities were subdivided into the various propulsion systems using the technology share (see figure 4). All powertrains used from passenger transport were also taken into account here. The respective energy consumption could then be calculated with the vehicle efficiency. Finally, the emissions were calculated with the corresponding emission factors.

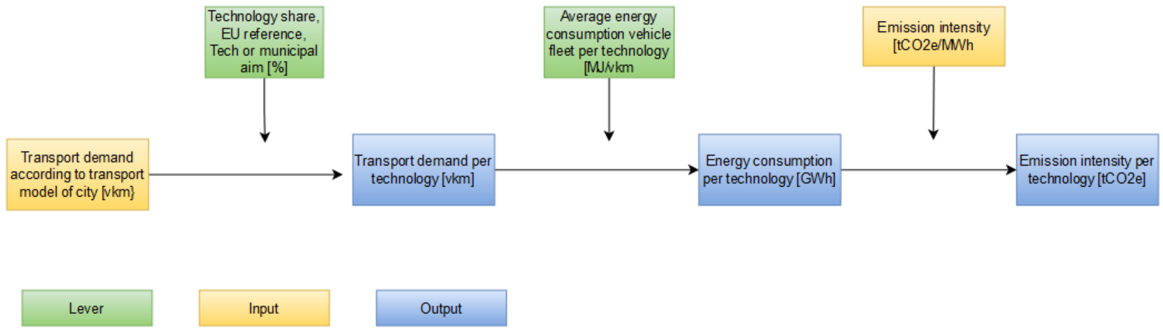


Figure 4 Calculation tree emission intensity freight transport

Implementation of technological developments

In the project, there was technological information on the reference year and the target year for each lever. For instance, in Plymouth, the BEV share is 1% in 2018 and 56% in the target year 2034 in the ambitious scenario. However, the development between these years also had to be taken into account. The development in the meantime is not in the dataset, so it was calculated with a sigmoid function whose course is represented by curves. Evidence has shown that the adoption of new technologies is usually not linear, but follows an "s-shaped" course. A new technology starts slowly (starting point is the base year) and reaches the innovators and early adopters who are a minority, then it accelerates and reaches the majority, and finally it slows down again and reaches the laggards [Roger, 1995], [Felton, 2008]. The technology share for battery electric vehicles (BEV) serves as an example, i.e. how high the share of BEVs is on the roads (Figure 6).

For this reason, we have decided to implement different types of ambition levels curve shapes, in order to be as realistic as possible (Figure 5). The ambition levels trajectories between the base year (2015) and 2050 will depend on different parameters:

- Starting time: when will the new trend or new technology start to spread?
- Duration: how long will it take to reach its maximum potential?
- Final ambition: what is the maximum potential we expect?
- Shape of uptake: will it evolve smoothly, or is it most likely to start slowly and accelerate after this starting phase?

Reflecting the diversity of settings, the different levers can take different shapes: linear development (L-curve), S-shaped development (S-curve) or half S-shaped curve (HS-curve) in case the trend is already in the acceleration phase (Figure 5). When none of these curves is suitable, each lever can also be fitted to its own curve.

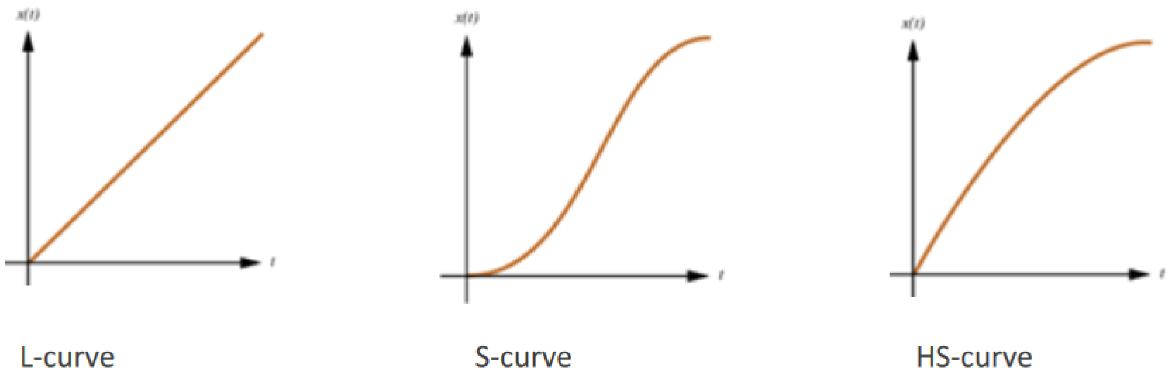


Figure 5 Levers curve shapes, Taylor et al.,2019

For the model, S-curve will usually be used for the diffusion of new technologies (fig.6), and other types of curves will be used when necessary, based on expert judgment and the settings done for the EU Calculator project.

