MODELLING METHODOLOGY REPORT

URBAN MOBILITY MODEL FOR BAKU, AZERBAIJAN

Federal Ministry
for the Environment, Nature Conservation
and Nuclear Safety

International Transport Forum

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Provided to authorities in the context of the model hand-over session

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ITF Project deliverable

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Table of contents

A strategic urban passenger model for Baku agglomeration area, Azerbaijan

Objectives

The objective of the model is to provide policy-makers with a user-friendly tool to identify and assess possible pathways towards the decarbonisation of the urban passenger transport sector in the agglomeration area of Baku until 2050. Users of the tool are free to test different policy packages through the building of scenarios.

The spreadsheet-based model is a ready-to-use tool for urban transport planners and policy-makers to determine the urban mobility impacts of alternate policies and programs, in terms of mode shares, mobility levels, carbon emissions (well-to-wheel) and local pollutants.

The tool is developed based on the ITF Global Urban Passenger Transport Model which was first presented in 2017[1] and enhanced in the context of the Horizon 2020 project 'Decarbonising Transport in Europe' in 2020[2]. This note describes in detail the data sources, modelling steps and assumptions of the tool. It is a reference document for any user of the tool wishing to understand the hypotheses made and the relationships between the different variables.

The model will be handed over to Baku Transport Authority in a 'model hand-over' session in September 2021. The model was developed in the context of the ITF project 'Decarbonising Transport in Emerging Economies' (DTEE), funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

Model scope

Geographic scope

The model represents the urban mobility of the agglomeration area of Baku in Azerbaijan. The study area corresponds to the City of Baku area, consisting of 12 districts, plus the city of Khirdalan and the city of Sumgayt. The area, the population and gender shares were calculated based on data available from ***Baku General Plan 2040, Explanatory Memorandum***, version of January 2021, provided by the Baku Transport Agency, further in this text referred as '*Baku Masterplan*'. The '*Baku Masterplan'* has the data for the City of Baku for the years 2020, 2027, 2040. Based on these data the growth rates were calculated and applied for every five years from 2015 to 2050. These growth rates were extrapolated to Sumgayt and Khirdalan. The base year values (2015) for these two cities were obtained from the State Statistical Committee of the Republic of Azerbaijan. The corresponding model sheet (*Socio-econ. Inputs*) highlights the data sources.

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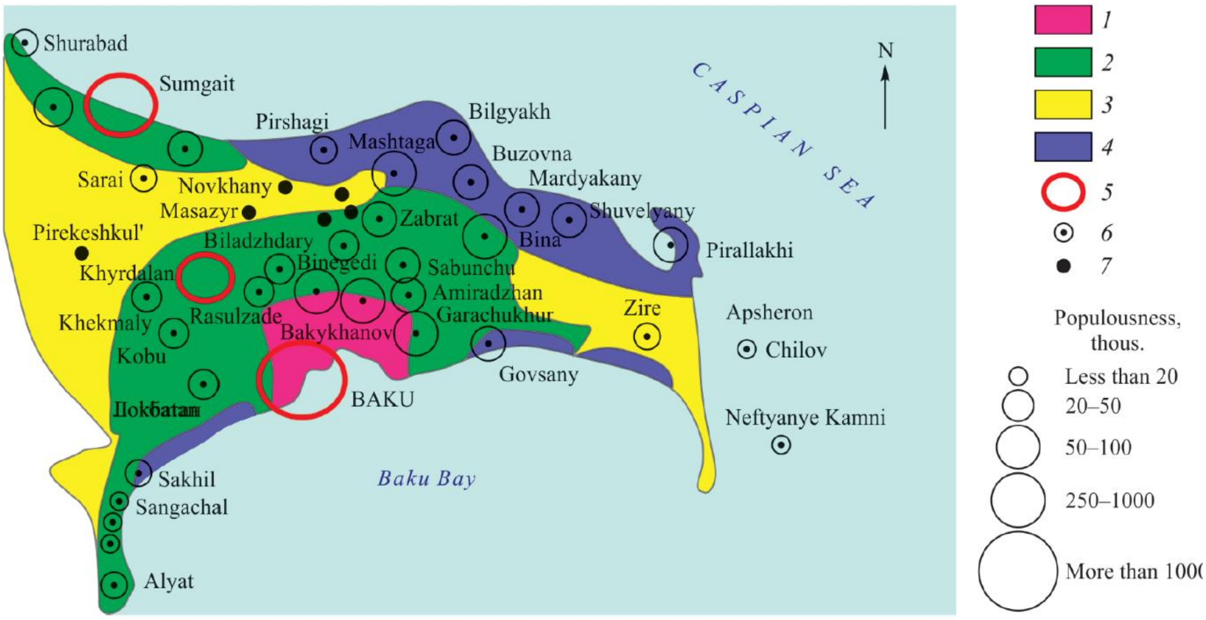
[1] Chen, Guineng, and Jari Kauppila. "Global Urban Passenger Travel Demand and CO 2 Emissions to 2050: New Model." Transportation Research Record: Journal of the Transportation Research Board 2671, no. 1 (January 2017): 71–79. https://doi.org/10.3141/2671-08.

[2] ITF, "The ITF Urban Passenger model – Insights and example outputs", Horizon 2020 project "Decarbonising Transport in Europe", 2020, https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5cc3ef7f1&appId=PPGMS

Figure 1 shows a schematic map of the Baku urban agglomeration area / Absheron peninsula. The study area for 2015-2020 corresponds to the sum of the 'core' and 'industrial' areas on the map. The city centre corresponds to the 'core'.

Figure 1: Schematic map of regionalisation of the Baku urban agglomeration, for 2015 - 2020



Schematic map of regionalization of the Baku urban agglomeration.
Zones: *1* – core, *2* – industrial, *3* – industrial-agricultural, *4* – recreational. Settlements: *5* – cities, *6* – villages, *7* – rural settlements.

Source: Badalov, E.S. Main directions of development of the Baku urban agglomeration. Geogr. Nat. Resour. 37, 174–180 (2016). https://doi.org/10.1134/S1875372816020128

The selected study area also corresponds to the Functional Urban Area (FUA) that come from the joint EC-OECD Cities in the World project. A FUA is defined based on population density and functional unity and used as the basis for the ITF Global Urban Passenger model. The fact that the study area is nearly equal to the FUA allows the transfer of the calibrated parameters and some area characteristics from the ITF Model (e.g. the projections until 2050) to the model for Baku.

The city centre for the years 2015 - 2020 consists of 6 Baku districts (Sabail, Yasamal, Nasimi, Narimanov, Nizami and Khatai), cities of Sumgayt and Khirdalan.

For future growth, the entire study area remains nearly the same (with some very small growth calculated as described above) while the city centre structure implies two scenarios.

- In one scenario it remains the same as in the base year with an addition of settlement of Garachukhur. The district is added to the 6 city centre districts according to the '*Baku Masterplan*'. Therefore, in this scenario, 3 centres remain (Baku, Sumgayt and Khirdalan). This scenario is further referred to as the "Baseline city centre development scenario".
- Another scenario assumes that according to the '*Baku Masterplan*' the city will become polycentric when several regions around Baku centre will become local centres. Only settlements in each of the new regions that have considerably higher population density (or will have in 2040 according to the "*Baku Masterplan"*) than the rest of the region are included in the model as parts of the

future city centre. This selection was justified by the “city core” definition adopted from the Cities in the World Project. That means an area containing 50 000 people or more made up of contiguous 1 square kilometre cells, each with at least 1 500 people. This scenario is further referred to as the “Polycentric scenario”.

So in 2040 the selected regions/settlements were added to the city centre of the first scenario (consisting of 6 districts of Baku + settlement of Garachukhur), implying the total population and area expansion. These regions/settlements are:

- Mardakan: Mardakan, Mashtaga, Buzovna, Shagan, Gala, Shuvelan
- Alat: Alat + Gobustan
- Lokbatan: Lokbatan
- Khirdalan: Khirdalan + Khojahasan
- Binadi: Binagadi, Biladjari, M. A. Rasulzade

Then the population and area increase at a constant rate between 2020 and 2050. The rate for the population is calculated in the following way: The population for 2020 is taken from the ‘*Baku Masterplan*’ for both scenarios. The population in 2040 is approximated by applying the growth rate calculated for the entire Baku Area population (obtained from “*Baku Masterplan*”).

Then, for the 8 centres scenario, an additional population is added to it based on the “Residential Capacity of Development Areas” column from the table for each settlement, presented by the ‘*Baku Masterplan*’. For the area calculation, the growth rate of the total area is applied.

Table 1 displays the characteristics of the study area for selected years.

Table 1 Characteristics of the study area, 2015, 2020, 2050.

Year	GDP per Capita, USD	Urban Area, sq. km	Urban Density, pers./sq.km	Core Urban Area, sq. km	Core Urban Density, pers./sq.km	Population, pers.	Core Population, pers.
2015	10 049	2 271	1 289	368	3 682	2 927 848	1 354 479
2020	8 960	2 271	1 353	368	3 682	3 072 044	1 355 000
2050	12 637	2 272	1 756	407	4 338	3 988 859	1 763 642

Source: ITF Global Urban Passenger Model, based on Baku General Plan 2040, Explanatory Memorandum, Jan 2021

Level of details

The model analyses 18 modes, covering all the existing modes and potential future modes. These modes are listed and described in Table 2.

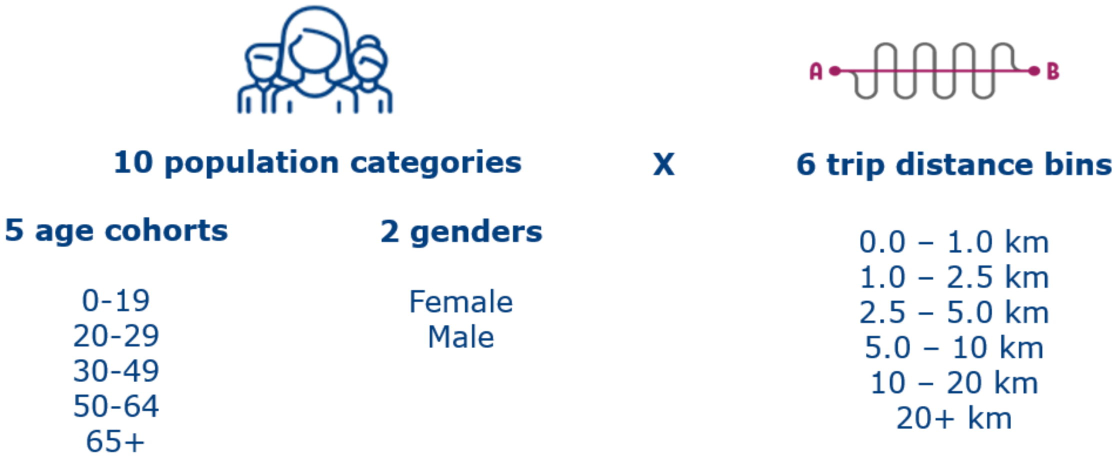
Table 2: List of transport modes included in the model

Active modes	
Walk	Walk
Bike	Private bicycle
Scooter-sharing	Shared electric kick scooter system

Bike-sharing	Shared bike and electric bike system
Parivate vehicles	
Motorcycle	Private motorcycle
Car	Private car
Public transport	
PT-Rail	Heavy rail system for long distances
PT-Metro	Heavy rail system for short to medium distances
PT-LRT	Light Rail Transit system
PT-Bus	Bus system
PT-BRT	Bus Rapid Transit system
Paratransit	
PT-InformalBus	Informal bus system not managed by a public administration
PT-ThreeWheeler	Informal three wheeler or richshaw system not managed by a public administration
Shared mobility	
Taxi	Taxi system
Ride-sharing	Private ride hailing system
Car-sharing	Shared car system
Monibus-sharing	Ride sharing system based on high capacity vehicles. Also referred to as Taxi-bus

To enhance the representation of urban mobility for different market segments, the model further breaks down the travel demand by gender (male and female), 5 different age categories and 6 travel distance categories, as shown in Figure 2. For example, male and female travellers can have different preferences towards transport modes and depending on the trip distances, some modes are more preferred or applicable than others.

Figure 2: Population and trip categories in the model



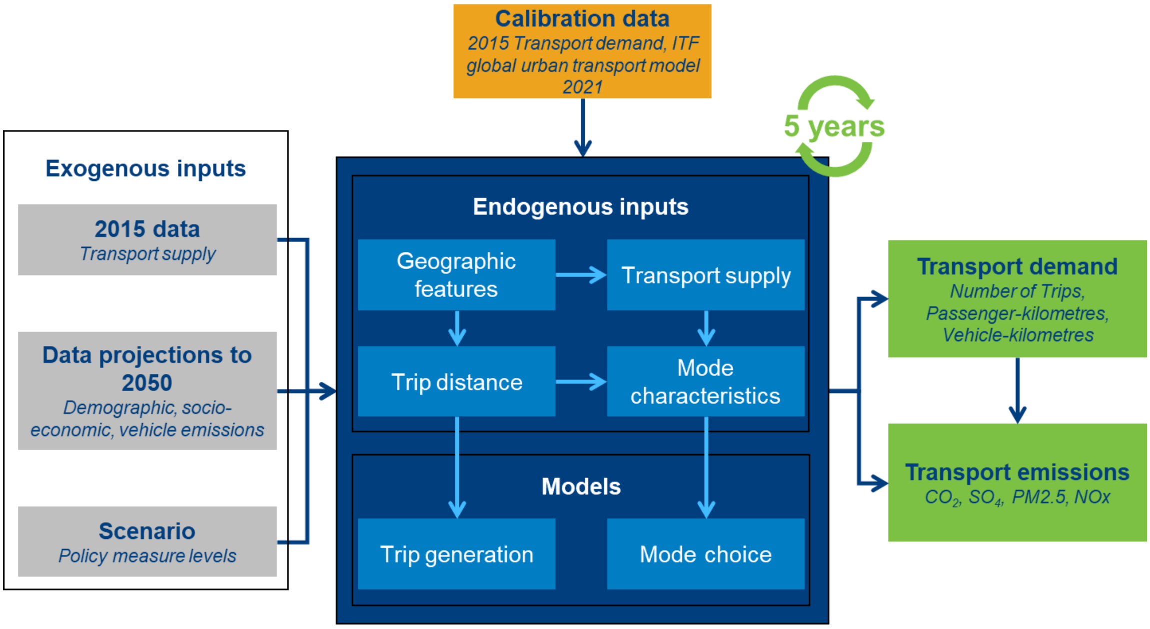
In terms of the forecast timeframe, the model produces projections of future travel demand and related emissions with an incremental of 5 years between 2015 and 2050.

Modelling approach

Overall modelling steps

The core of the model is inspired by the traditional 4-step transport modelling approach to determine travel demand, with an additional step to calculate CO_2 emissions and local pollutants resulting from travel demand. The outputs of each step feed into the next step as inputs as illustrated in Figure 3.

Figure 3: Overall Modelling Framework



The figure does not describe exhaustively the regression models linking the exogenous and endogenous input variables, which allow building future projections. The figure does not differentiate either between the inputs which are fixed in the model, and those which may alter due to different (policy) scenario settings. Both relationships are described more in-depth in the following sections.

First, the model is initialised with different data inputs, which include 1) base year data for 2015, 2) external/exogenous projections that depict the evolution of the urban area (e.g. demographics, socio-economics developments, available vehicle technology pathways) until 2050, and 3) different scenario inputs - a set of policy measures and assumptions either predefined in the model or freely set by the users.

Second, the model updates the geographic features (e.g. urban area size, density) of the study area based on the demographic and socio-economic inputs, as well as the scenario measure inputs. Based on this information, transport supply (i.e. the available transport infrastructure and transport services) and average trip distances for each trip distance bin (category) are computed. This enables the next step, which is the adjusting of mode availability and mode characteristics for each distance and gender category.

Third, the core of the transport model runs. The model generates the total number of trips based on demographic, socio-economic, geographic data. Then, a mode choice model, accounting for different mode characteristics, yields the trip mode shares.

Lastly, the main model outputs are produced. The passenger travel demand results from a combination of the generated trips, average trip distances, and mode shares. Passenger travel demand is then converted into vehicle travel demand using assumptions on vehicle load factors. Finally, technology assumptions, such as fuel mix, fuel economy and emission factors, allow assessing the CO2 and local pollutant emissions resulting from the vehicle kilometres.

An initial calibration exercise defines the parameters of the formulas used in the model. This calibration has been carried out against 2015 transport demand data for Baku obtained from the Baku Transport Agency (BNA), the State Statistical Committee of the Republic of Azerbaijan, and the ITF global urban passenger transport model 2020, as explained in the following section.

Model calibration

This current model is essentially an extraction of the ITF Global Urban Passenger Transport Model (2020 version), which has been designed and updated for producing the ITF Transport Outlook 2021. It is calibrated for each world region rather than at the national level, aiming at keeping consistent results across world regions.

As such, the model coefficients presented in the following sections are calibrated by the ITF Global Urban Passenger Transport Model for the entire region of ex-Soviet States (ESS), to which Azerbaijan belongs in the ITF Model nomenclature. Further, where the data was available, the coefficients were adapted to the local context of Baku to reproduce the observed travel demand and behavioural characteristics for the base year, e.g. mode shares and trip rates, etc.

It is worth noting that not all the calibration parameters might be exactly optimal for Baku due to the data constraints, but the parameter values are relevant starting points for calibrating the model. Once good quality data are available for different sub-models in the future, it is straightforward to recalibrate some of the parameters and incorporate them in the model. This methodological note presents the corresponding formulas.

Model validation

The model results for the base year were validated against existing studies for Baku, mainly Absheron Integrated Rail System (AIRS) report and Strategic Masterplan (ADY/GEMMS, 2020). Table 3 presents the validated values. As the table shows most of the values are very close to the ones observed in the AIRS report. The walk share differs by 1%, which could be because bike mode was not included in the compared study (bike share is 1% in the ITF model).

Table 3 Model validation, key transport characteristics

	ITF model		AIRS report	
	Year	Value	Year	Value
Population of the study area, base year	2015	2.93 million	2018	2.83 million
Population of the study area, projection	2040	3.66 million	2040	3.6 million
Trips per day	2015	5.76 million	2018	6 million
Walk share of total trips	2015	13.6%	2018	15%
Car trips of all motorised trips	2015	57.2%	2018	56%
Metro share of all PT trips	2015	38.1%	2018	38.9%
Bus share of all PT trips	2015	59.4%	2018	60.2%

Model inputs: exogenous

This chapter presents the inputs needed to initialise the model, which are base year data in 2015, exogenous[3] variables, and user/scenario inputs.

Base year inputs

Transport supply data

The base year of the model is 2015. The transport infrastructure supply data of 2015 mostly come from extractions of the OpenStreetMaps (OSM)[4] database, which yields total lengths of roads by type, and information on Public Transport (PT) infrastructure. The obtained data on the road lengths were validated using The State Statistical Committee of the Republic of Azerbaijan database.

Information on the mode attributes (average waiting and access time, number of transfers, costs and travel times) were obtained from open sources and validated by the BNA.

Where no data were available for the study area, assumptions and models have been applied to produce synthetic data based on the entire ESS region. This proxy-data approach was also applied for other related transport supply inputs, such as average waiting times.

Transport demand data

The transport demand data used for the calibration includes the trip rate and the mode share for each mode, obtained from the State Statistical Committee of the Republic of Azerbaijan database, and other open sources on the internet. In cases where the data for Baku were not available, the model relies on assumptions and data from other cities in the region or other regions (e.g., in the case of the Distance Bins Model, as described below).

The obtained demand data is then used for model calibration: a process of using various regression and optimisation techniques to identify coefficients of the sub-models so that the modelled results match the observed data or expert judgement. To ensure that the data from all the different sources are compatible, a thorough data cleaning and aggregation/disaggregation process were undertaken.