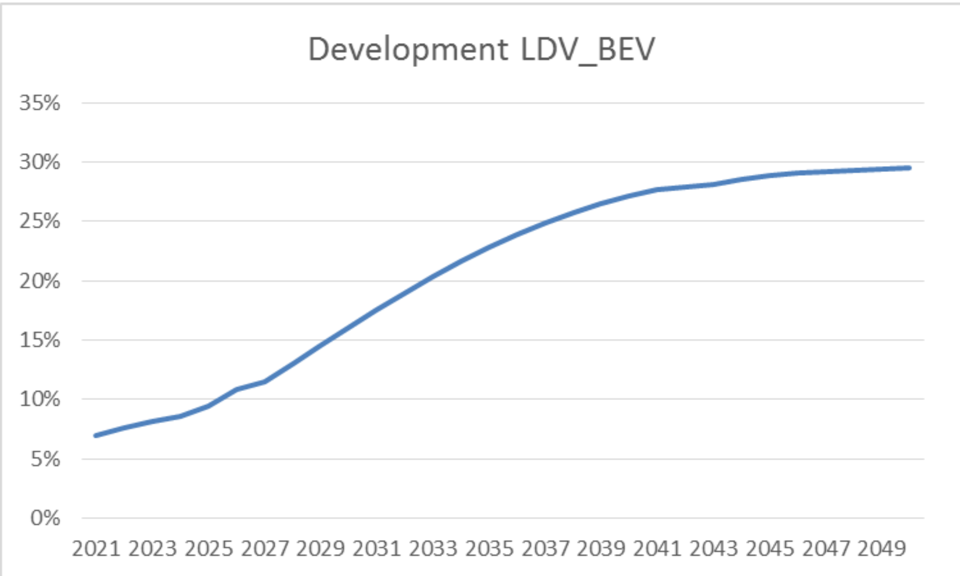


Figure 6 Example of an S-curve for the share of electric cars (T-share) in Bydgoszcz

Technological scenarios

Technological changes have an important influence on emissions in the transport sector, in particular the change of powertrains[1]. This is about gasoline or diesel engines becoming cleaner, but above all about the shift from fossil fuel to post-fossil fuel ones like those in battery electric or hydrogen vehicles. In order to investigate the contribution of future changes in the share of post-fossil technologies (T-share lever[3]), two different scenarios developed within the EUCalc model called EU reference and Tech were simulated.

The **EU reference scenario** includes the impact of current EU policies and the combination of lever positions under this scenario reproduces as far as possible the key sectoral assumptions and outcomes of the EU reference scenario as described in Capros et al. 2016. To stay within the language use of this project, it can also be called business as usual scenario.

In contrast, the **Tech scenario** represents very ambitious technological changes. In this scenario, the ambition levels for technologies and fuels are raised from those of the EU-reference scenario to the maximum reduction level assumed in the EUCalc by 2050.

Renewable energy sources are balanced to meet specific demand and oversupply of electricity is limited to <50% of annual storage capacity. Furthermore, Zero Emission Vehicle reach 100% of car passenger sales in 2050 and it was assumed that the hydrogen was only produced from renewable energies (green hydrogen).

	% 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

Table 3 Share of electric cars for each city and different technological scenarios

* Red = EU reference scenario, blue = Tech scenario.

[3] 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

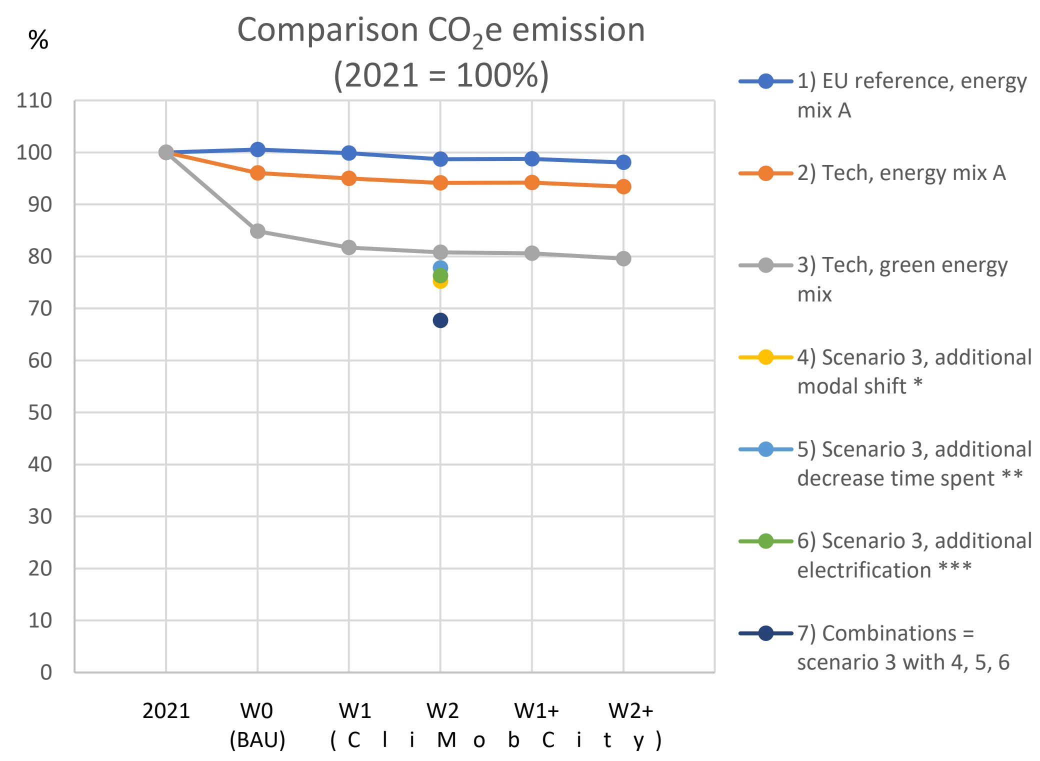
The shares of post-fossil fuel powertrain of the two scenarios are shown per partner in Table 3. The values come from the calculations of the EU Calculator and were adjusted to the years of the cities under consideration.