Exogenous projections to 2050

Demographic and economic data

The population and area size data, by gender and age category, come from the in-model calculations based on the 'Baku Masterplan', as described in the *Model scope* section of this document. The population might

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[3] Exogenous variable is one whose value is determined outside the model and is imposed on the model.

[4] https://www.openstreetmap.org/

undergo variations for the future years based on the scenario policy variables related to population density (described in the *Scenario measures* section).

The economic data on the total Gross Domestic Product (GDP) of Baku between 2015 and 2050 comes from the OECD Economics Department. Globally, the GDP at the city level in the base year is estimated by redistributing the national GDP volume from the OECD into the urban areas according to a GDP distribution map obtained from LANDSAT 2010[5], which provides GDP rasters that measure the GDP density for each cell grid. A division of this urban GDP by the population yields the average GDP per capita for the urban area.

Vehicle emissions data

Data on vehicle technology pathways comes from two main sources. For each mode, the vehicle fleet composition (by fuel type), respective CO_2 emission factors (tank-to-wheel (TTW) and well-to-tank (WTT)), and vehicle load factors between 2015 and 2050 come from the Mobility Model (MoMo)[6] of the International Energy Agency (IEA). Here, two trajectories of vehicle technology and emission from the MoMo model are integrated into the model. These are the trajectories of the IEA's *New Policy Scenario* (NPS) reflecting the baseline trajectory and the *Sustainable Development Scenario* (SDS) representing a more ambitious greening of the vehicle fleets until 2050. The emission factors of local pollutants (e.g. SO_4, NOx, and PM2.5) by mode and fuel type come from the ICCT Transport Roadmap Model[7].

Scenario/User inputs

To allow the users to freely design and test different future policy scenarios, the tool allows assessing 29 measures, as listed in Table 4. These measures can be direct policy measures, such as road pricing levels, or rather refer to desired outcomes, such as the technological development of the vehicle fleet, e.g. the uptake speed of electric vehicles.

Users can set target levels of each measure for 2050 in the "Scenario setting" sheet. These targets are translated into intermediate parameters in the "Scenario parameters" sheet for each 5-year step between 2015 and 2050. By default, these parameters are set to reach the final 2050 target at a steady linear growth pattern starting from the base year onwards. The detailed information on how each measure impacts the model is provided in the "Scenario parameters" sheet and the respective section of this report.

Table 4: List of measures in the model

Measure name	Measure description
Pricing measures	
Road pricing	Increase in non-fuel-related vehicle use costs
Parking pricing	Increase of parking costs
Carbon pricing	Tax levied on tank-to-wheel carbon emissions
Shared modes incentives	
Car sharing incentives	Increase in car-sharing vehicles per capita

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[5] https://landsat.gsfc.nasa.gov/

[6] IEA (2020), IEA Mobility Model, https://www.iea.org/areas-of-work/programmes-and-partnerships/the-iea-mobility-model.

[7] ICCT (2019), Transportation Roadmap, https://www.theicct.org/transportation-roadmap (accessed on 13 March 2019).

Measure name	Measure description
Motorcycle sharing incentives	Increase in motorcycle sharing vehicles per capita
Incentives for car-based ride sharing	Increase in ride-sharing vehicles per capita
Incentives for minibus-based ride sharing	Increase in minibus sharing vehicles per capita
Carpooling incentives	Growth in vehicle load factors
Restrictive measures	
Parking restrictions	Share of the city that is under (strong) parking restrictions
Urban vehicles restriction	Percentage of cars that will be restricted from circulating within the city
Speed limitations	Increase in speed limit reductions for cars
Public transport incentives	
Public transport priority	Percentage of bus network that has priority over other road modes.
Mobility as a Service	Percentage of population with a MaaS subscription.
Public Transport Integration	Percentage reduction of the transfer costs among PT modes. Stronger effect on heavy PT modes.
Suburban rail improvements	Percentage increase in stop density within an urban area.
Public transport service improvement for BRT, LRT, metro and rail	Percentage increase in frequency and optimised stop positioning.
Public transport service improvement for bus and paratransit	Percentage increase in frequency and optimised stop positioning.
Public transport infrastructure improvement - LRT	LRT total network length (in km).
Public transport infrastructure improvement - Metro	Metro total network length (in km).
Public transport infrastructure improvement - Bus corridors	Bus corridors total network length (in km).
Soft modes and low-emission vehicles incentives	
Bike and pedestrian infrastructure enhancement	Increase in the lengths of footpaths and bike lanes
Vehicle fuel technology development and uptake - pre-defined scenarios	Reduction of the tank-to-wheel emissions of diesel and gasoline vehicle fleet (on top of pre-defined technology/fuel-efficiency scenarios of the IEA – see below)
Sales targets for low-emission vehicles - Cars	Percentage share of different vehicle technologies in car sales/registrations in 2050 (overwriting the IEA scenarios – see below)
Sales targets for low-emission vehicles - Buses	Percentage share of different vehicle technologies in the bus fleet (overwriting the IEA scenarios – see below)
Exogenous developments	
Technology scenarios	Triggering of 2 possible pre-defined scenarios that define vehicle technology shares and fuel efficiencies: 0 - IEA NPS, 1- IEA SDS (see more info in respective report section)
Autonomous vehicles	Share of autonomous vehicles in the car fleet
Teleworking	Share of the active population that telework
Transit-Oriented Development	Percentage increase in land-use mixture
Increase pop. Density	Increase in population density across the city (defined for core and non-core areas separately)

Measure name	Measure description
Polycentric city centre structure	Trigger of 2 possible city centre structure scenarios: 0 - current structure with three main centres (Baku, Sumgayt, Khirdalan), 1- Polycentric structure with 8 centres

Model inputs: endogenous

This section describes the endogenous[8] data inputs used to run the core sub-models, and how their future values are estimated up to 2050. In almost all cases, data from the base year come from the ITF Global Urban Passenger Model, which has compiled various sources at the city and national level. Several relationships were built based on this data, both to fill data gaps whenever the case arose, and to build scenarios for future development. The remainder of this section describes the various relationships between the variables and the way these relationships are used in the model.

Trip distance

This module computes the average distance assigned to each trip distance bin and also determines the proportion of trips that occur in each distance bin (i.e. x% of trips in Baku are <= 1 km).

Assumed average trip distance

For each trip distance bin, the assumed average trip distance is determined as a function of the average city radius. More specifically, the following algorithm applies:

1) For the category "0 - 1 km", set $distance$ = 0.75 km
2) For other categories, if $bound_{lower}$ > 3 x $radius$, then $distance$ = NA; otherwise,
    - For the category "> 20 km", set $distance$ = 1.5 x $radius$
    - For the remaining categories,
        - if $bound_{upper}$ > 3 x $radius$, then $distance$ = 1.25 x $bound_{lower}$
        - otherwise, $distance$ = 0.4 x $bound_{lower}$ + 0.6 x $bound_{upper}$

Where, $distance$ is the average distance in kilometres of trips in the distance bin, the $bound_{lower}$ and $bound_{upper}$ being the lower and upper bounds of the distance bin, $radius$ being the average city radius in km.

Additional constraints are set so that the biggest distance bin (>20km) does not have an average trip distance over 50km or under 25km.

Share of trips by distance bin

The share of trips by distance bin is explained by the urban area size, urban population density, and the land-use mix coefficient. It is calibrated using a discrete choice model with a multinomial logit format. The utility function of each distance bin U_{dist} is formulated as follows:

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[8] An endogenous variable is a variable in a statistical model that's changed or determined by its relationship with other variables within the model.

$$\begin{aligned} U_{dist} = \mu \times (ASC_{dist} &+ parameter_{dist}^{area_{core}} \times area_{core} + parameter_{dist}^{area_{total}} \times area_{total} \\ &+ parameter_{dist}^{density_{core}} \times density_{core} + parameter_{dist}^{density_{total}} \times density_{total} \\ &+ parameter_{dist}^{LandUseMix} \times (LandUseMix - 0.3)) \end{aligned}$$

Where μ is a standard coefficient, ASC_{dist} is the alternative specific constant of the distance bin, and $parameter_{dist}^{variable}$ is the model parameter related with the $variable$ for the distance bin $dist$.

The total trip share of the distance bin $dist$, $Dist_{share}$, is then computed with the multinomial logit formula:

$$Dist_{share} = \frac{e^{U_{dist}}}{\sum_{i=0}^{5} e^{U_i}}$$

In the case of Baku, the model coefficients provided by the ITF Global Urban Passenger Model were overestimating shorter trips and underestimating longer trips given a relatively large extent of the study area (as discussed with the BNA). Therefore, the alternative specific constants were adjusted accordingly to re-balance the respective distance bin shares.

Transport supply

This module projects the future transport supply of the urban area considered in the model. The transport supply indicators are updated by taking into consideration the future demographic and socio-economic characteristics of the urban area, as well as the assumptions of the related measures defined in the scenario setting sheet. The first submodule determines at what point in time (i.e. under which conditions) specific modes appear, while others focus on updating the existing infrastructure for each mode.

Apparition of "new" modes

Not all of the 18 modes considered in the model are available in the urban area. Yet, the alternatives available may evolve over time. For example, paratransit may be replaced by formal public transit, and shared mobility modes may enter into service. To estimate the apparition of these modes, mode-specific thresholds of the city population, GDP per capita and density have been defined. These thresholds are detailed in the Activation of New Modes section, in the Sub-models calibration sheet of the excel tool.

In principle, if a mode does not yet exist, it can appear if the defined thresholds are met. In the case of shared mobility modes, these thresholds can vary over time via a temporal coefficient as follows (thresholds for other modes do not vary over time):

$$threshold_{new} = threshold_{old} \times coefficient^{\,year-2015}$$

Further, again in the case of shared mobility, two different thresholds reflect different initial levels of penetration for shared mobility services and the underlying assumption that shared mobility uptake will be quicker in denser cities with higher levels of GDP per capita.

While this submodule mostly focuses on the apparition of modes, it also ensures that paratransit modes disappear when respective thresholds are met.

Road transport

The road transport submodule covers the evolution of the road infrastructure, as well as the change in car, motorcycle and bike ownership over time.

Road infrastructure supply

The base year data on road infrastructure supply is extracted from the OpenStreetMaps database and validated based on data from the State Statistical Committee of the Republic of Azerbaijan database. This gives the total length of roads per road type for the urban area. There are five road types, from road type 1 (urban highways) to road type 5 (small walkable roads). The exact typology is described in the excel sheet "sub-model calibration".

Where data is missing for some road length in the city, or where the length of a road type is 0, the road type length is approximated by using the following formula:

$$length_{type_i} = default\ road\ type\ share\ _i \times total\ road\ density_{old} \times area_{old}$$

Where, $total\ road\ density_{old}$ and $area_{old}$ are the road density and area size computed in the previous model iteration.

Road type 1 (urban highway) is only generated if the population of the urban area is over 300 000 inhabitants, and Road type 2 (trunk road) is only generated if the population of the urban area is over 150 000 inhabitants, both of which apply to the Baku study area.

When a road type already exists in the previous time step, its length in the current time step is updated based on the evolution of the population, the city area and its GDP per capita. The formula to compute the updated road type length is presented below:

$$\begin{aligned}
&length_{type_i} = \max(road\ type_{old}; \\
&0.5 \times\ length_{type_{i,old}} \times\ \frac{area}{area_{old}} + \\
&0.5 \times\ (length_{type_{i,old}} + coefficient_{pop}\ \ \times\ (Population\ - Population_{old}) + \\
&coefficient_{area}\ \times\ (area\ - area_{old}) + coefficient_{GDPcap}\ \times\ (\ln(GDP\ per\ capita) - \\
&\ln(GDP\ per\ capita_{old})))
\end{aligned}$$

The calibrated coefficients of the above regression model can be found in the sub-models calibration sheet of the excel file. The supply of road type 1 is further impacted by the potential increase of the Bike and pedestrian infrastructure measures set by the users in the scenario design module.

A constraint is introduced to limit the growth of the road infrastructure so that the surface area of all the roads in a city does not surpass 30% of the total urban area size.

Public transport

The 2015 values for the number of PT stops were established through the Google Maps data extraction.

The future growths of the number of PT stops for rail, metro, LRT, and BRT systems are based on the growth of GDP per capita. For rail, the user also can set the growth in the Scenario Setting section of the model. A constraint is set to avoid having a reduction of PT stops when GDP per capita decreases, such as in 2020 due to the Covid-19 pandemic. The PT stops growth model is formulated as the following:

$$PT\ stops = PT\ stops_{old}^{\frac{GDP\ per\ capita}{GDP\ per\ capita_{old}} \times coeff_{power\ growth}}$$

Shared transport services

The base year 2015 data for the fleets of shared transport services (e.g. shared vehicles and shared mobility, including taxis) is an estimated input due to the absence of data. The fleets of shared vehicles are updated for every incremental step of the model using the formula below:

$$fleet = \mathrm{fleet_{old}} \times (1 + Power\ growth \times coeff \times exp(CarR))^5$$

Where, $CarR$ is a scenario parameter reflecting the impact of the car restrictions measures, and $Power\ growth$ and $coeff$ are coefficients that vary by mode. Impacts of additional measures can also have an impact on the fleet of shared services. The detailed formulas are available in the excel model. The exponential coefficient of 5 corresponds to the five-year model steps.

Mode Characteristics

Once the transport supply and the assumed average trip distances by distance bin are computed, it is possible to determine the characteristics of each mode for making a trip. These elements are the key inputs for the later mode choice model. The mode characteristics module estimates the features of each mode during a trip, including reliability, access time to the mode, waiting time for the mode, travel time and travel cost of the mode and of parking, the number of transfers for PT modes and the infrastructure connectivity.

These mode characteristics are calculated for each of the trip distance categories. Certain modes, such as walking and biking, are only applicable for short-distance trips. Therefore, an applicability matrix is first set to determine whether a mode alternative is included in the mode choice or not.

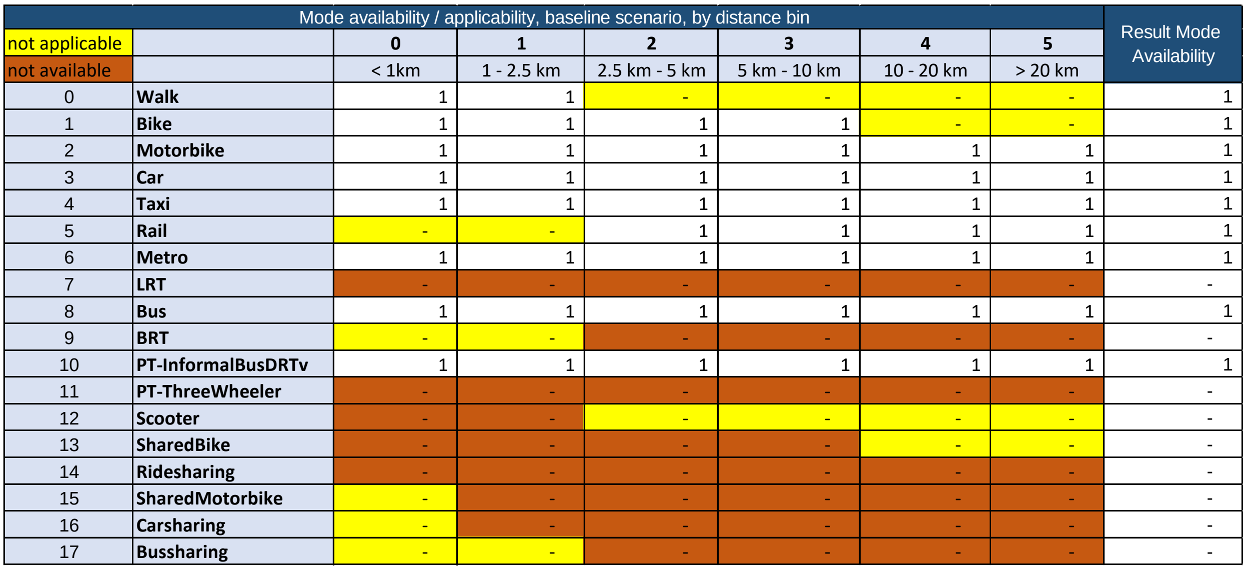
Mode availability and applicability

The mode availability and applicability submodule limit the number of mode alternatives considered in the mode choice. These mode availability and applicability are respectively determined by:

- The transport supply in the urban area - While some modes are available everywhere such as walk, biking and private car, some are less common such as metro and BRT. In order to account for this, a mode alternative is only considered in the mode choice if there is a transport supply for this mode. For instance, shared mobility or PT modes are available only if corresponding vehicle fleets or infrastructure exist in the urban area.
- The distance bin - For instance, walking is often considered for short-distance trips, while not feasible for very long-distance trips. Hence, walking is not considered for the highest trip distance categories in this model. The applicability of each mode for each distance bin can be manually defined in the table - *Mode Applicability Assumption by Distance Bin* - in the sub-models calibration sheet in the excel tool. This applicability is represented as a matrix, with 1 indicating that the mode is applicable for the related distance bin and 0 otherwise. An extract of the availability/applicability matrix for Baku is provided in Figure 4.

Combining the transport supply and the distance bin applicability elements allows determining the final applicability of the mode for the mode choice model.

Figure 4: Mode availability/applicability matrix for Baku



	Mode availability / applicability, baseline scenario, by distance bin							Result Mode Availability
🟨 not applicable		0	1	2	3	4	5	
🟧 not available		< 1km	1 - 2.5 km	2.5 km - 5 km	5 km - 10 km	10 - 20 km	> 20 km	
0	**Walk**	1	1	🟨 -	🟨 -	🟨 -	🟨 -	1
1	**Bike**	1	1	1	1	🟨 -	🟨 -	1
2	**Motorbike**	1	1	1	1	1	1	1
3	**Car**	1	1	1	1	1	1	1
4	**Taxi**	1	1	1	1	1	1	1
5	**Rail**	🟨 -	🟨 -	1	1	1	1	1
6	**Metro**	1	1	1	1	1	1	1
7	**LRT**	🟧 -	🟧 -	🟧 -	🟧 -	🟧 -	🟧 -	-
8	**Bus**	1	1	1	1	1	1	1
9	**BRT**	🟨 -	🟨 -	🟧 -	🟧 -	🟧 -	🟧 -	-
10	**PT-InformalBusDRTv**	1	1	1	1	1	1	1
11	**PT-ThreeWheeler**	🟧 -	🟧 -	🟧 -	🟧 -	🟧 -	🟧 -	-
12	**Scooter**	🟧 -	🟧 -	🟨 -	🟨 -	🟨 -	🟨 -	-
13	**SharedBike**	🟧 -	🟧 -	🟧 -	🟧 -	🟨 -	🟨 -	-
14	**Ridesharing**	🟧 -	🟧 -	🟧 -	🟧 -	🟧 -	🟧 -	-
15	**SharedMotorbike**	🟨 -	🟧 -	🟧 -	🟧 -	🟧 -	🟧 -	-
16	**Carsharing**	🟨 -	🟧 -	🟧 -	🟧 -	🟧 -	🟧 -	-
17	**Bussharing**	🟨 -	🟨 -	🟧 -	🟧 -	🟧 -	🟧 -	-

Reliability

The reliability indicator has been set up to indicate whether a mode is reliable or not. If a mode is often disrupted and experiences exceptional delays, then it is considered unreliable. A reliability indicator of value 0 means that the mode is fully reliable and not disrupted (e.g. for walking). The indicator becomes negative for less reliable modes. Negative values represent a likelihood of failure of the mode. The higher the negative value, the less reliable is the mode.

This reliability indicator is not considered for PT modes, since their reliability is characterized by the waiting time, infrastructure connectivity and the average number of transfers instead.

For private vehicles and bicycles, the reliability indicator is calculated based on the formula below:

$$reliability = (\log(parameter_{threshold}) - \log(vehicle\ fleet))^{parameter_{power}}$$

The $parameter_{threshold}$ and $parameter_{power}$ are calibrated fixed parameters that are presented in the sub-models sheet. If the vehicle fleet is above the $parameter_{threshold}$, the mode supply is considered dense enough so that the mode is considered reliable.

For shared mobility vehicles, the reliability indicator is calculated based on the formula:

$$reliability = parameter_{multiplier} \times \log(0.5 \times vehicle\ fleet + 0.5 \times vehicle\ fleet_{old}))$$

The $parameter_{multiplier}$ is a calibrated fixed parameter that is presented in the sub-models sheet of the excel file. The reliability of shared mobility modes depends on the average of the previous and current vehicle fleet.

Access time

The access time, as the name indicates, measures the average time (in minutes) needed to access a mode. Initial values are given for the base year, which is then updated in the model for future years. For private vehicles, it is the average time to reach the place where the vehicle is parked. For Public transport, it is the average time to reach the stop/station. The PT and shared mobility access time are assumed to decrease with the growth of GDP per capita (and hence the availability of such services). The related formula is displayed below:

$$access\ time = access\ time_{old}^{1-\frac{GDP\ per\ capita}{GDP\ per\ capita_{old}}^{parameter_{GDP\ power}}}$$

In addition to this core formula, several user-defined measures can have an impact on the access time for PT modes, such as Transit-oriented Development (TOD) and Mobility-as-a-Service (MaaS) measures. For private vehicles, the evolution of access time only comes from the introduction of policy measures, for instance, the enhancement of bike and pedestrian infrastructure supply, the setup of car access restriction zones, parking constraints, or others. Additional constraints are also introduced to avoid unrealistic access time values.

Waiting time

The waiting time is the average time (in minutes) spent waiting for a vehicle to stop or be available at a PT or shared mobility station. The initial values of 2015 are updated in future years. It is set to 0 for walking and private modes.

For PT modes, the waiting time is estimated as the following:

$$waiting\ time = waiting\ time_{old}^{2-\frac{GMP\ per\ capita}{old\ GMP\ per\ capita} \times (1+parameter_{PTiS}\ x\ PTiS) \times (1-parameter_{PTiI} \times PTiI)}$$

Where, $PTiS$ and $PTiI$ are variables that reflect PT service and infrastructure improvements.

For shared mobility modes, waiting time is updated with the formula:

$$waiting\ time = waiting\ time_{old}^{1-parameter_{Power} \times \frac{vehicle\ fleet}{vehicle\ fleet_{old}}}$$

Additional constraints are set to avoid unrealistic variations, or negative effects of GDP per capita reductions, for example for the year 2020.

Number of public transport transfers

The number of PT transfers is a variable representing how many transfers between PT vehicles happen during a PT trip, on average. It is generally assumed to be between 0 and 1, as PT transfers are relatively burdensome. For all PT modes, the base formula assumes that the development of scooter sharing fleets enables the travellers to avoid the first access trip leg to reach the main PT mode, thus decreases the average number of PT transfers:

$$PT\ transfer = PT\ transfer_{old}^{1+(parameter_{scooter\ sharing} \times \frac{scooter\ sharning\ fleet}{scooter\ sharing\ threshold})}$$

The impact of additional measures, such as infrastructure improvements, are also accounted for in the average number of PT transfers for bus and paratransit modes. Additional constraints are introduced to avoid unrealistic future variations.

Infrastructure connectivity

The infrastructure connectivity indicator represents the advantage of extended and connected infrastructure for making more efficient trips. It is considered for PT and motorised private modes.

For motorised private vehicles, the infrastructure connectivity is explained by the ratio between the average travel speed and the reference speed of the vehicle, formulated as the following:

$$\text{infrastructure connectivity} = 1 - \left(\frac{Speed}{Reference\ speed}\right)^{parameter_{Power}}$$

Where, $Reference\ speed$ is the average road speed in the urban area, and speed is the speed of the mode for which the infrastructure connectivity is computed.

For metro, LRT and BRT, it follows the formula:

$$\text{infrastructure connectivity} = \frac{network\ length}{Urban\ area} - parameter_{Network\ density\ reference}$$

Travel distance and time

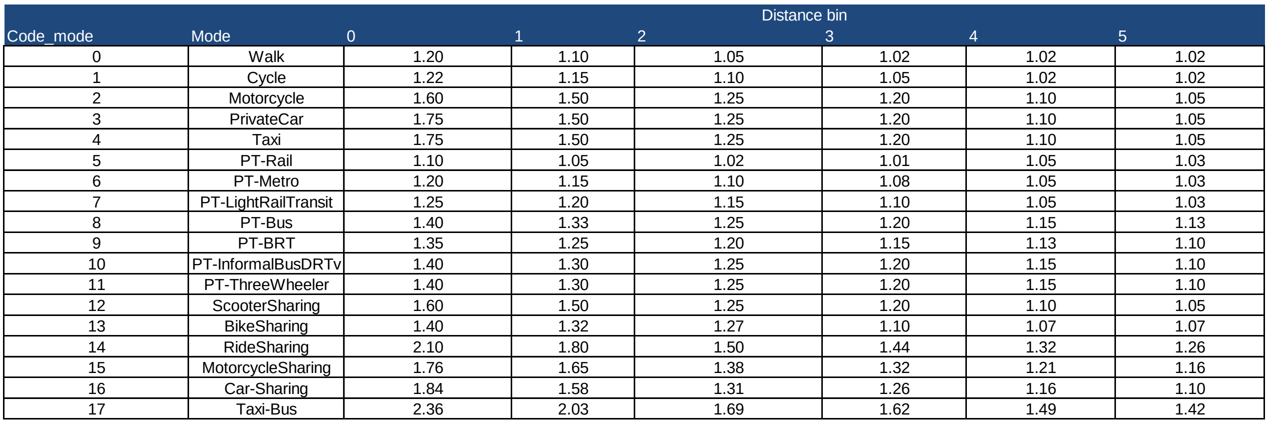
Travel time (in minutes) is traditionally and intuitively one of the most important factors for mode choice. In order to compute it, it is necessary to define the real travel distance (in kilometres), the trip distance (in kilometres), and the average speed (in kilometres per hour) of the mode.

First, it is important to distinguish the trip distance from the real travel distance. The trip distance is considered as a crow fly distance, while there are some additional detours for the real travel distance. The travel distance is always longer than the trip distance. In order to convert one into the other, distance detour coefficients are applied:

$$travel\ distance = \ coefficient_{detour} \times trip\ distance$$

These coefficients vary based on the mode and the distance bin and are always above 1. The initial distance detour matrix providing all the distance detours is provided in Figure 5. Reading the first row, it is possible to say that for the first distance bin (i.e. under 1km), the distance detour for the walk mode is at 1.20, and decreases down to 1.02 for the longest distance categories 3, 4 and 5. The distance detour matrix is based on expert judgement and can be edited in the sub-models calibration sheet of the excel file.

Figure 5: Initial distance detour matrix



		Distance bin					
Code_mode	Mode	0	1	2	3	4	5
0	Walk	1.20	1.10	1.05	1.02	1.02	1.02
1	Cycle	1.22	1.15	1.10	1.05	1.02	1.02
2	Motorcycle	1.60	1.50	1.25	1.20	1.10	1.05
3	PrivateCar	1.75	1.50	1.25	1.20	1.10	1.05
4	Taxi	1.75	1.50	1.25	1.20	1.10	1.05
5	PT-Rail	1.10	1.05	1.02	1.01	1.05	1.03
6	PT-Metro	1.20	1.15	1.10	1.08	1.05	1.03
7	PT-LightRailTransit	1.25	1.20	1.15	1.10	1.05	1.03
8	PT-Bus	1.40	1.33	1.25	1.20	1.15	1.13
9	PT-BRT	1.35	1.25	1.20	1.15	1.13	1.10
10	PT-InformalBusDRTv	1.40	1.30	1.25	1.20	1.15	1.10
11	PT-ThreeWheeler	1.40	1.30	1.25	1.20	1.15	1.10
12	ScooterSharing	1.60	1.50	1.25	1.20	1.10	1.05
13	BikeSharing	1.40	1.32	1.27	1.10	1.07	1.07
14	RideSharing	2.10	1.80	1.50	1.44	1.32	1.26
15	MotorcycleSharing	1.76	1.65	1.38	1.32	1.21	1.16
16	Car-Sharing	1.84	1.58	1.31	1.26	1.16	1.10
17	Taxi-Bus	2.36	2.03	1.69	1.62	1.49	1.42

Source: ITF Analysis

Second, the average speed for each mode enables the conversion of the travel distance into a travel time. Initial values are provided for 2015 modal speeds, and these values are updated based on the different scenario measures implemented. The bike and pedestrian infrastructure development measure will increase the average walk and bike speed over time, while speed limits will decrease it.

The final travel time is obtained by multiplying the travel distance by the mode speed and vary for each distance bin and mode.

Travel costs

The last modal attribute, probably as important as the travel time on mode choice, is the travel cost (in USD). This travel cost consists of different components, which are fixed costs such as parking or ticket cost, marginal costs varying with travel time or distance, and other long-term maintenance costs. These cost components also vary with mode.

Gasoline cost per passenger-kilometre

The initial 2015 gasoline costs assumptions came from open sources and were validated by the BNA, and then converted into gasoline costs per passenger-kilometre (PKM). When not available, they have been estimated based on similar cities in the same country or market and adjusted by the GDP per capita level.

The future gasoline costs per passenger-kilometre are estimated as follows:

$$\begin{aligned} gasoline\ cost = {} & 0.8 \times gasoline\ cost_{old} + 0.2 \\ & \times 7.5 \times 0.01 \times parameter_{Multiplier} \times \exp(parameter_{Constant} \\ & + parameter_{GDP\ per\ capita} + parameter_{pop\ category}) \times \frac{1}{Average\ car\ load\ factor} \end{aligned}$$

Where, $parameter_{GDP\ per\ capita}$ and $parameter_{pop\ category}$ are parameters depending on the GDP per capita category and the population category of the urban area. The 0.8 and 0.2 values are set to add some inertia to the formula, while 7.5 x 0.01 is the average fuel consumption per vehicle-km.

Public Transport Fares

The initial 2015 PT fares come from the websites of the Baku Public Transport operators and then were validated by the BNA PT fares can be a ticket or monthly subscription fares. Monthly subscription fares are produced at the trip level to be comparable.

The estimation of future PT fares follows the same approach for both tickets and monthly subscription fees:

$$\begin{aligned} PT\ fare = {} & 0.5 \times PT\ cost_{old} \\ & + 0.5 \times parameter_{multiplier} \times exp\big(parameter_{constant} + parameter_{GDP\ per\ capita} \\ & + parameter_{pop\ category}\big) \end{aligned}$$

Where $parameter_{GDP\ per\ capita}$ and $parameter_{pop\ category}$ are parameters depending on the GDP per capita category and the Population category of the urban area. The 0.5 values are set to add some inertia to the PT fare updates. Additional constraints are added to ensure a minimal and maximal evolution of the fares. MaaS and PT integration measures can also affect the PT fares.

Based on the difference between the ticket and monthly subscription costs, a share of the ticket versus monthly subscription is estimated. The share of tickets ranges between 25% and 100% of tickets and can be influenced by the implementation of the MaaS measure. The final PT fare cost is computed by weighing the PT ticket and monthly subscription fares by their respective share.

An additional cost to the bus mode could appear with the introduction of a carbon pricing measure, depending on the average CO_2 emissions of the vehicles.

Taxi Fare

The Taxi fare is divided into three components: a fixed start cost, a variable per kilometre cost and a variable per hour cost. The initial 2015 data comes from the taxi operators websites and is validated by the BNA.

The formula for the evolution of the start cost, per kilometre and per hour costs is the same as the one for the evolution of PT fares, except that the measure influencing it is not MaaS or PT integration, but the development of autonomous vehicles.

The final Taxi cost is set by the formula

1) $if\ taxi\ cost_{fixed} > taxi\ cost_{per\ km} * travel\ distance + \ taxi\ cost_{per\ hour} * travel\ time,$

$$then\ taxi\ cost_{fixed}$$

2) otherwise, $taxi\ cost_{per\ km} * travel\ distance + \ taxi\ cost_{per\ hour} * travel\ time$

The final taxi cost is computed as a combination of per kilometre and per hour costs, except if this combined cost goes under the minimal taxi start cost.

An additional cost can occur with the introduction of a carbon pricing measure, representing the cost of the CO_2 emissions of the trip.

Private vehicle cost

The private vehicle cost is relatively complex and involves the costs computed in the previous subsections.

A generic component representing the maintenance and ownership costs in the urban area influenced by the GDP per capita of the urban area is at the beginning of the private vehicle cost formula, followed by average costs per distance:

$$private\ vehicle\ cost = \left(0.12 \times 1.1 \times \left(\frac{GDP\ per\ capita}{30\ 000}\right)^{\frac{1}{3}} + 0.6\ \times cost\ per\ VKM + 0.4 \times gasoline\ cost\right) \times travel\ distance$$

The average $cost\ per\ VKM$ comes from the vehicle fleet input of the MoMo model from the IEA. The 0.6 and 0.4 coefficients are weights given to IEA's per vehicle-kilometre cost and to the gasoline cost, respectively. This cost can be additionally affected by the carbon pricing and road pricing measures introduced by users in the scenario setting.

Parking cost

The parking cost indicator represents the costs to park a vehicle. It mostly concerns private vehicles and depends on the private vehicle engine type, as it is assumed that electric vehicles are not charged with parking costs as an incentive for their adoption. It is considered alongside the distance-based costs of private vehicles in the mode choice.

The initial 2015 parking cost data is a user input value. The parking cost update depends on a fixed base increase and the change in land use mixture. A high land-use mix that is above the fixed threshold will diminish the parking demand through the reduction of car use, which eventually curbs the parking cost increase. It is estimated with the following formula:

$$parking\ cost = parking\ cost_{old} \times \ (parameter_{Base\ increase} \\ + parameter_{LUmix\ threshold}\ - Land\ Use\ mixture)$$

The evolution of the parking cost can also be increased by road pricing and parking pricing measures introduced in the scenario setting.

Trip generation and mode choice models

This chapter describes the key steps of generating the trips and splitting this overall travel demand across the available modes.

Trip generation model

The trip generation submodule estimates the trip rate (average daily number of trips per inhabitant) for the urban area and each population group. The population groups are determined by the 2 gender categories, and by 5 age categories: under 20, 20 to 34, 35 to 54, 55 to 69, and 70 and above. The trip rate evolution is, primarily, a function of GDP per capita. It is also influenced by other measures, such as teleworking. The trip rate is estimated with the formula below:

$$\begin{aligned}Trip\ rate = log\big(&parameter_{GDP\ per\ capita} \times GDP\ per\ capita\big)\\ &\times exp\big(parameter_{Constant} + parameter_{city\ population\ category} + parameter_{gender}\\ &+ parameter_{age\ category}\big) \times\ parameter_{Teleworking\ multiplier}\end{aligned}$$

$parameter_{GDP\ per\ capita}\ and\ parameter_{Constant}$ are fixed parameters of the trip generation function calibrated for the urban area. $parameter_{population\ category}$, $parameter_{GDP\ per\ capita\ category}$, $parameter_{gender}$ and $parameter_{age\ category}$ are parameters with fixed values depending on the respective population and GDP per capita groups of the urban area, and gender and age categories. Lastly, $parameter_{Teleworking\ multiplier}$ is a parameter set up in the teleworking scenario, which captures the negative impacts of teleworking on the average daily number of trips. All of these parameters are calibrated and can be adjusted in the sub-models sheet.

Mode choice model

Discrete choice model

The mode choice model is a logit model with eighteen alternative modes as presented in the transport supply section in the previous chapter. This model uses a standard discrete choice approach, explaining the aggregate mode shares with socio-economic variables and the attributes of each transport mode (e.g. travel time, travel cost, access time, reliability, infrastructure connectivity, parking cost, etc.).

The following equation describes the probability, *P,* of choosing mode *m,* over *K* modes.

$$P_m = \frac{e^{u_m}}{\sum_{k=1}^{K} e^{u_k}}$$

As explained in the transport supply section of the

Model inputs chapter, although there are eighteen available modes in the default settings, the availability and applicability of each mode will be activated or deactivated according to the existence of each mode over time and also the applicability of the mode for certain travel distance ranges.

The utility, U_m, of each mode m is computed using the generic utility functions below. The utility functions vary across the different modes. For example, the number of transfers is only applied to the public transport modes.

$$\begin{aligned} U_m = \; & ASC_m + \beta_{tt} * travel\ time_m + \beta_{tc} * travel\ cost_m + \beta_{rel} * reliability_m + \beta_{acc} \\ & * access\ time_m + \beta_{wt} * waiting\ time_m + \beta_{not} * \#\ of\ PT\ transfers_m + \beta_{parking} \\ & * parking\ cost_m + \beta_{infr} * infrastructure_m \end{aligned}$$

ASC is the alternative specific constant for each mode, accounting for any of the other decision making criteria that are not reflected in the included modal attributes; β is the estimated coefficient for each of the modal attribute, including travel time, travel cost, reliability, access time, waiting time, number of PT transfers, parking cost, and infrastructure.

Travel time is relevant for all modes. It is broken down further into waiting time and access time in the case of public transport and shared modes, as these times are typically perceived differently. **Travel cost** is also relevant for all modes, except for walking and biking - modes that have no monetary cost to the traveller. For private motorised modes, such as private cars and motorcycles, parking cost is also included to reflect the impacts of parking cost on mode choice.

The parameters and the ASCs for each of the modes as obtained by the discrete choice model are tabulated in Table 5.

Table 5: Calibrated coefficients of the mode choice model

Mode Share Model										
Mode	Code	ASC	Reliability	Access time	Waiting time	Average number of transfers	Cost	Parking cost	Modal infrastructure connectivity	Time
Walk	0	-0.56	0.00	-0.10	-0.10	-0.02	-0.11	-0.02	1.00	-1.00
Bicycle	1	-3.00	1.00	-0.09	-0.09	-0.02	-0.10	-0.03	1.00	-0.05
Motorcycle	2	-2.80	0.15	-0.03	-0.03	-0.02	-0.07	-0.02	0.25	-0.03
Car	3	-0.65	0.14	-0.01	-0.01	-0.02	-0.04	-0.07	0.90	-0.05
Taxi	4	-3.63	1.00	0.00	0.00	-0.01	-0.01	-0.01	0.10	0.00
PT-Rail	5	-3.00	0.33	-0.01	0.00	-0.06	-0.06	-0.02	10.00	-0.01
PT-Metro	6	-0.96	0.10	0.00	0.00	-0.03	-0.04	-0.06	15.00	0.00
PT-LRT	7	-1.29	0.10	-0.01	-0.01	-0.16	-0.06	-0.03	10.00	-0.01
PT-Bus	8	0.01	0.15	-0.02	-0.02	-0.03	-0.05	-0.04	10.00	-0.04
PT-BRT	9	-1.20	0.10	-0.01	-0.01	-0.16	-0.05	-0.02	10.00	-0.01
PT-InformalBusDRTv	10	-2.03	1.00	0.00	0.00	-0.01	-0.06	-0.03	0.10	0.00
PT-ThreeWheeler	11	-2.23	0.15	0.00	0.00	-0.01	-0.06	-0.03	0.10	0.00
Scooter	12	0.02	2.00	-0.05	-0.05	-0.02	-0.09	-0.01	0.25	-0.05
Bike-sharing	13	-2.70	2.00	-0.04	-0.04	-0.02	-0.07	-0.01	0.25	-0.04
Ride-sharing	14	-1.41	2.75	-0.01	-0.01	-0.02	-0.02	-0.02	0.25	-0.01
Motorcycle-sharing	15	-3.54	1.00	-0.01	0.00	-0.02	-0.01	-0.02	0.25	0.00
Car-sharing	16	-2.15	4.00	-0.01	0.00	-0.02	-0.02	-0.13	0.25	0.00
Minibus-sharing	17	-0.50	6.00	-0.01	-0.01	-0.02	-0.04	-0.02	0.25	-0.01

Source: ITF Analysis

Effects of other factors

Effect of Gender on mode choice

To differentiate the modal preferences for different gender cohorts for travellers, we have also calibrated gender-specific fixed terms to be included in the ASCs of the mode choice utility functions to reflect distinct modal preferences. Due to the data limitation, the gender preference terms are calibrated for private cars and motorcycles only, indicating that female travellers tend to use less cars and motorcycles for their trips. The reliability mode attribute also varies by gender due to different perceptions of the modes by different genders.