Comparable to the penetration degree of electric and hydrogen vehicles, the **energy mix of electricity production**, also being different per country, is expected to change over time (for values relevant for the partner cities see table A1. In the “energy mix A” scenario the share of fossil electricity production in 2050 still is substantial, while electricity production in the “green” scenario is near to completely post-fossil. Again PIK interpolates the country-specific values for 2050 to the year of the planning horizon envisaged by the partner cities.

Results of the partner cities

Bydgoszcz

For Bydgoszcz, the base year is 2021 and the target year is 2050, making it the city with the longest monitoring period. There are five different scenarios. The ultimate result of mobility changes from 2021 to 2050 **W0 (BAU)** is the increase of road vehicle-kms by about 30% (LGVs) 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 7).



*	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.

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.

Figure 7 CO_2e emissions Bydgoszcz

In the CliMobCity scenario 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). This pattern correlates with the change of private car vehicle-kms in the respective CliMobCity scenarios. In **W1** emissions are less than the **W0 (BAU)** emissions, as in the CliMobCity scenarios the public bus fleet is 100% post-fossil, in **W2** less than in **W1** because of the more effective combination of pull- and push measures

and the shorter distance, **W1+** and **W2** in comparison to respectively **W1** and **W2** because of the 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 = "scenario 3" in the figure 7) 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 regarding mobility. The Figure 7 also shows the results of some **experiments** changing the lever positions in the carbon model that reflect the following changes: like additional modal shift (10 %-points less car trips etc. than in scenario 3 in exchange for 5 %-points more bus and active travel), 10% less time spent than in scenario 3 (e.g. less distance travelled), or 10 %-points additional electrification than in scenario 3, or combinations of these measures, providing additional 6 %-points, 3 %-points, 5 %-points or 13 %-points reduction of CO_2e emissions respectively.

In this last experiment being the best of all envisaged scenarios, the remaining CO_2e emissions are 68% of the 2021 emissions. These for 54% consist of car emissions and for 46% of freight emissions (see Fig. 8)

Further reduction will depend on further mobility, land use and powertrain (electrification etc.) measures.

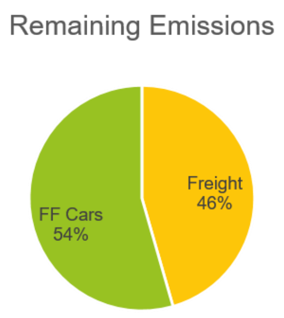
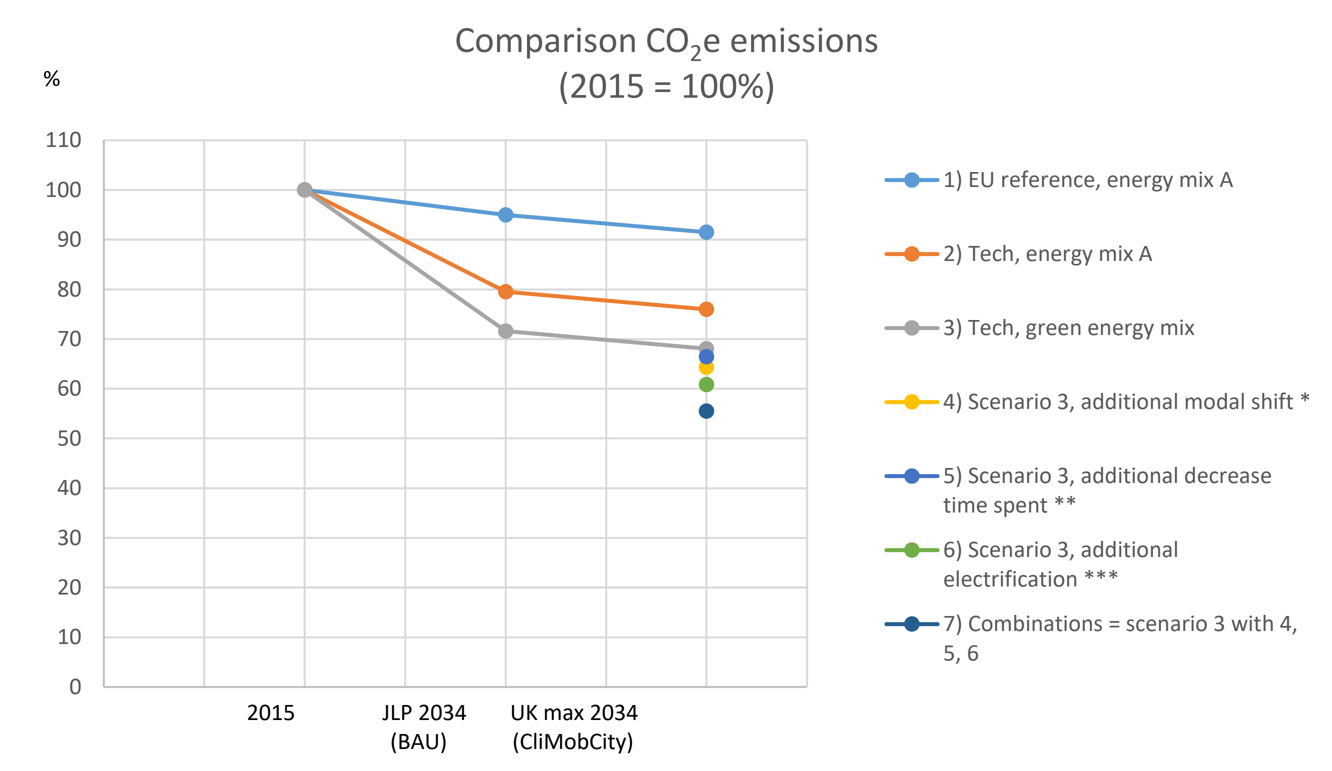


Figure 8 Remaining emissions Bydgoszcz

Plymouth

For Plymouth, the base year is 2015 and the target year is 2034, with carbon developments calculated for two different scenarios. One is based on the joint local plan (BAU) and the other scenario is based on the national transport specific UK max plan (2050 CliMobCity measure package). The same population growth 262,712 (2015) to 297,712 (2034) was assumed for all scenarios. From 2015 to **JLP 2034 (BAU)** car-kms increase by 20%, LGV-kms and HGV-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 9).

In the **UK Max (CliMobCity)** scenario the volume of car and HGV-kms declines compared to 2015, so do the CO_2e emissions. Still along the blue line (EU reference scenario), between 2015 and the 2034 **UK Max** scenario CO_2e emission declines by 9% (see figure 9).



* 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% 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.

Figure 9 CO_2e emissions Plymouth

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** then declines by 24% (orange line).

If also all electricity was produced by green energy, the CO_2e emissions in between 2015 and UKmax would decline by 32% (see grey line in the following figure). Still the remaining CO_2e emission level would be 68% of the 2015 level.

Experimenting with the levers in the carbon model shows – in a what-if fashion – that:

- additional modal shift (share cars -10 %-points; bus + 5 %-points, active travel +5 %-points) provides another 4% CO_2e reduction;
- 10 % additional reduction of the "time spent" (= arising from shorter distances) provides another 2% CO_2e reduction;
- additional share of post-fossil vehicles of 10 %-points provides another 7% CO_2e reduction;
- 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 experiments is on the level of 55% of the 2015 emissions, barely half way towards the MoP's target of climate-neutrality by 2030. More than 50% of the remaining emissions are immense due to the activities of cars (LDV) (Figure 10). A significant lever for reduction measures is above all a more efficient and environmentally friendly form of delivery traffic, which at 35% has a significant share of the remaining emissions (Figure 10).

All of these changes take place in the context of a growing population. The percentual **reduction** of CO_2e emissions **per capita** is 7 to 11 %-points higher than the percentual total CO_2e reduction, dependent on the scenario.

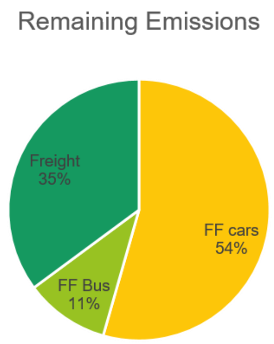


Figure 10 Remaining emissions Plymouth

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. Major options are discussed in the last chapter of the Project Summary.

Thessaloniki

Thessaloniki has a base year of 2018 and a target year of 2030. One challenge was the short time span of 2018-2030, especially in relation to technological changes (e.g. technology shift in fuels and efficiency gains), which are mainly influenced by national or international policies. Most of the technological impacts are not immediate and take time to reach their full impact at the city level. If the time span is short, it is not or only partially possible to assess the correct development. Therefore, it is possible that the mitigation potential of the measures is under- or overestimated. Before the MoT last year joined the EU initiative of 100 climate neutral cities in 2030, its CO_2e reduction aim was 42% less emission than in 1990. The projects CO_2e analysis has sticked to this aim.

The question, however, arises how much reduction 42% would represent if not 1990, but 2018 was the base year. The answer requires knowledge about the CO_2e development of Thessaloniki between 1990 and 2018. As it turns out, neither at the MoT nor at the Hellenic Institute of Transport (HIT) or Center for Renewable Sources and Energy Saving (CRES) can answer this question. The considerations led to the conclusion that the CO_2e emissions of mobility in Thessaloniki have increased by roughly 20% between 1990 and 2018. 42% reduction requirement from 1990 is then equivalent to 52% reduction from 2018 on.

There are two different scenarios, the first one is based on the sustainable urban mobility plan (SUMP and for climate business as usual BAU). In the second scenario, in addition to the first one, further measures specific to 2050CliMobCity have been added.

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)**. In the MoT the inauguration is accompanied by a reduction of public transport busses of 30%. These are diesel ones. The metro is electricity powered. However, the electricity production is far from green. These and other changes as foreseen in the **BAU scenario** provide a CO_2e reduction of <u>8%</u> (blue line in the following figure 11). This relative small value in comparison to the decline of vehicle-kms is caused by the relative high share of fossil fuel vehicles (from 0.2% in 2018 to still only 1.5% in 2030) in the remaining kilometrage .

In the **CliMobCity scenario**, which adds measures to the BAU scenario, CO_2e emissions can be reduced by another <u>6%</u> (total reduction now is <u>14%</u>; still blue line figure 11). The 6% reduction is the result of including the electrification ambition of the MoT for 2030, which is higher than the electrification expectation in the EU reference scenario for 2030, furthermore the result of the further reduction of the number of public transport diesel busses in service as many of them will be replaced by electric busses, and to a small extent the result of introducing the shared electric car scheme.
Given the more ambitious replacement of fossil-fuel by post-fossil fuel vehicles corresponding with the Tech scenario (grey line). However, the expected reduction is only slightly larger.