Effect of COVID-19 on mode choice

Fixed terms are calibrated and added to the ASCs of the mode choice utility functions to reflect the increasing or decreasing attractiveness of different modes due to COVID-19 as shown in Table 6. The calibrated assumptions indicate that the COVID-19 has a negative impact on the attractiveness of public (formal and informal) transport and shared modes, whereas it increases the attractiveness of walking and cycling. The impact will gradually phase out after 2025.

Table 6: Calibrated impact of COVID-19 on mode attractiveness

Modes	2020	2025
Public transport	-0.25	-0.10
Shared modes	-0.38	-0.15
Active modes	0.25	0
Informal/paratransit modes	-1.00	0

Source: ITF Analysis

Vehicle stock model

The vehicle stock module of the model estimates the fuel and age compositions of the private vehicle fleet. It also has a section for the bus fuel composition estimation. The module is developed to have a realistic representation of how the vehicle fleets evolve over the study period. It also avoids having to rely exclusively on assumptions of vehicle fleet composition and fuel efficiency that are external to the model.

Private light-duty vehicles

The private light-duty vehicles stock model assesses the evolution of the vehicle stock of passenger cars and light trucks in the study area. A stock model estimates how many cars enter and exit the fleet at each time interval during the study period, and traces vehicle stocks over time. With a set of assumptions (e.g. the average vehicle mileage per vehicle type and vehicle age), the stock model projects how many new vehicles will be necessary to cover the forecasted travel demand. It also retraces when the vehicles leave the fleet - either because they are scrapped, or because they are exported to a secondary market that is not within the scope of the model.

Setting up a vehicle stock model requires a set of input data and assumptions – such as future vehicle activity (from which the required vehicle stock can be derived), the vehicles' lifetimes, the current fleet, future vehicle characteristics and future vehicle use. The following section provides more information on specific assumptions and input data.

Inputs and assumptions

The first of the required input data, future vehicle activity, is a direct output of the previous steps of the model. The model produces the demand for passenger movement by mode in passenger-kilometres. Using assumptions on the load factor of private cars from IEA's MoMo model, pkms are transformed into vkms. The average load factor for private cars is assumed to equal 2.1 passengers per car and remains stable during the study period. The future demand for vehicle activity is therefore available. This demand is loaded into the Vehicle-Stock module with a five-year lag to avoid circular referencing (vehicle stock affects the car ownership, car ownership affects the passenger kilometres and the passenger kilometres affect the vehicle stock). Additionally, this reflects some inertia of car owners reacting to the transportation situation.

Another item of input data is assumptions on the typical vehicle lifetime. This allows projecting how many new vehicles will need to enter the fleet at any point in time, to ensure that the future demand for vehicle activity is met. Figure 6 shows the survival curve used for this study. It gives information on the likelihood of a vehicle remaining in the car fleet for at least one more year after having reached a certain age. For example, a 15-year-old vehicle has a likelihood of around 75% of remaining in the fleet for at least one more year. Inversely, there is a 25%-likelihood that this vehicle will be scrapped or exported to a different market. This curve was initially developed for a European project (Ricardo, 2016), and has been used in several ITF publications (e.g. ITF, 2017). While differences surely exist, no other sources were found in the literature to provide private vehicle survival rates for Baku. The survival probabilities were slightly increased for Baku compared to Europe based on expert judgement. This can be updated in future if the data is available.

The current vehicle fleet is used to create the starting point of the vehicle stock model. The data on the age composition of the fleet and total car ownership for Baku and Sumgayt were obtained from the BNA and the State Statistical Committee of the Republic of Azerbaijan database. This was combined with external sources to create a realistic representation of the current vehicle fleet in the study area.

Future vehicle characteristics come from the IEA's Mobility Model (Table 5), which provides data for ATE region, to which Azerbaijan belongs in the IEA's Model nomenclature. It is assumed that the sales of future vehicles (see Table 6 for assumed vehicle sales shares) and their average on-road fuel economy in the study are similar to those regional ones. These values are used for an initial baseline scenario. Final values for the sales shares for the baseline and alternative scenarios are user inputs.

Table 7: New private vehicle average on-road fuel consumption (LGE/100km)

Fuel Type	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	7.2	7.6	6.6	6.3	6.2	5.8	5.5	5.2
Gasoline-hybrid	7.5	7.6	6.6	6.4	6.4	6.1	5.7	5.6
Diesel	5.3	5.9	5.1	5.0	5.1	4.9	4.7	4.6
Diesel-hybrid	4.3	5.9	4.3	4.3	4.4	4.4	4.3	4.3
LPG/CNG	5.5	7.2	6.0	6.2	6.1	5.9	5.8	5.7
Hydrogen	-	-	-	-	-	-	-	-
Hydrogen-hybrid	-	-	-	-	-	-	-	-
Electric	-	-	-	-	-	-	-	-

Source: IEA's Mobility Model, 2020, New Policy Scenario (NPS)

Table 6: New vehicle sales share

Fuel Type	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	100%	100%	100%	100%	100%	100%	100%	100%
Gasoline-hybrid	82%	91.6%	90%	88.5%	86%	83.4%	81%	73.0%
Diesel	0%	0.0%	2%	4.0%	7%	8.9%	11%	17.1%
Diesel-hybrid	14%	4.9%	4%	4.4%	4%	3.7%	4%	3.4%
LPG/CNG	0%	0.0%	0%	0.2%	0%	0.4%	1%	0.9%
Hydrogen	4%	3.5%	3%	2.6%	2%	1.8%	2%	1.3%
Hydrogen-hybrid	0%	0.0%	0%	0.0%	0%	0.1%	0%	0.2%
Electric	0%	0.0%	0%	0.0%	0%	0.0%	0%	0.0%

Source: IEA's Mobility Model, 2020, New Policy Scenario (NPS)

The IEA values presented above can be overwritten by the user in the Scenario Setting sheet. Section *Sales targets for low emission vehicles (cars)* provides more information on that.

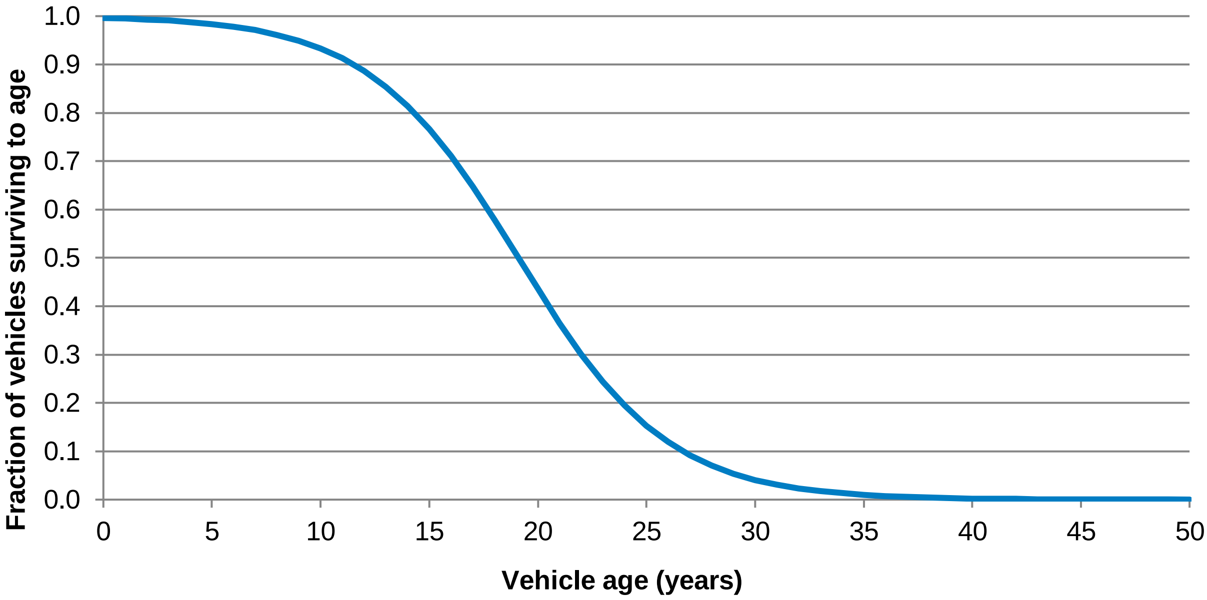
Finally, vehicle activity per vehicle is assumed to decrease with increasing vehicle age (see Table 7). Newer vehicles are used more, doing more vehicle kilometres per year. Vehicle mileage (per vehicle age) is assumed to remain constant over time and to be independent of vehicle technology. This is despite the fact that certain vehicle technologies (e.g. diesel, hybrid) frequently show above-average vehicle use. However, given the assumed penetration of different vehicle technologies over time, the assumption of technology-neutral vehicle mileage was judged to be the most suitable in the context of this study.

Table 7: Average annual vehicle activity by vehicle age group (in km)

Vehicle age	Share of average annual VKM per vehicle
0-5	0.23
5-10	0.21
10-15	0.18
15-20	0.16
20-25	0.15
25-50	0.07

Note: Numbers are a result of the estimated total annual vkm and the registered private vehicle fleet

Figure 6: private vehicle survival curve



Source: ITF

Fleet evolution and CO_2 Factors

In each model year, the vehicles that remain in the vehicle fleet are calculated via the survival curve. Using the average vehicle activity per vehicle age group, the total amount of vehicle kilometres done by those vehicles is calculated. The difference between this and the projected activity must be met by new vehicles. This allows the estimation of the number of vehicles that need to enter the fleet. These vehicles follow the forecasted sales by fuel type and the equivalent fuel efficiency (as per IEA's technology scenarios – see the section on CO2 calculation below) unless the model user chooses to overwrite these scenarios by providing their own technology/fuel efficiency assumptions in the respective measures. This process is repeated for the entire study period.

For calculation of the number of vehicles entering the fleet, both new vehicles and second-hand ones are considered. Based on 2015 data from the Baku Transport Agency, the initial split was set as 13% of vehicles sales are 0-5 years old, 65% - 5-10 years old, 22% - 10-15 years old. Then this percentage was assumed to change through the model years with sales of 0-5 old vehicles reaching 30% in 2050. The user can change these values.

A value called multiplier for annual km reduction is also used in the vehicle stock module. It is based on an assumption that people might buy a car even if they do not need to travel a lot, and this tendency increases with the years. These values can be changed by users or set to 1 to remove this assumption.

The projected fleet can now be used to estimate CO_2 factors. With the number of cars by age and fuel type and the average on-road fuel consumption for each of them, it is possible to estimate average CO_2 emissions per vehicle km travelled (see the following section on CO_2 calculations).

Public transport vehicles

The section for the public transport fleet in the Vehicle stock model covers regular buses and has only decomposition by fuel type, taken from the IEA data.

Outputs

This chapter describes the final steps transforming travel demand (in passenger-kilometres) into vehicle activity (in vehicle-kilometres), and eventually into related emissions. The main outputs of the model include mode share (produced in the last mode choice section), passenger-kilometres, vehicle kilometres, CO2 emissions, and local pollutant emissions.

Passenger-kilometres

The total number of trips is first computed by multiplying the total population by the average trip rate (number of trips per day per inhabitant). This demand is then allocated to the different modes through the application of the estimated mode shares stemming from the mode choice model; the multiplication by the average trip distance by mode gives the total number of passenger-kilometres for each of the eighteen modes.

Vehicle-kilometres

Vehicle-kilometres by mode directly result from the application of an average load factor (number of persons per vehicle) to the passenger-kilometres. Load factors of the baseline scenario correspond to the assumptions in the New Policies Scenario (NPS) of the IEA MoMo model. Load factors in the alternative scenarios can either take the assumptions from the Sustainable Development Scenario (SDS) of the IEA MoMo model or can be directly defined by the model user.

Values for the base year are summarised in Table 8 below. Load factors for individual modes tend to decline in projections, to the contrary of those for public transport.

Table 8: Vehicle load factors by mode in 2015

Mode	Load factor (pers. / veh.)
Two-wheeler	1.1
Three-wheeler	1.2
Passenger car	1.5
Bike-sharing	1.0
Scooter sharing	1.0
Bus	25.7
Minibus (formal and informal)	6.8
Metro rail	198.5

Source: IEA’s Mobility Model, 2020, corrected for passenger car with the Baku Transport Agency data

CO_2 and local pollutant emissions

Tank-to-Wheel CO2 emissions

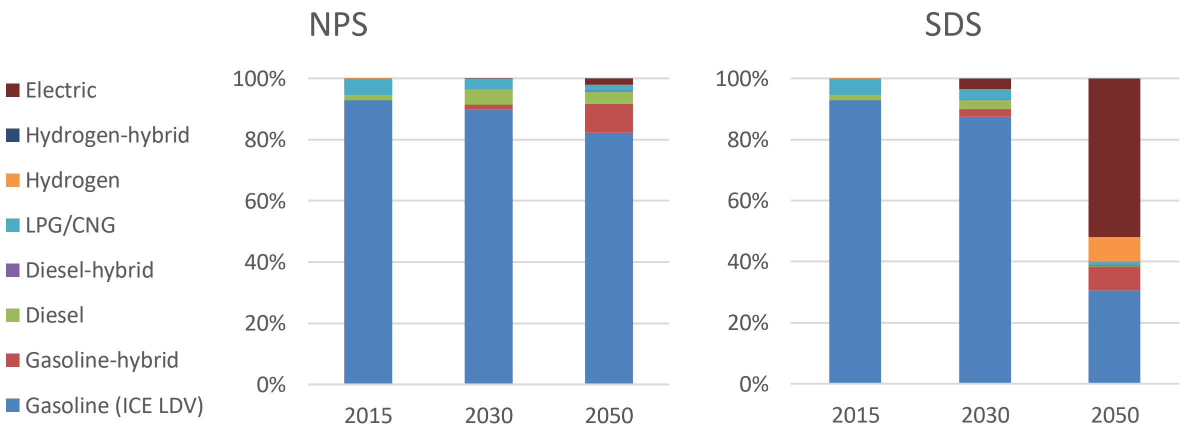
CO_2 emissions are calculated as a result of transport demand by mode and the vehicle types used. First, the total number of vehicle-kilometres by mode is assigned to the different vehicle technologies. Then, fuel consumptions by fuel type are calculated by applying the average fuel economy for each mode, vehicle technologies and fuel type to the vehicle-kilometres travelled. CO_2 emissions for each fuel type then result from the application of CO_2 emission factors (kg per litre gasoline-equivalent) by fuel type.

Information on vehicle fleet composition evolution comes from the Vehicle-Stock Model. In the baseline scenario, the shares (in vehicle-kilometres) are those used in the New Policies Scenario (NPS) of the IEA MoMo model. IEA's NPS promotes 'Business As Usual, reflecting energy demand and supply based on current trends and announced climate policies. These policies will lead to global warming of 2.7°C to 3.3°C. The NPS scenario assumptions are relatively more conservative when it comes to the penetration of alternative fuel and electric vehicle sales targets.

Alternative scenarios can test higher penetration rates of alternative-fuelled vehicles. The alternative vehicle technology scenario used in this study comes from the IEA's Sustainable Development Scenario (SDS)[9]. The IEA's SDS outlines a major transformation of the global energy system, showing how the world can change course to deliver on the three main energy-related Sustainable Development Goals simultaneously. The SDS holds the temperature rise to limited to 1.65 °C with a 50% probability. SDS presents strong support for electric mobility, alternative fuels and energy efficiency. In the SDS scenario, the energy efficiency of all technology improves much more significantly than in the NPS scenario.

Figure 7 displays the private cars fleet composition by fuel type for the base year and the projected years for both IEA scenarios. The share of gasoline vehicles reduces substantially by 2050 in SDS, while the share of electric vehicles grows significantly in this scenario.

Figure 7 Shares for the type of fuel under different IEA scenarios (private cars) for the ATE region



Source: IEA's Mobility Model, 2020

The model user can also overwrite the technology and fuel efficiency settings of the IEA scenarios for the private car fleet, and the technology settings for the bus fleet by choosing to make use of the respective measures (see further description below).

Well-to-Tank CO2 emissions

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[9] https://www.iea.org/reports/world-energy-model/sustainable-development-scenario

In this model, the outputs also consider the well-to-tank (WTT) CO2 emissions in order to reflect the full picture of the emissions for the transport sector. The WTT emissions consider the emission from fuel production and distribution. Data for this analysis come from the IEA. Two well-to-tank emission factors are possible, each coming from one of the IEA NPS and SDS scenarios. The two scenarios diverge on the possible sources of electricity for the coming decades. In the SDS scenario, there is almost a 100% shift to renewable energies by 2050. This has a significant impact on the overall emissions of any urban rail (e.g. metro, light rail) scenario, or any scenario where electric vehicles largely penetrate the market.

Local Pollutants

Urban transport is an important contributor to local air pollution, principally through the emission of oxides of nitrogen (NOx), sulphates (SO4) and particulate matter measuring 2.5 microns or less (PM2.5). Emissions of CO2 are strictly proportional to the fuel consumption of vehicles, while the quantity of local pollutants per unit of fuel in exhaust fumes can vary greatly. This model uses emission factors from the Roadmap model of the International Council on Clean Transportation[10] to estimate the emission of local pollutants resulting from the urban mobility levels of the two scenarios examined. The ICCT Roadmap includes expected improvements in vehicle efficiency standards and their probable penetration in vehicle fleets until 2050.

Model caveat

Despite the model's capacity in capturing most of the dynamics in the urban transport system, there are some limitations in the model due to the data, technical and time constraints. However, the model framework is designed in a way that is flexible to incorporate additional modules and dynamics, once good quality data is available in the future.

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[10] ICCT (2019), Transportation Roadmap, https://www.theicct.org/transportation-roadmap

Scenario measures

This chapter details the definition of each measure that feeds the Scenario Setting sheet in the Excel model, and how it affects different model components and parameters (e.g. urban area growth, transport supply, mode share, travel demand, etc.).

Measures overview

The model contains a total of 30 measures from five main categories: Pricing measures, Restrictive measures, Shared modes incentives, Public transport incentives, and Soft Modes and Low-emission Vehicles incentives. There is also a group of exogenous scenario variables, of which, it is assumed that the decision-making authority does not have full control. These measures cover a wide range of policy and technology alternatives, affecting the built environment, transport supply, transport demand and average vehicle emissions. This variety of measures enables testing the combined impact of several measures together within a scenario, on the final urban transport demand and related CO_2 emissions (including TTW and WTT emissions).

A target value by 2050 is assigned to each measure by the user. The model automatically converts this 2050 target into a set of parameters for each five-year temporal step of the model, which are used in the model iterations. These parameter values can be further edited in the scenario parameter sheet if non-regular/non-linear measure implementations are desired.