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 <u>21%</u> (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 lever experiments in the carbon model (= what-if experiments). These were based on scenario 3 (CliMobCity, Tech, green energy):

- (scenario 4) reduce the share of cars by 10 %-points and conduct corresponding increases of public transport use and active travel;

- (scenario 5) 10% less time spent because of less road vehicle-kms,
- (scenario 6) increase the share of post-fossil cars by 10 %-points,
- (scenario 7) combinations of these.

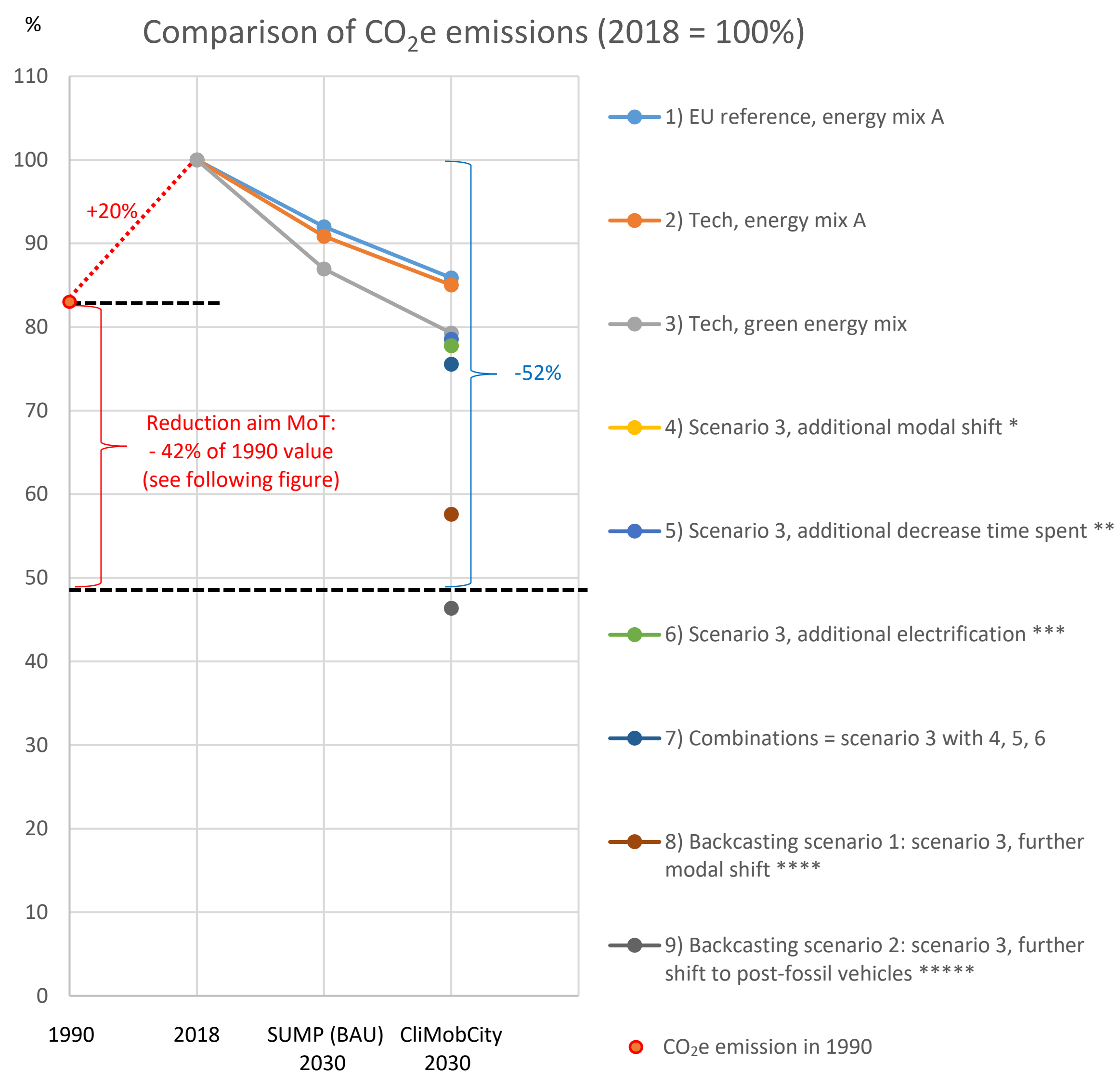
The result is respectively 1%, 1%, 2%, and 4% CO_2e reduction.
The total reduction including the lever experiments is 24% of the emissions of 2018, the remaining CO_2e emissions having the level of 76%.

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 scenario 3:

- (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 by. The achieved CO_2e reduction is 46%, hence despite of the backcasting intention not sufficient. But more car shift is not possible.
- (scenario 9) a powerful shift to post-fossil 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%.

Such measures in the envisaged time frame (2018-2030) are not realistic. But the exercises provide orientation.
The remaining emissions being 46% of the 2018 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.

The carbon reduction will partly depend on national and EU measures discouraging the use of fossil fuel vehicles and privileging alternatives (like electric cars or other modes) to make them more attractive. But also more local measure packages can relevantly contribute to reducing fossil fuel (road) vehicle-kms.



*	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% .
****	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.

Figure 11 CO_2e emissions Thessaloniki

Leipzig

For Leipzig, the base year is 2015 and the target year is 2035; there are two scenarios based on urban plans. A distinctive characteristic is that Leipzig, with 70 thousand, has the highest population growth of all partner cities.