The user needs to set 2050 targets for each measure in the scenario definition sheet. The column “Target for 2050” shows the final measure inputs for the scenario. The 2050 target values inserted in the scenario setting sheet are then converted into the scenario parameter values in the scenario parameters sheet. The scenario parameters vary every five years, for each measure. The year 2015 and 2020 are fixed, as they represent the base year and current situations, and are not supposed to evolve between scenarios. The parameters from 2025 to 2050 are automatically computed based on the 2050 targets set up in the scenario setting sheet. The temporal evolution follows, by default, a steady/linear development. However, users can manually update them to represent non-linear evolutions.

In the following sections, information on each measure that the model user can use to define scenarios is provided. A description of the measure if is followed by a description of how the measure is implemented in the model. In the last section on each measure, also the impact of the measure on CO2 emissions (and relevant other indicators) is provided. The impact assessment for each measure is done by comparing two scenarios with each other that only differ in the settings of the specific measure that is being discussed. The exact settings of this measure in the two scenarios are provided in the overview graph.

The baseline scenario, to which the measures are compared is presented in Table 9. As the table shows, this scenario assumes that some measures will be implemented by certain extent by 2050.

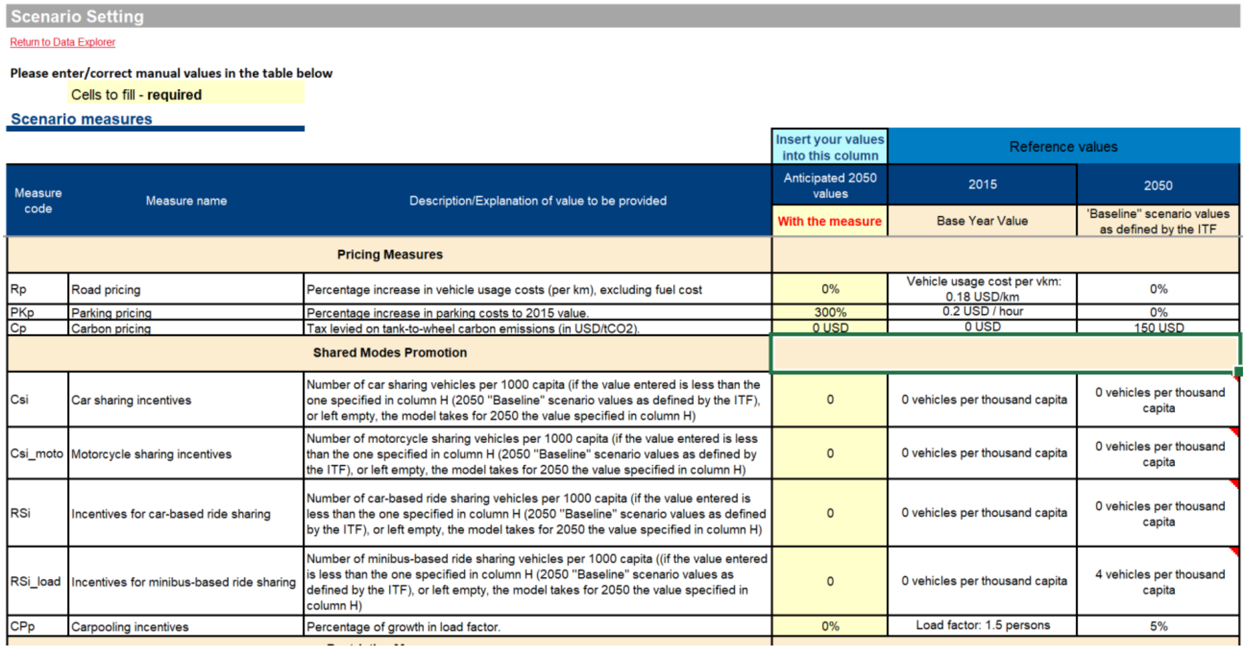
Table 9 “Baseline” scenario used for benchmark in the meausres sensitivity analysis

Measure name	Description/Explanation of value to be provided	Anticipated 2050 values
		Benchmark scenario

Pricing Measures		
Road pricing	Percentage increase in vehicle usage costs (per km), excluding fuel cost	0%
Parking pricing	Percentage increase in parking costs to 2015 value.	0%
Carbon pricing	Tax levied on tank-to-wheel carbon emissions (in USD/tCO2).	0 USD
Shared Modes Promotion		
Car sharing incentives	Number of car sharing vehicles per 1000 capita (if the value entered is less than the one specified in column H (2050 "Baseline" scenario values as defined by the ITF), or left empty, the model takes for 2050 the value specified in column H)	0
Motorcycle sharing incentives	Number of motorcycle sharing vehicles per 1000 capita (if the value entered is less than the one specified in column H (2050 "Baseline" scenario values as defined by the ITF), or left empty, the model takes for 2050 the value specified in column H)	0
Incentives for car-based ride sharing	Number of car-based ride sharing vehicles per 1000 capita (if the value entered is less than the one specified in column H (2050 "Baseline" scenario values as defined by the ITF), or left empty, the model takes for 2050 the value specified in column H)	0
Incentives for minibus-based ride sharing	Number of minibus-based ride sharing vehicles per 1000 capita ((if the value entered is less than the one specified in column H (2050 "Baseline" scenario values as defined by the ITF), or left empty, the model takes for 2050 the value specified in column H)	4
Carpooling incentives	Percentage of growth in load factor.	5%
Restrictive Measures		
Parking restrictions	Share of the city that is under (strong) parking restrictions.	5%
Urban vehicles restrictions	Percentage of cars that will be restricted from circulating within the city.	5%
Speed limitations	Percentage of speed limit reduction.	5%
Public Transport Promotion		
Public transport priority	Percentage of bus network that has priority over other road modes.	15%
Mobility as a Service	Percentage of population with a MaaS subscription.	5%
Public Transport Integration	Percentage reduction of the transfer costs among PT modes. Stornger effect on heavy PT modes.	30%
Suburban rail improvements	Percentage increase in stop density within urban area.	110%
Public transport service improvement for BRT, LRT, metro and rail	Percentage increase in frequency and optimised stop positioning.	30%
Public transport service improvement for bus and paratransit	Percentage increase in frequency and optimised stop positioning.	10%
Soft modes and low-emission vehicles promotion		
Bike and pedestrian infrastructure enhancement	Percentage increase in the footpaths and bike lanes infrastructure.	300%
Vehicle fuel technology development and uptake - pre-defined scenarios	Trigger of 2 possible technology and vehicle efficiency scenarios: 0 - IEA NPS, 1- IEA SDS ***(see the methodology note for information on these scenarios)***	**0**
Sales targets for low-emission vehicles - Cars	This measure overwrites the pre-defined vehicle technology scenarios of the TECH measure. Provide **% shares of the different vehicle technologies for 2050 private car sales/registrations. Please, note that if you specify the shares, they will substitute the default shares of the IEA nps/sds scenarios. Please, make sure the sum of the shares is 100%, otherwise the default IEA nps/sds shares will be used.**	74%
		17%
		3%
		1%
		1%
		0%
		0%
		4%
		100%
		0%

Technology targets for the bus fleet	This measure overwrites the pre-defined vehicle technology scenarios of the TECH measure. Provide **% shares of the different vehicle technologies in 2050 bus fleet. Please, note that if you specify the shares, they will substitute the default shares of the IEA nps/sds scenarios. Please, make sure the sum of the shares is 100%, otherwise the default IEA nps/sds shares will be used.**	0%
		0%
		0%
		50%
		0%
		0%
		50%
		100%
Soft modes and low-emission vehicles promotion		
Public transport infrastructure improvement - LRT	LRT total network length (in km). Please fill in all the cells or left all empty/zeroes.	0.0
		0.0
		16.8
		33.5
		50.3
		67.0
		67.0
		67.0
Public transport infrastructure improvement - metro	Metro total network length (in km). Please fill in all the cells or left all empty/zeroes.	36.6
		36.6
		70.0
		119.0
		119.0
		119.0
		119.0
		119.0
Public transport infrastructure improvement - Bus corridors	Bus corridors total network length (in km). Please fill in all the cells or left all empty/zeroes.	0.0
		8.5
		26.6
		53.3
		79.9
		115.0
		115.0
		115.0
Urban transport infrastructure expansion		
Autonomous vehicles	Share of autonomous vehicles in the car fleet.	0%
Teleworking	Share of active population that regularly teleworks, starting from 2.5% in 2015; each 1% of the active teleworking population is assumed to reduce the total trip number of trips by around 0.25%.	6.3%
Transit Oriented Development	Precentage increase of land-use mixture (that is, increased diversity of land-use types).	5%
Increase pop. density in the city centre	Percentage increase in population density of the core of Baku.	0%
Increase pop. density in the city suburb	Percentage increase in population density of the suburbs (out of the core area) of Baku.	0%
Polycentric city centre structure	Trigger of 2 possible city centre structure scenarios: 0 - current structure with three main centres (Baku, Sumgayt, Khirdalan), 1-Polycentric structure with 8 centres (see the Methodology note for the list of the centres)	**0**

Figure 8: Screenshot of the scenario measures setting



Scenario Setting

Return to Data Explorer

Please enter/correct manual values in the table below

Cells to fill - **required**

Scenario measures

			Insert your values into this column	Reference values	
Measure code	Measure name	Description/Explanation of value to be provided	Anticipated 2050 values	2015	2050
			With the measure	Base Year Value	'Baseline" scenario values as defined by the ITF
		Pricing Measures			
Rp	Road pricing	Percentage increase in vehicle usage costs (per km), excluding fuel cost	0%	Vehicle usage cost per vkm: 0.18 USD/km	0%
PKp	Parking pricing	Percentage increase in parking costs to 2015 value.	300%	0.2 USD / hour	0%
Cp	Carbon pricing	Tax levied on tank-to-wheel carbon emissions (in USD/tCO2).	0 USD	0 USD	150 USD
		Shared Modes Promotion			
Csi	Car sharing incentives	Number of car sharing vehicles per 1000 capita (if the value entered is less than the one specified in column H (2050 "Baseline" scenario values as defined by the ITF), or left empty, the model takes for 2050 the value specified in column H)	0	0 vehicles per thousand capita	0 vehicles per thousand capita
Csi_moto	Motorcycle sharing incentives	Number of motorcycle sharing vehicles per 1000 capita (if the value entered is less than the one specified in column H (2050 "Baseline" scenario values as defined by the ITF), or left empty, the model takes for 2050 the value specified in column H)	0	0 vehicles per thousand capita	0 vehicles per thousand capita
RSi	Incentives for car-based ride sharing	Number of car-based ride sharing vehicles per 1000 capita (if the value entered is less than the one specified in column H (2050 "Baseline" scenario values as defined by the ITF), or left empty, the model takes for 2050 the value specified in column H)	0	0 vehicles per thousand capita	0 vehicles per thousand capita
RSi_load	Incentives for minibus-based ride sharing	Number of minibus-based ride sharing vehicles per 1000 capita ((if the value entered is less than the one specified in column H (2050 "Baseline" scenario values as defined by the ITF), or left empty, the model takes for 2050 the value specified in column H)	0	0 vehicles per thousand capita	4 vehicles per thousand capita
CPp	Carpooling incentives	Percentage of growth in load factor.	0%	Load factor: 1.5 persons	5%

Pricing Measures

Road pricing

Description

Road or congestion pricing in urban areas is the setting of a price for road travel to reduce congestion and the time losses and adverse environmental impacts that it entails. Congestion pricing can be variable when the price is fixed at different levels during different periods or dynamic when the price changes in real-time according to monitored traffic levels. Congestion pricing can also apply to specific city zones such as in London, to roads such as the cordon/ring road in Stockholm or segments of urban highways such as tolled express lanes in the United States of America.

Impact in the model

The user sets a 2050 target for the expected percentage of vehicle use cost coming from road pricing, starting with 5% in 2015. The model converts this value into:

- Increase in the average use cost of private car and motorcycle.
- Decrease in car ownership because higher use cost lowers car attractiveness.

The impact on each model component is set up with parameters in the sub-model parameters sheet, which can be adjusted by the user.

Impact on CO2 and other indicators:

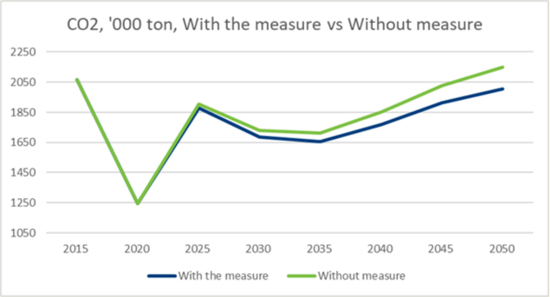
Road Pricing – Impact

User inputs

- Impact assessment: non-fuel vehicle use costs increases by 300% by 2050 (from 0.18 USD/km) vs. no vehicle use cost increase.

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050



	w/o measure	with measure
Car Share (2050)	34.9%	32.7%
CO2 decrease	6.7%	

Parking pricing

Description

Every private car trip requires parking at its destination. Introducing parking pricing typically means to start charging motorists for the use of parking facilities. They can apply to commuter, non-commuter and residential parking. Parking pricing can have a significant impact on the cost of car ownership and use. As it does not vary with travel distances, its impact is more relevant for relatively shorter trips. As such, parking pricing policies can help manage travel demand (e.g. reduce demand and/or shift demand to different modes, times or locations) and hereby reduce congestion and related impacts. They also generate revenue for parking space operators. In recent years, an increasing number of cities has adopted dynamic parking pricing systems, i.e. pricing that varies with parking demand, or pricing that varies with the environmental performance of the vehicle (e.g. its CO2 emissions).

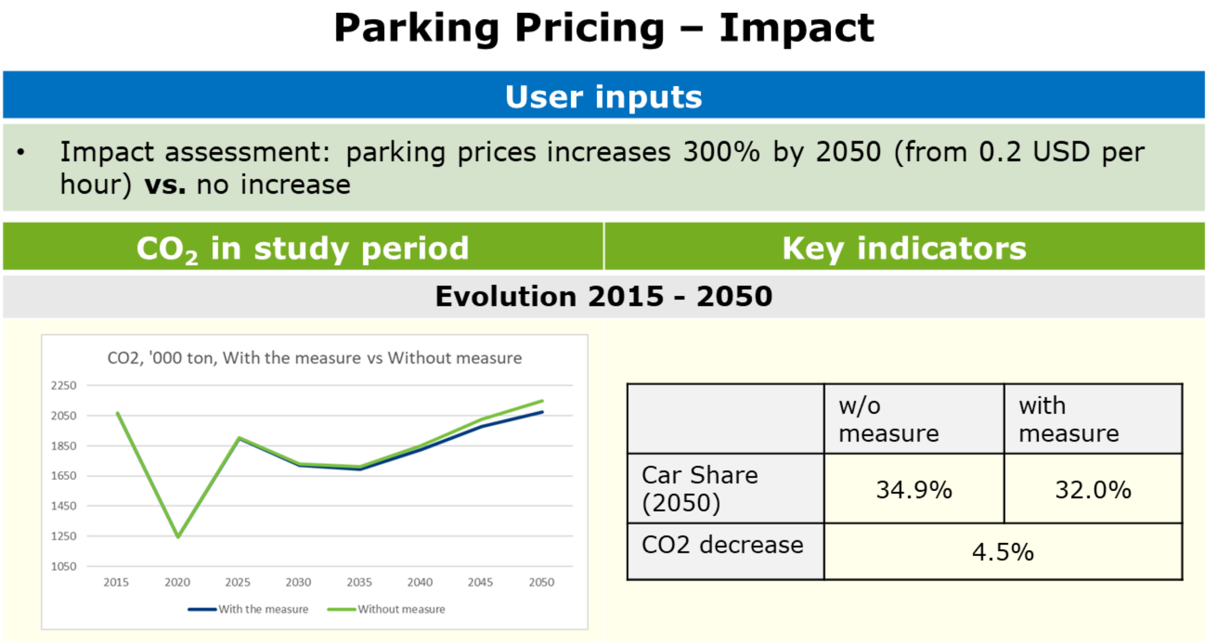
Impact in the model

The user sets a target for the expected percentage increase of the parking cost between 2015 and 2050. The model converts this value into:

- Increase in the average parking costs for private cars and motorcycles.
- Decrease of the growth of car ownership because higher costs lower car attractiveness.

The impact on each model component is set up with parameters in the sub-model parameters sheet, which can be adjusted by the user.

Impact on CO2 and other indicators:



Parking Pricing – Impact

User inputs

- Impact assessment: parking prices increases 300% by 2050 (from 0.2 USD per hour) **vs.** no increase

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050

	w/o measure	with measure
Car Share (2050)	34.9%	32.0%
CO2 decrease	4.5%	

Carbon pricing

Description

Carbon tax affects the cost of travel and hence leads to changes in passenger demand, mode choice and the flow of traffic in road networks; all of which are significant when it comes to low-carbon emission transportation (road). There are two common ways to implement a carbon tax - fuels taxes and cap-and-trade systems that allocate CO2 emission permits to drivers and hence, putting a price on CO2 emissions. Most carbon pricing schemes in the road sector are currently due to fuel excise taxes, which are economically similar to carbon taxes and their effective carbon price may be as high as EUR 300 per tonne. It is important to note that most countries tax diesel at lower effective carbon rates than gasoline and that several countries, such as France, grant reduced rates to heavy-duty vehicles. Carbon taxes, specific taxes on energy use (primarily excise taxes) and the price of tradable emission permits are the three components that make up the effective carbon rates (ECR). Essentially, effective carbon rates are the total price of CO2 emissions from energy use, after the application of market-based policy instruments.

Impact in the model

The user sets a 2050 target for the expected carbon tax level in USD per ton of CO_2, starting from 0 USD in 2015. The model converts this value into:

- Increase in the average cost of all CO_2 emitting motorised modes based on their emission levels.
- Decrease of the growth of car ownership because higher costs lower car attractiveness.

The impact on each model component is set up with parameters in the sub-model parameters sheet, which can be adjusted by the user.

Impact on CO2 and other indicators:

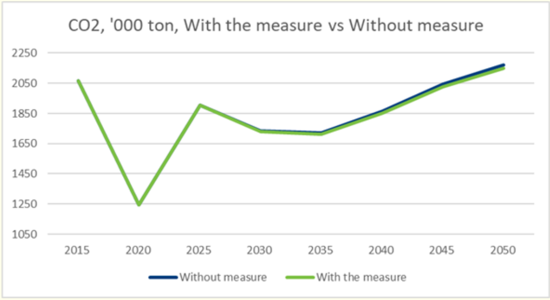
Carbon Pricing – Impact

User inputs

- Impact assessment: Tax levied on tank-to-wheel carbon emissions, starting from 0 USD/tCO2 in 2015 to 150 USD/tCO2 in 2050 vs. no carbon pricing.
- 150 USD/tCO2 corresponds to 0.02 USD per VKM in 2050

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050



	w/o measure	with measure
Car Share (2050)	35.4%	34.9%
CO2 decrease	1.0%	

Restrictive Measures

Parking restrictions

Description

Parking restrictions are measures that affect the cost or availability of car parking. They include limitations of parking spaces or pricing policies of public and private parking spaces. It can be applied to specific zones or the whole metropolitan area. When implementing parking restrictions measures, the cost of owning and using a car is increased and the zone on which the restriction is applied has a decreased car accessibility level. Policymakers must pay attention to avoid deteriorating the parking restricted zone's attraction by ensuring other modal alternatives' availability before implementing such measures.

Impact in the model

The user sets a 2050 target for the expected share of the urban area that is under strong parking restrictions. The model converts this value into:

- Increase in the average access time for cars and motorcycles, because of reduced and consolidated parking locations.
- Decrease in the average car ownership level, because parking restrictions make owning a private car less attractive.

The impact on each model component is set up with parameters in the sub-model parameters sheet, which can be adjusted by the user.