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 cars in the same period (as expected in the EU reference scenario) and of relevance for the remaining car-kms, induce a carbon reduction of 39%. The number of public transport vehicle-kms is increasing, but these in 2035 all are electric vehicle-kms.

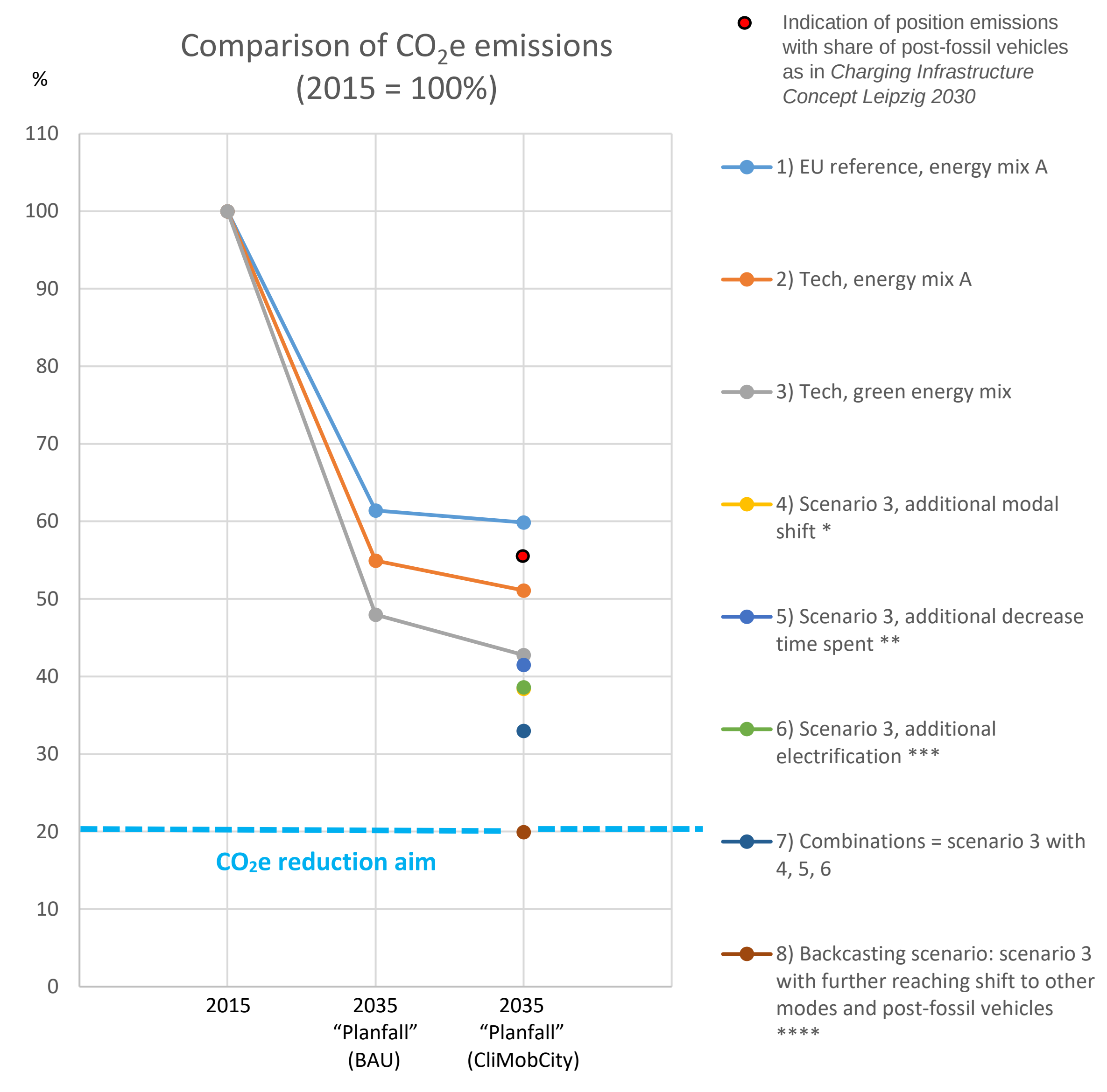
In the **CliMobCity scenario** there is additional electrification: 100% of the public busses are electric ones in 2034. The general electrification is facilitated more strongly by an extended mobility station (passenger hub) policy according to the new (draft) Smart mobility policy. All municipal activities (e.g. logistics etc.) are to become climate-neutral by 2030.

The CO_2e reduction of the CliMobCity scenario is 40%, just little bit more than of the BAU scenario (see fig. 12). The actual difference, however, is larger because, not only is, as just mentioned, the BAU reduction actually less than shown in the figure (meaning that the BAU dot should lie higher), but also is the electrification ambition in the CliMobCity scenario higher than in the EU reference scenario (meaning that the CliMobCity dot should lie lower, between the blue and the orange line).

In the Tech scenario having a larger replacement of fossil fuel vehicles, CliMobCity CO_2e emissions would decline by 49% (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 57% (grey line figure 12).

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

- (scenario 4) the share of cars and other LDVs would decline by 10%-points in favour of more busses and active travel?
- (scenario 5) there would be 10% less “time spent” for travelling because of less road vehicle-kms?
- (scenario 6) the share of post-fossil vehicles would be 10%-points larger?
- (scenario 7) the three improvements were combined?



*	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 is 10% higher.
****	Share of cars and other LDVs: -25%-points LDV, share of public transport busses +15%-points, of active travel +10%; share of post-fossil vehicles: +32%-points BEV, -20%-points gasoline, -12%-points diesel.

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.

Figure 12 CO_2e emissions Leipzig

This would lead to total reductions in comparison to 2015 of respectively 62%, 58%, 61% or 67%. 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.

Therefore a backcasting-like lever exercise has been carried out. In such exercise one or more levers are moved into positions which lead to sufficient CO_2e reduction for a climate aim. A result was that 80% reduction in comparison to 2015 (such fits to the aim of climate neutrality in 2040) can be achieved if (scenario 8) the share of cars and other LDVs can be reduced by 25%-points, in favour of 15%-points additional public transport busses and 10%-points more active travel AND if the share of post-fossil vehicles (BEVs) moves up by 32%-points at the dispense of gasoline cars (-20%-points) and diesel cars (-12%-points). Also this backcasting is a what-if exercise, to be validated by demand considerations.

The CO_2e reductions per capita are, regarding all scenarios, 2-7 %-points higher than the total CO_2e reductions.

Reflecting on mobility, powertrain and emission changes, and the increasing share of public transport of flows from and to Leipzig has a positive impact for the change of CO_2e emissions. On the other side, the remaining large share of car use in the flows from and to Leipzig in combination with the increasing car distance has a negative impact on the development of CO_2e emissions. The net change is negative, however hardly for Leipzig (as the emission analysis is limited to travel distances inside the municipal area), but surely for the surrounding of Leipzig.

Annex

Energy mix for electricity production

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

A 1 Shares of energy sources in energy production (from EUCalculator)

Electrification	Bydgoszcz			
	Base	BAU	CliMob (W1)	CliMob (W2)
bus_ICE-diesel	0,9861561	0,9861561	0	0
bus_ICE-gasoline	0,0039554	0,0039554	0	0
bus_ICE-gas	0,0057533	0,0057533	0	0
bus_BEV	0,0041352	0,0041352	0,7	0,7
bus_FCEV	0	0	0,2	0,2
bus_PHEV-diesel	0	0	0,1	0,1
rail_ICE-diesel	0,45	0,2	0,2	0,2
rail_CEV	0,55	0,8	0,8	0,8
rail_FCEV	0	0	0	0
metro_CEV	0	1	1	1
tram_CEV	1	1	1	1
HGV_ICE_diesel	0,84	0,7466	0,7466	0,7466
HGV_ICE_gasoline	0,16	0,068	0,068	0,068
HGV_BEV	0,02	0,047	0,047	0,047
HGV_PHEV_diesel	0	0,068	0,068	0,068
LGV_ICE_diesel	0,84	0,7466	0,7466	0,7466
LGV_ICE_gasoline	0,16	0,068	0,068	0,068
LGV_BEV	0,02	0,047	0,047	0,047
LGV_PHEV_diesel	0	0,068	0,068	0,068

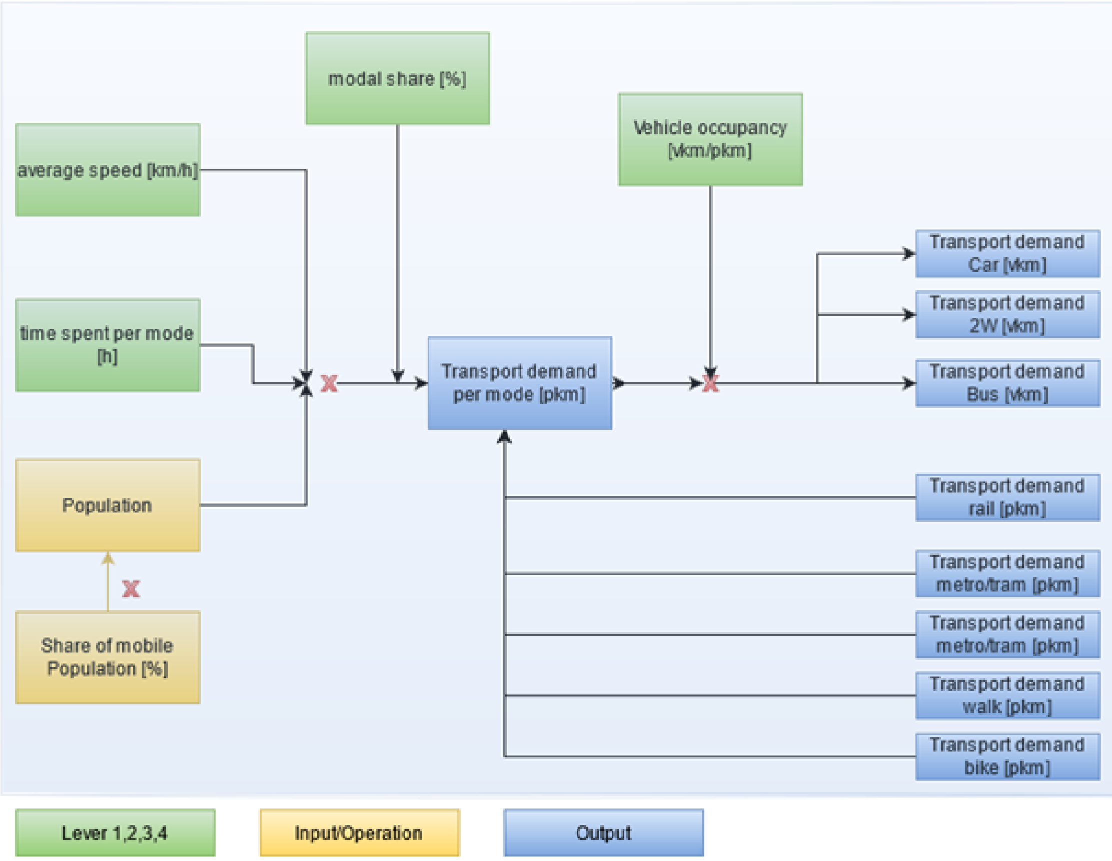
Electrification	Leipzig		
	Base	BAU	CliMob
bus_ICE-diesel	0,929805	0,5	0
bus_ICE-gasoline	0,0205517	0,4	0
bus_ICE-gas	0,0228731	0,025	0
bus_BEV	0,0079141	0,025	0,9
bus_FCEV	0	0,025	0,1
bus_PHEV-diesel	0	0	0
rail_ICE-diesel	0,5	0	0
rail_CEV	0,5	1	1
rail_FCEV	0	0	0
metro_CEV	0	1	1
tram_CEV	1	1	1
HGV_ICE_diesel	0,2645905	0,26	0,26
HGV_ICE_gasoline	0,5218739	0,52	0,52
HGV_BEV	0,0037609	0,018	0,018
HGV_PHEV_diesel	0,0041848	0,015	0,015
LGV_ICE_diesel	0,2645905	0,26	0,26
LGV_ICE_gasoline	0,5218739	0,52	0,52
LGV_BEV	0,0037609	0,018	0,018
LGV_PHEV_diesel	0,0041848	0,015	0,015