Impact on CO2 and other indicators:

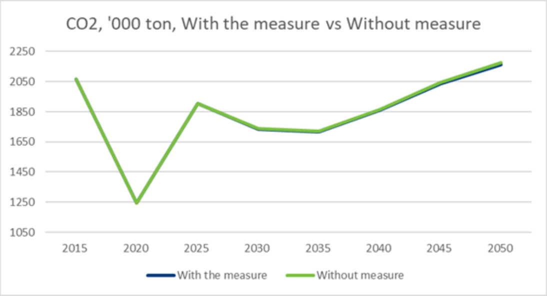
Parking Restrictions - Impact

User inputs

- Impact assessment: 0% of the city is under parking restrictions by 2050 vs. 30% by 2050

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050



	w/o measure	with measure
Car Share (2050)	35.4%	35.0%
CO2 decrease	0.6%	

Road speed limitation

Description

Traffic calming aims to reduce the dominance and speed of motorised vehicles. It employs a variety of techniques to cut vehicle speeds as a primary goal, improving safety and environmental quality in urban areas. Normally, traffic calming should be applied as an area-wide technique. If applied only to a particular street, it runs the risk of pushing accidents, pollution and cut-through driving into neighbouring areas. Initially, it was applied in residential areas. In more recent years, it is increasingly implemented in whole city areas. Traffic calming techniques include low-speed zones (e.g. 30 or 20 km/h) and/or the deployment of calming street infrastructure elements, such as speed humps, lumps or bumps, stop signs, traffic circles etc. (usually both speed limits and infrastructure elements are combined for effective traffic calming).

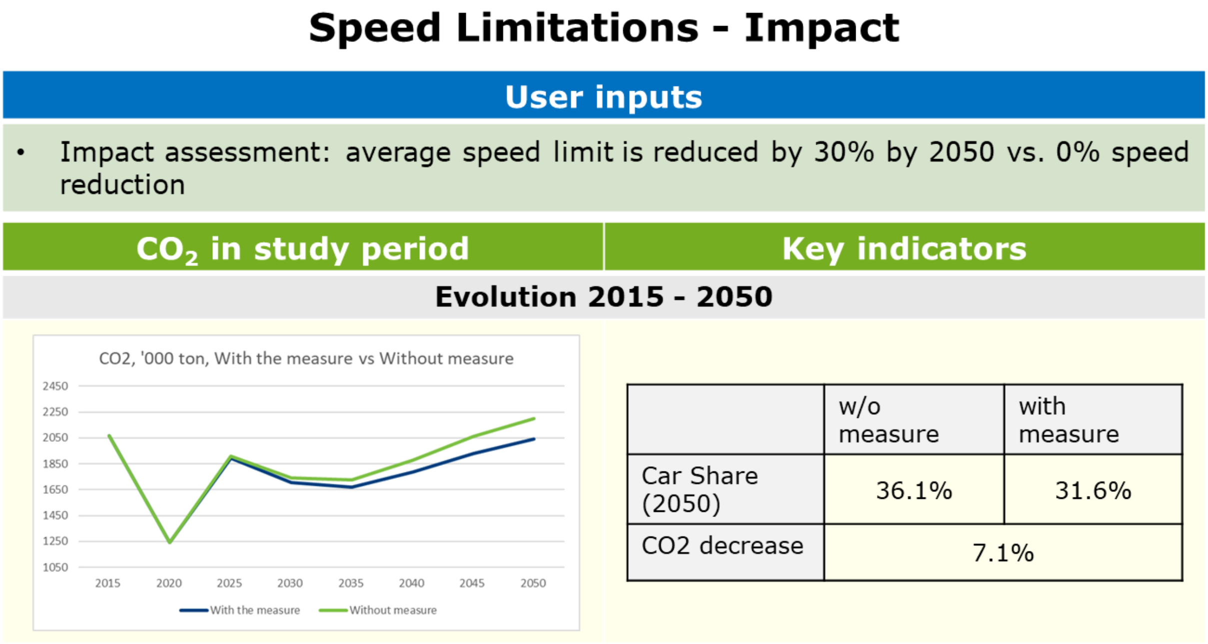
Impact in the model

The user sets a target for the percentage reduction of the road speed limits between 2015 and 2050. The model converts this value into:

- Decrease in the average speed of all road-based motorised vehicles except PT, because of a speed restriction.
- Decrease in car ownership due to the lower attractiveness of cars with a lower speed.

The impact on each model component is set up with parameters in the sub-model parameters sheet, which can be adjusted by the user.

Impact on CO2 and other indicators:



Speed Limitations - Impact

User inputs

- Impact assessment: average speed limit is reduced by 30% by 2050 vs. 0% speed reduction

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050

	w/o measure	with measure
Car Share (2050)	36.1%	31.6%
CO2 decrease	7.1%	

Urban vehicles restriction

Description

Urban vehicle restriction policies refer to setting a "cordon" in urban areas, i.e. block an area for a subset of the urban vehicle fleet for specific periods, to reduce congestion, increase traffic speeds and/or reduce pollution. Car restriction policies may apply only during peak traffic periods (morning and/or evening) or during the entire working day (e.g. a specific day or specific days during a week). Sometimes they may only be implemented on days that are identified as "critical" from an environmental perspective. Car restriction policies have generally applied rules based on the last digit of the car's license plate.

Impact in the model

The user sets a 2050 target for the expected share of private cars that would be under circulation restrictions. The model converts this value into:

- Decrease the growth of car ownership, because reduced car access makes the private car less attractive.
- Increase of the shared vehicle fleets, which are not restricted like private vehicles, thus making them more attractive.
- Increase in the access time for private cars and motorcycles due to further parking caused by vehicle circulation restrictions.
- Decrease in the average speed of private vehicles and shared mobility due to the circulation restrictions.

The impact on each model component is set up with parameters in the sub-model parameters sheet, which can be adjusted by the user.

Impact on CO2 and other indicators:

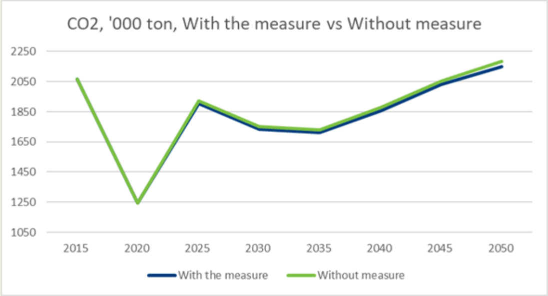
Urban Vehicles Restrictions - Impact

User inputs

- Impact assessment: 30% of cars will be restricted from circulating within cities by 2050 vs. 0%

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050



	w/o measure	with measure
Car Share (2050)	36.6%	34.8%
CO2 decrease	1.6%	

Shared Modes Promotion

Vehicle sharing incentives

Description

Vehicle sharing schemes are a type of car or motorcycle rental where members of the scheme can rent vehicles for short periods of time (e.g. by the hour). In fixed location schemes, vehicles are taken from and returned to fixed locations/stations. Depending on the design of the system, the returning point of the vehicle may or may not differ from the point where the vehicle was taken. In free-flow schemes, the organisation operating the vehicle sharing scheme has an agreement with the municipality that allows users to park their rental vehicle at any available parking location. Typically, users can localise vehicles or stations through web and/or mobile phone applications. Prices for the use of the vehicles usually depend on the time and distance travelled, and the type of vehicle that is rented (in case different types are available). Schemes may also offer monthly and/or annual subscriptions that allow quicker access to the vehicles and/or preferential rates (e.g. the first 30min/10km are for free). The vehicle sharing operator is typically in charge of the maintenance of the vehicles. Refuelling may either be done by the operator or the vehicle user - costs for the refill are typically included in the time- and/or km-based user charges. Membership of vehicle sharing schemes is usually attractive to individuals who make only occasional use of a vehicle, as well as others who would like occasional access to a vehicle of a different type than they use day-to-day. The organization renting the vehicles may be a commercial business, or the users may be organised as a company, public agency, cooperative, or ad-hoc grouping.

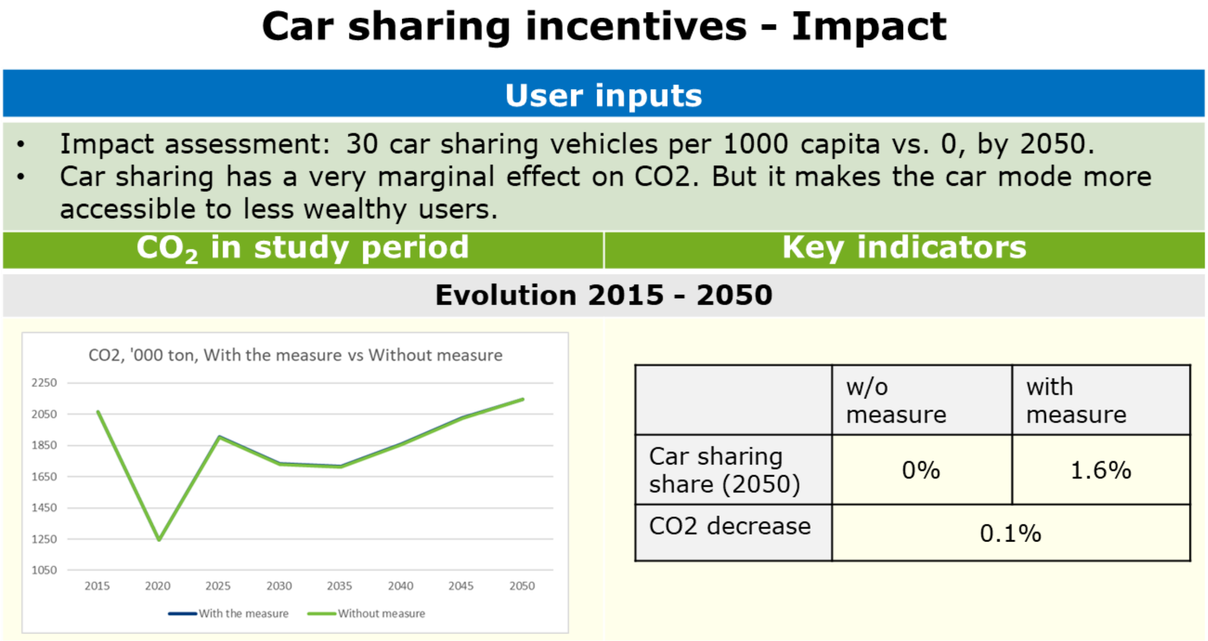
Impact in the model

The user sets a target for the number of vehicles per capita in 2050 for car-sharing and motorcycle-sharing vehicles. The number of vehicles between 2025 and 2050 is distributed then on the growth rate basis, starting from 1 vehicle per 1000 capita in 2025. This starting value can be changed by the user in the Scenario Parameters sheet of the model.

In case the user does not set the value or sets zero, the shared modes might still appear for some years under certain conditions depending on the city size/population density/GDP/etc. These values can be changed in the sub-model parameters sheet, table ‘Thresholds for the apparition of shared mobility and disappearance of informal modes’. The table contains two thresholds. Reaching the threshold indicated with 1 would result in a more substantial number of shared vehicles per capita than reaching the threshold indicated with 2.

The impact on each model component is set up with parameters in the sub-model parameters sheet, and the average energy consumption, which can be adjusted by the user.

Impact on CO2 and other indicators:



Car sharing incentives - Impact

User inputs

- Impact assessment: 30 car sharing vehicles per 1000 capita vs. 0, by 2050.
- Car sharing has a very marginal effect on CO2. But it makes the car mode more accessible to less wealthy users.

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050

	w/o measure	with measure
Car sharing share (2050)	0%	1.6%
CO2 decrease	0.1%	

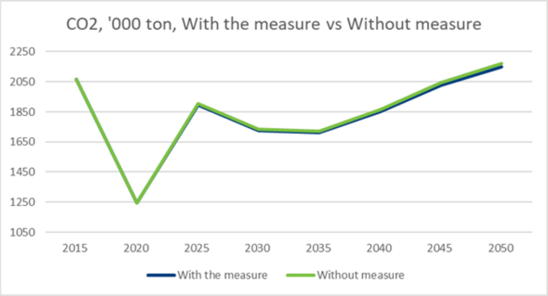
Motorcycle sharing incentives - Impact

User inputs

- Impact assessment: 30 Motorcycle sharing vehicles per 1000 capita vs. 0, by 2050

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050



	w/o measure	with measure
Car share (2050)	35.4%	35.0%
Motorcycle sharing mode share (2050)	0%	0.9%
CO2 decrease	1.0%	

Carpooling incentives

Description

Carpooling policies aim at favouring the practice and adoption of high occupancy car use. They aim at increasing the average car load factor in metropolitan areas, which is generally low and close to one in many cities over the world, to reduce the traffic and the emissions per car user. Carpooling policies can favour the development of carpooling companies, such as reduced administrative burden, provide advantages for high occupancy cars such as dedicated High Occupancy Vehicle (HOV) lanes or access to restricted zones or lanes, or reward carpooling with tokens or subsidies.

Impact in the model

The user sets a target for the number of carpooling vehicles per capita in 2050. The number of vehicles between 2025 and 2050 is distributed then on the growth rate basis, starting from 1 vehicle per 1000 capita in 2025. This starting value can be changed by the user in the Scenario Parameters sheet of the model.

In case the user does not set the value or sets zero, the carpooling might still appear for some years under certain conditions depending on the city size/population density/GDP/etc. These values can be changed in the sub-model parameters sheet, table ‘Thresholds for the apparition of shared mobility and disappearance of informal modes’. The table contains two thresholds. Reaching the threshold indicated with 1 would result in a more substantial number of shared vehicles per capita than reaching the threshold indicated with 2.

The impact on each model component is set up with parameters in the sub-model parameters sheet, which can be adjusted by the user. The impact on motorcycle or taxi load factor can be set to 0 to restrict the measure only to car, for instance.

Impact on CO2 and other indicators:

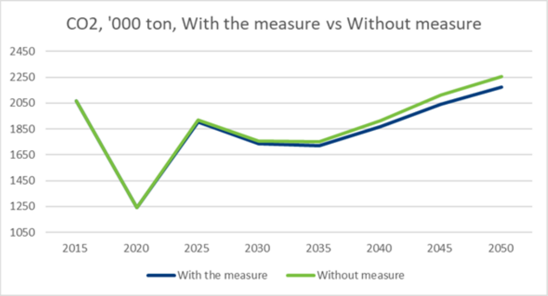
Carpooling incentives - Impact

User inputs

- Impact assessment: load factor increases 5% by 2050 vs. 0% increase

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050



	w/o measure	with measure
Car vkm, annual (2050)	10.6 bil	10.1 bil
CO2 decrease	3.8%	

Ride-sharing incentives

Description

Ride-hailing schemes are a type of vehicle sharing strategy that normally refers to an act when a person uses a smartphone app to arrange a ride in a usually privately owned vehicle. Ride-sharing is a joint trip of at least two participants that share a vehicle. Successful ride-sharing requires the coordination of itineraries that include specifications of pick-up and drop-off locations of a passenger. Most of the time, ride-sharing services are also provided by the same ride-hailing platforms. These market services enable financial transactions to be carried out via a digital platform that coordinates the drivers and riders. Normally the payment is credit card and app-based and does not involve any direct money transaction between driver and rider. The operation of such services typically requires appropriate licensing and enforcement by the relevant authority.

Impact in the model

The user sets a target for the number of vehicles per capita in 2050 for ride-sharing vehicles. The number of vehicles between 2025 and 2050 is distributed then on the growth rate basis, starting from 1 vehicle per 1000 capita in 2025. This starting value can be changed by the user in the Scenario Parameters sheet of the model.

In case the user does not set the value or sets zero, the ride-sharing might still appear for some years under certain conditions depending on the city size/population density/GDP/etc. These values can be changed in the sub-model parameters sheet, table ‘Thresholds for the apparition of shared mobility and disappearance of informal modes’. The table contains two thresholds. Reaching the threshold indicated with 1 would result in a more substantial number of shared vehicles per capita than reaching the threshold indicated with 2.

The impact on each model component is set up with parameters in the sub-model parameters sheet, which can be adjusted by the user.

Impact on CO2 and other indicators:

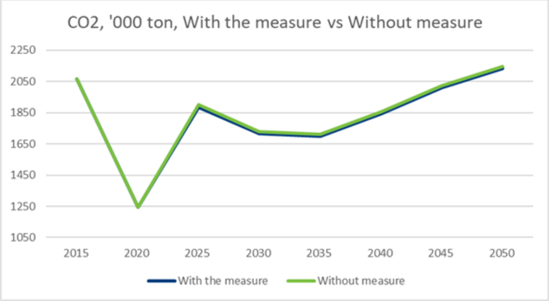
Incentives for car-based ride sharing - Impact

User inputs

- Impact assessment: 30 car-based ride sharing vehicles per 1000 capita vs. 0, by 2050

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050



	w/o measure	with measure
Car share (2050)	35.4%	32.5%
Car-based ride sharing share (2050)	0%	6.3%
CO2 decrease	0.6%	

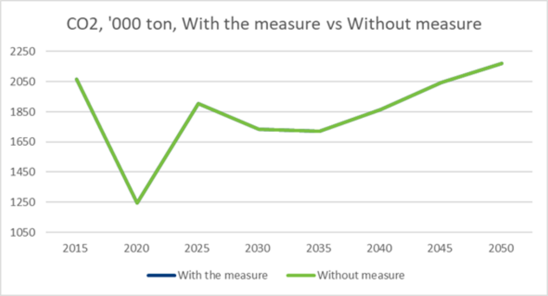
Incentives for minibus-based ride sharing - Impact

User inputs

Impact assessment: 30 minibus-based ride sharing vehicles per 1000 capita vs. 4, by 2050. The CO2 decrease is very small, as the mini-bus ride-sharing mode share is small and besides car users, it gets passengers from soft modes and PT. It also relies on the consumption of minibuses.

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050



Year 2050	w/o measure	with measure
Car share	34.9%	34.6%
Mini-bus share	0.2%	1.0%
PT share	46.0%	45.6%
CO2 decrease	0.2%	

Public Transport Promotion

Integrating public transport

Description

Integrated public transport systems facilitate public transport transfers across different modes, operators or geographies. Within this broad definition, it can take a number of forms, including the use of a common payment mechanism, a single ticket on different operator services, a single ticket across different modes, or combinations of these elements. Integrated ticketing is often implemented as a 'smart ticket', where information is stored electronically rather than being printed on a paper ticket. Benefits to users include ease of access and the ability to treat a public transport system as one single integrated system. In most cases, an integrated ticketing system will also involve integrated tariffs, where common pricing structures exist across different modes and operators. Integrated ticketing can have the additional benefits of time savings, greater flexibility and convenience for customers, which can encourage public transit ridership.

Impact in the model

The user sets a target for the percentage reduction of the transfer cost among PT modes between 2015 and 2050. The model converts this value into:

- Lower increase in the average PT fare and subscription cost.
- Relative increase in the fare of bus and paratransit modes. Since bus and paratransit are usually cheaper than other PT modes, thus integrating them will increase their relative costs compared to mass PT modes.
- Increase the value of PT infrastructure modal attribute by the percentage equal to half of the parameter value

The impact on each model component is set up with parameters in the sub-model parameters sheet, which can be adjusted by the user.

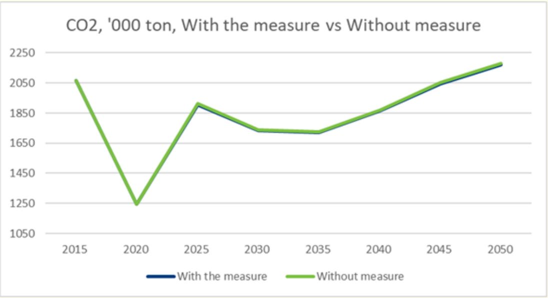
Impact on CO2 and other indicators:

User inputs

- Impact assessment: 30% reduction of PT transfers costs (these costs are not associated directly with PT fare), vs. 0%, by 2050

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050



	w/o measure	with measure
PT share (2050)	45.1%	45.3%
CO2 decrease	0.3%	

Suburban rail improvements

Description

The number and location of stations along with a line influence both the access and the travel time. An increase in the railway station density results in a decrease in the average distance and access time to the station for the passengers. On the other hand, if the density of stops grows without increasing the network length, this also increases the average passenger travel time, since the speed of the train reduces as the number of stops grows.

Impact in the model

The user sets a 2050 target for the rail stops density (per square km of the total area) increase. The model converts this value into:

- Decrease in the rail access time.

It is assumed that with the increase of the stops density in the study is, the rail network also grows so that the stops density per km of rail remains constant. Therefore, the speed of the rail does not vary.

The impact on each model component is set up with parameters in the sub-model parameters sheet, which can be adjusted by the user ("Other parameters" section).

The difference in access time due to increase in stop density is calculated as $a * \left(\sqrt{\frac{\pi}{stops\ density\ 2015}} - \sqrt{\frac{\pi}{stops\ density\ current\ year}}\right)$, where a is calculated as $average\ access\ time\ 2015\ /\ \sqrt{\frac{\pi}{stops\ density\ 2015}}$.

Impact on CO2 and other indicators:

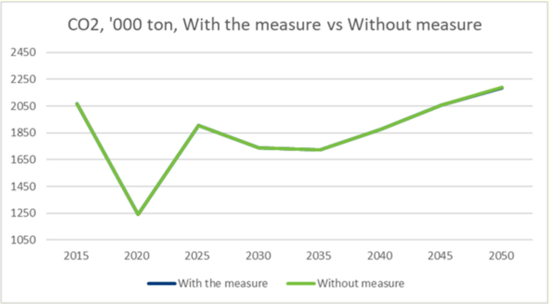
Suburban rail improvements - Impact

User inputs

- Impact assessment: 30% increase in stop density within urban area vs. 0%, by 2050

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050



	w/o measure	with measure
Rail share (2050)	0.8%	0.9%
CO2 decrease	0.2%	

Prioritising public transport circulation

Description

Delays induced by the operation of traffic signals typically account for 10 to 25% of the total travel time of buses. This has an impact on the quality of service for users, may lead to lower public transport ridership and has an impact on fuel consumption and related emissions of public transit services. The creation of bus lanes (or express lanes) and the implementation of transit signal priority (TSP) for buses can enhance their efficiency and travel times. For the latter, buses are equipped with sensors that offer them priority when approaching traffic lights the due to can be adjusted by the user.

Impact in the model

The user sets a 2050 target for the percentage of a bus network that has priority over road modes. The model converts this value into:

- Decrease the average speed of all road-based motorised modes other than PT and informal modes by a function of a submodel coefficient times the parameter value
- Increase the value of bus infrastructure modal attribute by the percentage equal to the parameter value

Impact on CO2 and other indicators:

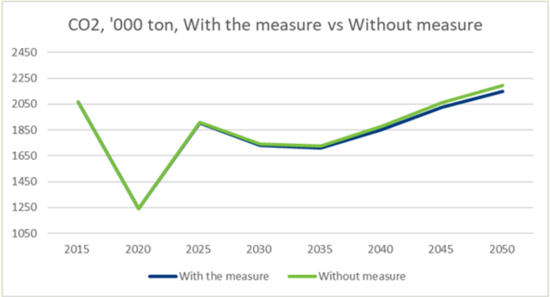
Public Transport Priority - Impact

User inputs

- Impact assessment: 30% percent of bus network the has priority over other road modes vs. 0%, by 2050

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050



	w/o measure	with measure
Bus share (2050)	11.4%	14.6%
CO2 decrease	2.1%	

Implementing Mobility as a Service (MaaS)

Description

MaaS is envisaged as an (app-based) transport service model. It integrates transport networks and services from all operators, such that all possible means of completing a journey (public and private) can be presented to, and completed by, the travellers using a single interface or point of contact. Users would complete the whole journey (point-to-point) planning, purchasing of tickets and booking of demand-responsive / shared / taxi modes through this application.

The delivery of MaaS would require the integration of ticketing and payment systems across modes and providers. Further legislative, commercial, governance and technological aspects would also need to be addressed to establish MaaS.

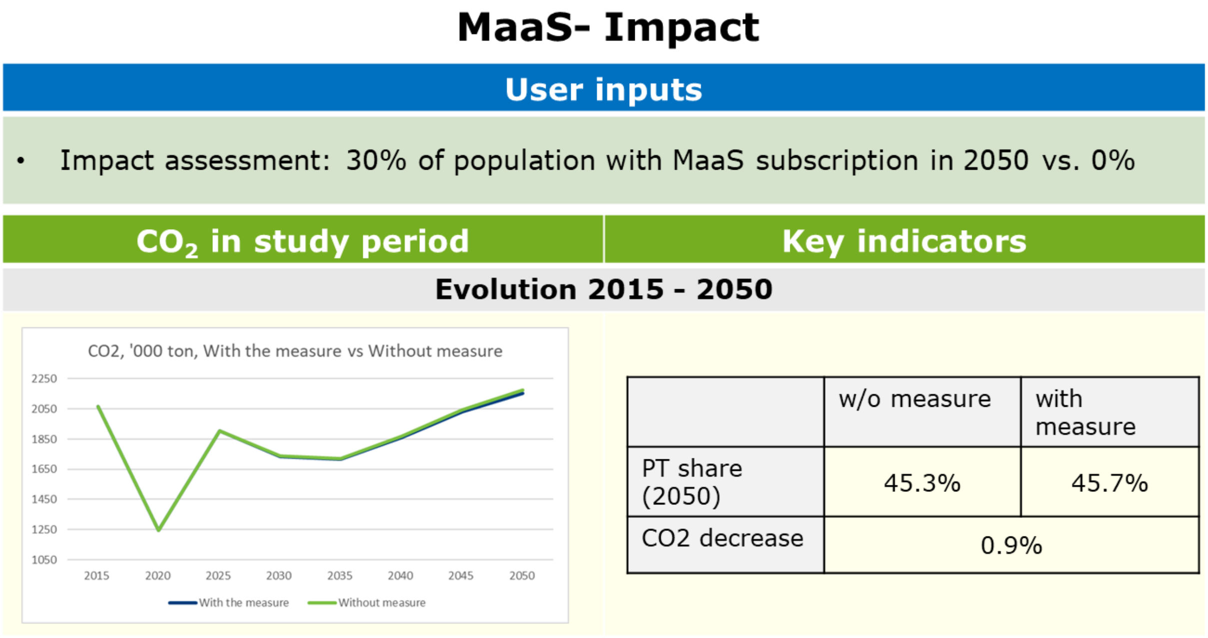
Impact in the model

The user sets a 2050 target for the expected share of the population with a MaaS subscription. The model converts this value into:

- Increase in the share of PT subscriptions, because MaaS systems make it more attractive.
- Decrease in car ownership, because MaaS reduces the need and attractiveness of owning private vehicles.
- Decrease in the average PT fare, thanks to the efficiency of MaaS and because it is the backbone of the system.
- Lower decrease in the average cost of bus, paratransit and shared mobility modes, due to the cost of the mass PT systems being distributed over the MaaS system.
- Increase in the starting size of shared vehicle and shared mobility fleets at the creation, thanks to wider adoption of MaaS.
- Decrease in the minimum GDP per capita threshold for triggering the apparition of shared mobility and shared vehicle, because MaaS is more developed to facilitate their implementations.
- Decrease in the average access time to all PT modes, because access trips are facilitated by shared scooters and shared bikes within a MaaS system.
- Increase in the average number of PT transfers for all PT, because MaaS increases intermodal trips interconnecting different PT lines and shared modes.

The impact on each model component is set up with parameters in the sub-model parameters sheet, which can be adjusted by the user.

Impact on CO2 and other indicators:



MaaS- Impact

User inputs

- Impact assessment: 30% of population with MaaS subscription in 2050 vs. 0%

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050

	w/o measure	with measure
PT share (2050)	45.3%	45.7%
CO2 decrease	0.9%	

Service improvement for public transport modes

Description

Improved public transport service includes better PT service planning by enhancing network route design, network frequency and timetable development, minimizing system costs and by optimising vehicle and staff scheduling. Adding new PT lines, new PT services, optimising operations through transit signal priority and queue jumper lanes, and the optimal relocation of stops are also covered in the measure.

Impact in the model

The user sets a 2050 target for the expected percentage increase in frequency and optimised stop positioning from 2015, for heavy PT and buses and paratransit. The model converts this value into:

- Decrease in the average access time for the related modes, thanks to better stop and route positioning.
- Decrease in the average waiting time for the related modes, thanks to improved frequencies.
- Increase in the average speed of the related modes, thanks to improved routing.
- Increase the value of PT infrastructure modal attributes by the percentage equal to the half of the parameter value

The impact on each model component is set up with parameters in the sub-model parameters sheet, which can be adjusted by the user.

Impact on CO2 and other indicators:

Public transport service improvement, heavy modes- Impact

User inputs

- Impact assessment: 30% increase in frequency and optimised stop positioning for heavy modes (metro, LRT, BRT, rail) vs. 0%, by 2050

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050

	w/o measure	with measure
Heavy modes share (2050)	27.0%	28.1%
CO2 decrease	1.5%	

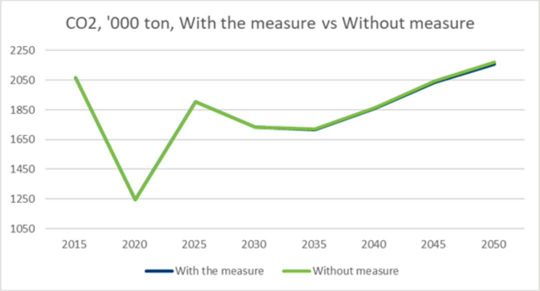
Public transport service improvement for bus*

User inputs

- Impact assessment: 30% increase in frequency and optimised stop positioning for bus and paratransit vs. 10%, by 2050

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050



	w/o measure	with measure
Bus mode share (2050)	12.9%	13.9%
CO2 decrease	0.6%	

*similar order of magnitude of the impact for other PT modes

Public transport infrastructure improvement

Description

Reinforcing the supply of public transport infrastructures increases its network length and capacity. It leads to improving the overall PT area coverage, environment quality and safety.

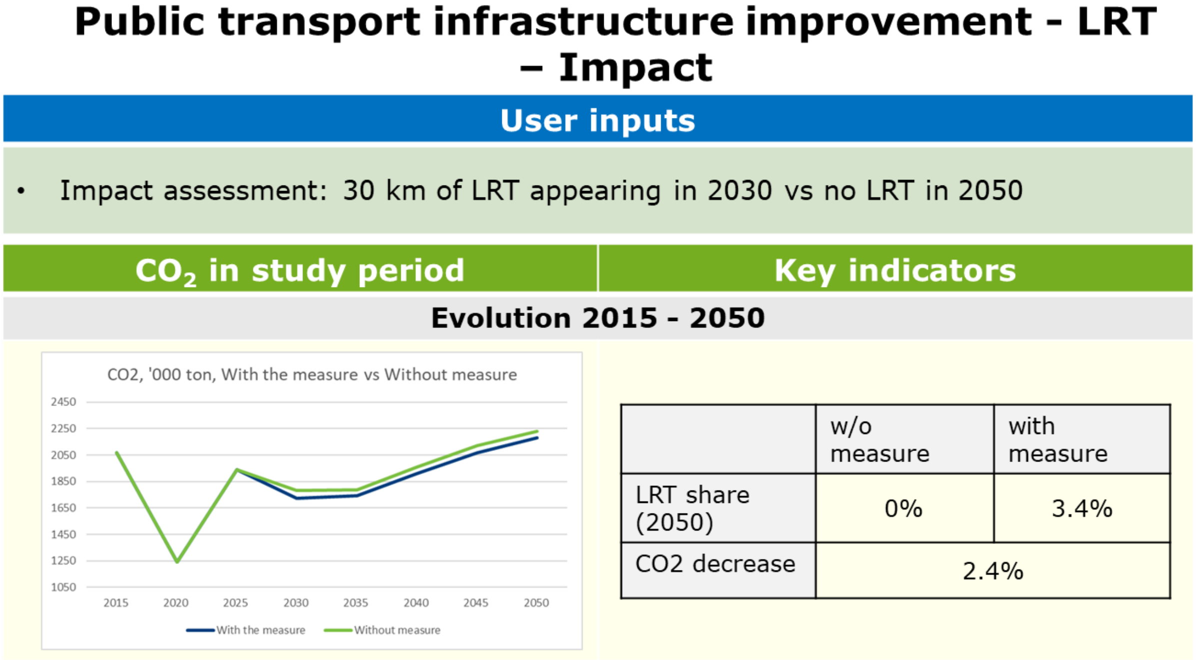
Impact in the model

The user sets a target for the actual network length of LRT, metro and BRT, between 2015 and 2050. The model also converts these values into:

- Decrease of the average access time and waiting time for each of the three modes.
- Increase in speed of each of the three modes
- Increase in the average number of all PT transfers because of the extended PT line combinations in the PT network.

The impact on each model component is set up with parameters from the sub-model parameters sheet, which can be adjusted by the user.

Impact on CO2 and other indicators:



Public transport infrastructure improvement - LRT – Impact

User inputs

- Impact assessment: 30 km of LRT appearing in 2030 vs no LRT in 2050

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050

	w/o measure	with measure
LRT share (2050)	0%	3.4%
CO2 decrease	2.4%	

Public transport infrastructure improvement - metro – Impact

User inputs

- Impact assessment: 120 km of metro in 2030 vs 36.6 km

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050

	w/o measure	with measure
metro share (2050)	12.1%	17.7%
CO2 decrease	7.9%	

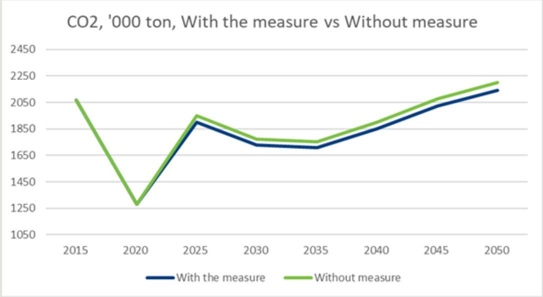
Public transport infrastructure improvement – bus corridors – Impact

User inputs

- Impact assessment: 30 km of BRT appearing in 2030 vs no BRT in 2050

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050



	w/o measure	with measure
metro share (2050)	0%	3.6%
CO2 decrease	2.7%	

Soft Modes and Low-emission Vehicles Promotion

Enhancement of bike and pedestrian infrastructure

Description

Enhancing the supply and network design of walking and cycling infrastructure in a city encourages more people to walk and cycle. Providing cycling infrastructure and bike lockers/parking spaces close to the origin and destination of potential journeys encourages cycling, especially if the cycling infrastructure is safely separated from other road traffic. Similarly, creating pleasant walking infrastructure (for instance by creating spacious, green and safe sidewalks and/or pedestrian areas) encourages walking in a city.

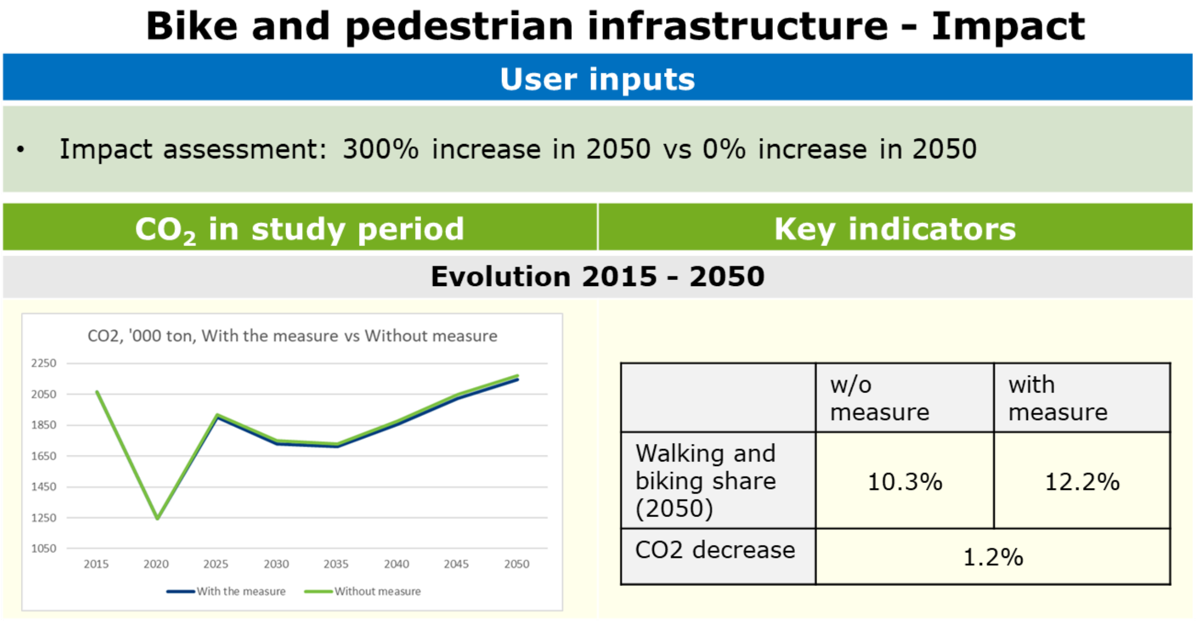
Impact in the model

The user sets a target for the percentage increase in the footpaths and bike lanes development between 2015 and 2050. The model converts this value into:

- Stronger increase in the bike and pedestrian networks.
- Decrease in the average access time to a bike, a private mode or a taxi, due to the reduced access detour by the improved networks.
- Increase in the average speed of walking and cycling, thanks to better infrastructure with higher capacity.
- Decrease in the average speed for road-based private vehicle and shared mobility modes, because of reduced urban space dedicated to road use through bike and pedestrian infrastructure development.
- Increase in the share of “walkable” or “bikeable” short-distance trips, because nicer and more direct bike and pedestrian infrastructure reduce the need for other modes with a longer detour.
- Increase in the attractiveness of active modes in the mode choice, owing to nicer and safer infrastructures.
- Increase the value of bike reliability modal attribute

The impact on each model component is set up with parameters in the sub-model parameters sheet, which can be adjusted by the user.