Electrification	Thessaloniki		
	Base	BAU	CliMob
bus_ICE-diesel	1	1	0,5
bus_ICE-gasoline	0	0	0
bus_ICE-gas	0	0	0
bus_BEV	0	0	0,5
bus_FCEV	0	0	0
bus_PHEV-diesel	0	0	0
rail_ICE-diesel	0,5	0,4	0,4
rail_CEV	0,5	0,6	0,6
rail_FCEV	0	0	0
metro_CEV	0	0	1
tram_CEV	0	0	1
HGV_ICE_diesel	0,93	0,88	0,88
HGV_ICE_gasoline	0,07	0,09	0,09
HGV_BEV	0	0,03	0,03
HGV_PHEV_diesel	0	0	0
LGV_ICE_diesel	0,67	0,63	0,63
LGV_ICE_gasoline	0,3	0,3	0,3
LGV_BEV	0,03	0,06	0,06
LGV_PHEV_diesel	0,06	0,06	0,06

Electrification	Plymouth		
	Base	BAU	CliMob
bus_ICE-diesel	0,98426295	0,85	0,85
bus_ICE-gasoline	0,00976096	0	0
bus_ICE-gas	0	0	0
bus_BEV	0,00587649	0,15	0,15
bus_FCEV	0	0	0
bus_PHEV-diesel	0	0	0
rail_ICE-diesel	0,4	0,1	0,1
rail_CEV	0,6	0,9	0,9
rail_FCEV	0	0	0
metro_CEV	0	0	0
tram_CEV	0	0	0
HGV_ICE_diesel	0,998	0,97	0,97
HGV_ICE_gasoline	0,002	0,002	0,002
HGV_BEV	0	0,03	0,03
HGV_PHEV_diesel	0,0042	0,0042	0,0042
LGV_ICE_diesel	0,45	0,446	0,45
LGV_ICE_gasoline	0,52914598	0,52914598	0,431
LGV_BEV	0,00376093	0,00376093	0,099
LGV_PHEV_diesel	0,0042	0,0042	0,0042

A 2 Electrification shares of transport modes other than cars (from EUCalculator)

Transport activity and demand, Mode of operation without prior traffic model



***Input" and "Output" labels apply when using calculator for cities directly, without prior traffic forecast**

Figure A3 Calculation tree transport demand. This step was not needed in 2050 CliMobCity, as traffic models already calculated the transport demand per mode. Pkm=person kilometer, vkm= vehicle kilometer MJ=Mega Joule

In the case of the CliMobCity project, there **were traffic models that already calculated the transport demand per mode**. Nevertheless, the procedure without prior transport models is briefly explained in this section so that the model logic is comprehensible and transparent.

There are two main results that come from the traffic modelling in our case:

- Road passenger transport demand expressed in vkm: the main driver for road vehicle emissions are the vehicle-kilometres, which are determined as the km driven by road vehicles and can be reduced if the vehicle occupancy increases (Car, 2W, Bus).
- Rail, metro/tram transport demand expressed in pkm, because public transport only works if the service offer and flexibility are sufficient. Diminishing the number of vehicles to have higher occupancy is therefore not always a consistent solution.

Different informations are required (**without prior traffic models**) to compute passenger transport demand by mode:

- Demography: the population input is provided by the cities; The share of mobile population, also to implement demographic changes
- The modal share (in land transport); provided by the cities in passenger trips, which is also a lever
- The occupancy of road vehicles; local data from the cities or national Data, the occupancy is also a lever
- Time spent per person per mode, provided by urban transport models
- Average speed per mode, provided by urban transport models

The modal share was calculated on the basis of passenger trips, the respective modal split accordingly represents the percentage of passenger trips (see figure 4). In combination with the average speed and the average time spent (time by speed), this makes it possible to make statements about the development of the average passenger travel distance. In this way, spatial infrastructure components can also be analysed. In addition to spatial infrastructure components (distance), behavioural aspects (time spent) and flow-specific components are also represented in the model

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