Impact on CO2 and other indicators:



Bike and pedestrian infrastructure - Impact

User inputs

- Impact assessment: 300% increase in 2050 vs 0% increase in 2050

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050

	w/o measure	with measure
Walking and biking share (2050)	10.3%	12.2%
CO2 decrease	1.2%	

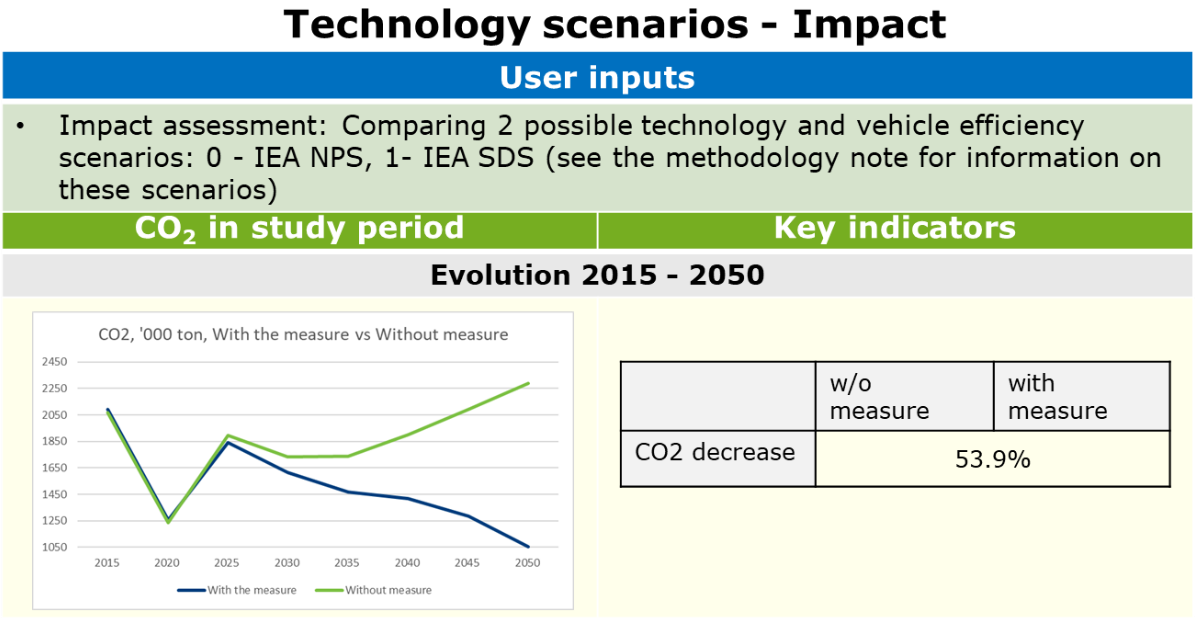
Technology scenarios

The user can activate IEA's technology scenarios. It can be 1) the New Policy Scenario (NPS) corresponding to a baseline approach, or 2) the Sustainable Development Scenario (SDS) corresponding to a high ambition approach. For the description of each scenario see the Output section of this document, CO2 emissions. See more details about the scenario in section *CO2 and local pollutant emissions.*

Impact in the model

The user chooses the IEA scenario: 1 triggers the IEA SDS scenario, while 0 triggers the IEA NPS scenario. This choice affects the way the emissions are calculated, according to the chosen scenario.

Impact on CO2 and other indicators:



Technology scenarios - Impact

User inputs

- Impact assessment: Comparing 2 possible technology and vehicle efficiency scenarios: 0 - IEA NPS, 1- IEA SDS (see the methodology note for information on these scenarios)

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050

	w/o measure	with measure
CO2 decrease	53.9%	

Sales targets for low emission vehicles (cars)

Description

Sales promotion is a particular type of incentive for low-emission vehicles. It comprises any measure that aims at increasing the sales of low (or zero) emission vehicles. This usually includes purchase tax exemptions or credits. These incentives aim at making the low-emission vehicles more competitive, in order to reduce the share of emission-intense Internal Combustion Engine (ICE) vehicles.

Impact in the model

The user sets targets for the expected sales shares for all available vehicle technologies/fuels in 2050. The model then recalculates the average tank-to-wheel CO_2 emissions based on the fleet composition at a given year (which is 'back-casted' from the 2050 target value) within the vehicle stock model.

Impact on CO2 and other indicators:

Sales targets for low-emission vehicles (cars)- Impact

User inputs

- Impact assessment: 5% Gasoline / 50% Gas.-hybrid / 4% Diesel / 1% LPG/CNG / 5% Hydrogen / 35% Electric in 2050 **vs.** 87% Gasoline / 0% Gas.-hybrid / 12% Diesel / 1% LPG/CNG / 0% Hydrogen / 0% Electric in 2050

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050

	w/o measure	with measure
CO2 decrease	25.3%	

Technology targets for the bus fleet

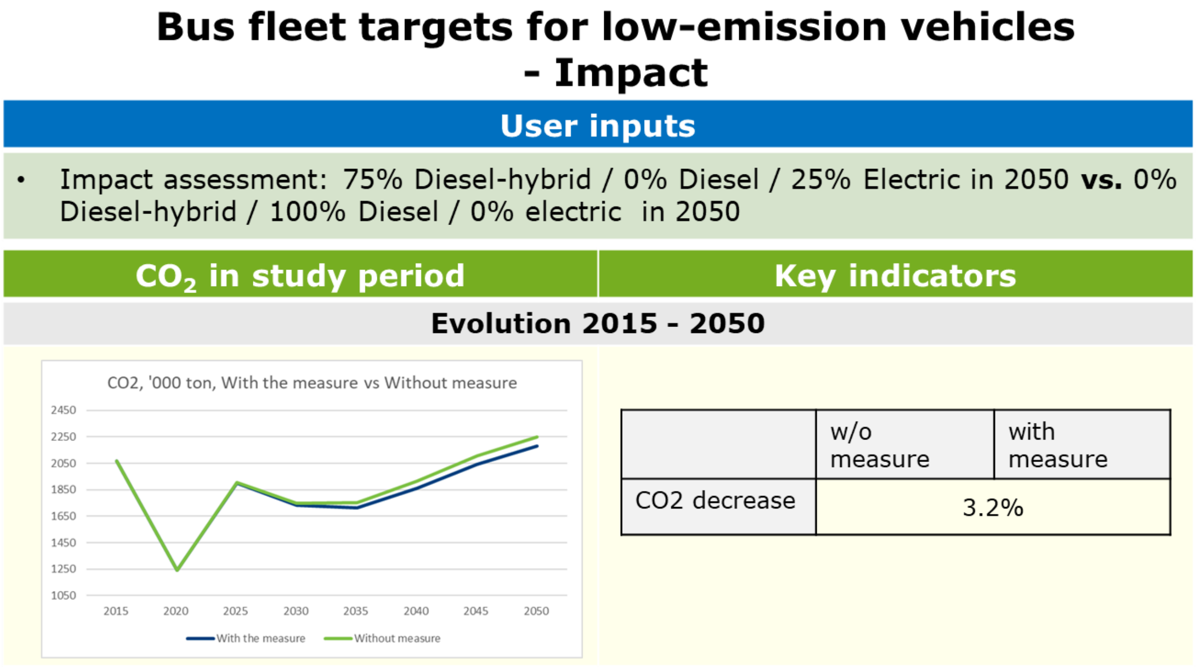
Description

Promotion of the ‘cleaner’ bus fleet composition is a particular type of incentive for low-emission vehicles. It comprises any measure that aims at increasing the shares of low (or zero) emission vehicles in the fleet. This usually includes purchase tax exemptions, credits or direct orders in the case of public operators. The incentives aim at bringing the low-emission vehicles to the bus fleet, in order to reduce the share of emission-intense Internal Combustion Engine (ICE) vehicles.

Impact in the model

The user sets targets for the expected bus fleet composition in terms of fuel for 2050. The model then recalculates the average tank-to-wheel CO_2 emissions based on the fleet composition at a given year (which is ‘back-casted’ from the 2050 target value) within the vehicle stock model.

Impact on CO2 and other indicators:



Bus fleet targets for low-emission vehicles - Impact

User inputs

- Impact assessment: 75% Diesel-hybrid / 0% Diesel / 25% Electric in 2050 **vs.** 0% Diesel-hybrid / 100% Diesel / 0% electric in 2050

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050

	w/o measure	with measure
CO2 decrease	3.2%	

Exogenous Variables

Development of autonomous vehicles

Description

Autonomous vehicles in this study are vehicles that can fully drive themselves, without human interaction. They are expected to have strong impacts on the mobility systems. Autonomous vehicles offer improved safety, the opportunity to conduct other activities during the trip, and lower stress for car occupants, among others. However, they could potentially generate more trips and congestion if not well regulated, given the removed driving barrier for all the population and higher empty runs due to picking up and self-parking trip legs.

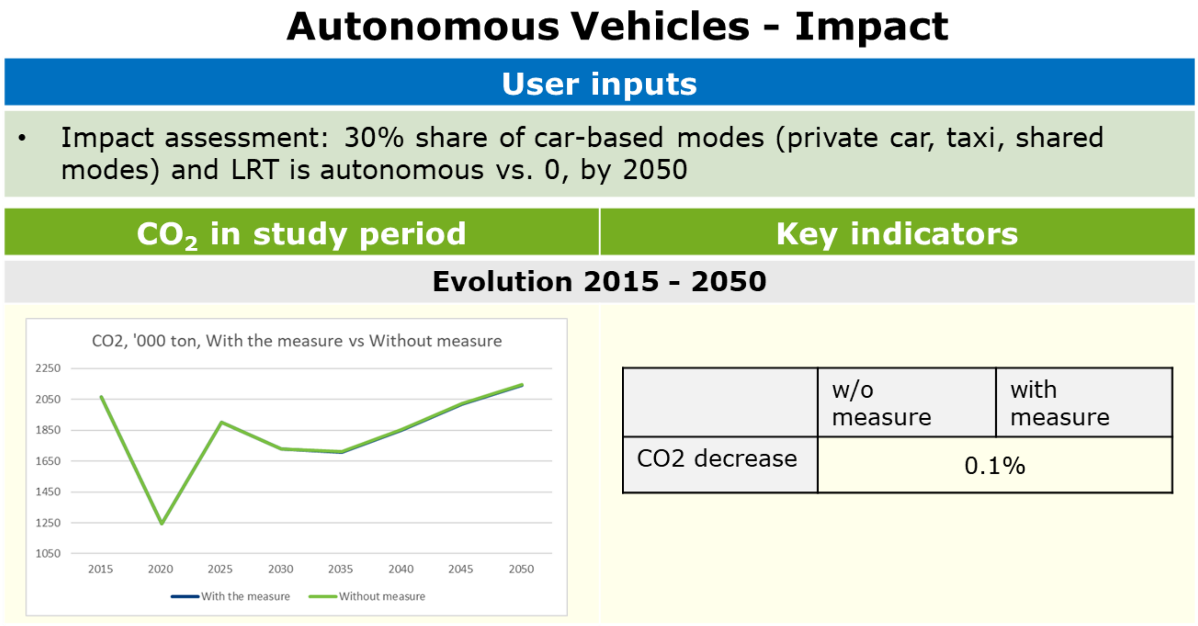
Impact in the model

The user sets a target for the expected share of automated vehicles in the vehicle fleet by 2050. The model converts this value into:

- Decrease in the average vehicle fuel consumption and driving detour, because autonomous vehicles are expected to have smoother, more rational and more fuel-efficient driving behaviours than human drivers.
- Decrease in the fixed and variable fares of taxis, because the labour cost disappears with automation, thus reducing the total cost.
- Increase in the average speed of car, taxi, LRT, bus and car-sharing, thanks to more efficient automated driving behaviour.

The impact on each model component is set up with parameters in the sub-model parameters sheet, which can be adjusted by the user.

Impact on CO2 and other indicators:



Autonomous Vehicles - Impact

User inputs

- Impact assessment: 30% share of car-based modes (private car, taxi, shared modes) and LRT is autonomous vs. 0, by 2050

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050

	w/o measure	with measure
CO2 decrease	0.1%	

Teleworking

Description

Teleworking is broadly defined as carrying out work at a location that is remote from the employer's site while staying connected to the office via network technologies. Telework can also encompass flexible working arrangements that shift commuting activities to off-peak hours. In the context of this analysis, however, teleworking is considered as working arrangements that reduce the total number of trips to the office. Telework helps to reduce the number of commuting work trips, thus alleviating traffic on transport networks during peak periods. To the extent it can reduce motorised trips, teleworking reduces CO2 emissions. Encouraging teleworking thus has a potential role in travel demand management strategies that aim to decarbonise transport.

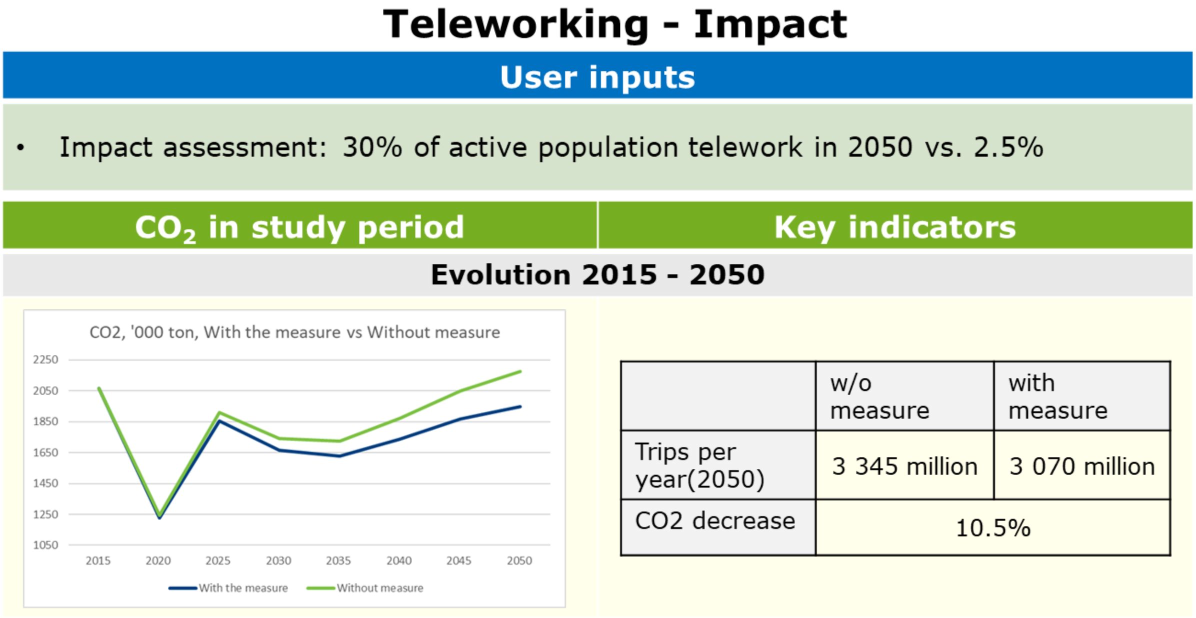
Impact in the model

The user sets a 2050 target for the expected share of the active population that would telework, starting from an estimation of 2.5% for 2015. The model converts this value into:

- Decrease in the total number of trips, because teleworking reduces the need of commuting trips to work.
- Increase in the share of trips under 5 kilometres, because teleworking potentially generates more needs for grocery and restoration purposes.

The impact on each model component is set up with parameters in the sub-model parameters sheet, which can be adjusted by the user.

Impact on CO2 and other indicators:



Teleworking - Impact

User inputs

- Impact assessment: 30% of active population telework in 2050 vs. 2.5%

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050

	w/o measure	with measure
Trips per year(2050)	3 345 million	3 070 million
CO2 decrease	10.5%	

Transit-Oriented Development (TOD)

Description

Transit-Oriented Development is *"the creation of compact, walkable, pedestrian-oriented, mixed-use communities centred around high-quality train systems"*11. It consists of considering both transport and land-use altogether. It leads to co-build high-density neighbourhoods and mass public transport solutions and can ultimately increase the land-use mixture, reducing the need to travel.

Impact in the model

The user sets a target for the increase of land-use mixture between 2015 and 2050. The model converts this value into:

- Decrease in the average access time to all PT and paratransit modes, because TOD brings transit closer to residential housings.
- Decrease in car ownership. Because TOD reduces the distance required for car trips, allows a greater portion of trips to be made by PT and active modes, thus decreases the car ownership of some households.

The impact on each model component is set up with parameters in the sub-model parameters sheet, which can be adjusted by the user.

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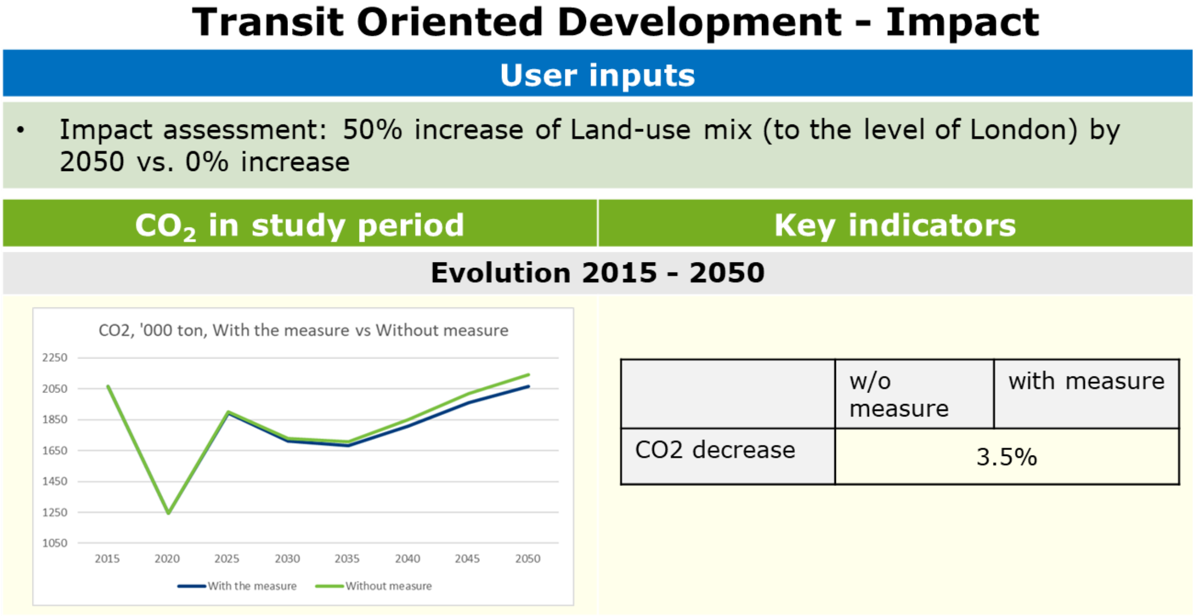
[11] http://www.tod.org/

Impact on CO2 and other indicators:



Transit Oriented Development - Impact

User inputs

- Impact assessment: 50% increase of Land-use mix (to the level of London) by 2050 vs. 0% increase

CO_2 in study period

Key indicators

Evolution 2015 - 2050

	w/o measure	with measure
CO2 decrease	3.5%	

Increase population density

Description

Increasing population density through land-use planning influences the way cities are constructed and evolve, which can be adjusted by the user. Increased density leads to shorter trips and therefore increased soft modes shares, which, in turn, leads to emission reduction. The user sets the target for the increase of:

- The density of the city core
- The density of the rest of the city ("suburbs")

The density increases through the increase of the population for the same area.

The impact on each model component is set up with parameters in the sub-model parameters sheet, which can be adjusted by the user. It is important to notice that the model already implies some population and, therefore, density growth, described in the Model scope section of this document.

Impact on CO2 and other indicators:

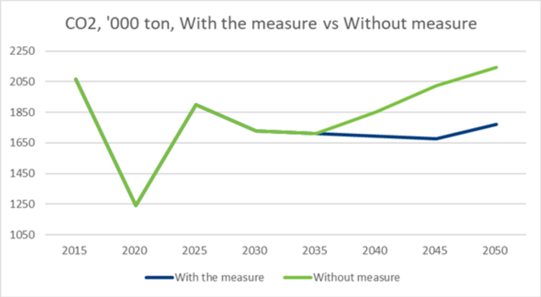
Increase of population density in the city centre - Impact

User inputs

- Impact assessment: 30% increase of the city core density vs. no change in population density, by 2050

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050



	w/o measure	with measure
Share of trips <1 km	14.43%	16.69%
Share of trips 1 km – 2.5 km	17.08%	19.56%
CO2 decrease	17.5%	

Increase of population density outside of the city centre - Impact

User inputs

- Impact assessment: 30% increase of the city suburb density vs. no change in population density, by 2050. This measure indicates some urban sprawl when not combined with increased density in the city centre.

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050

	w/o measure	with measure
CO2 decrease	0%	

Polycentric city structure

Description

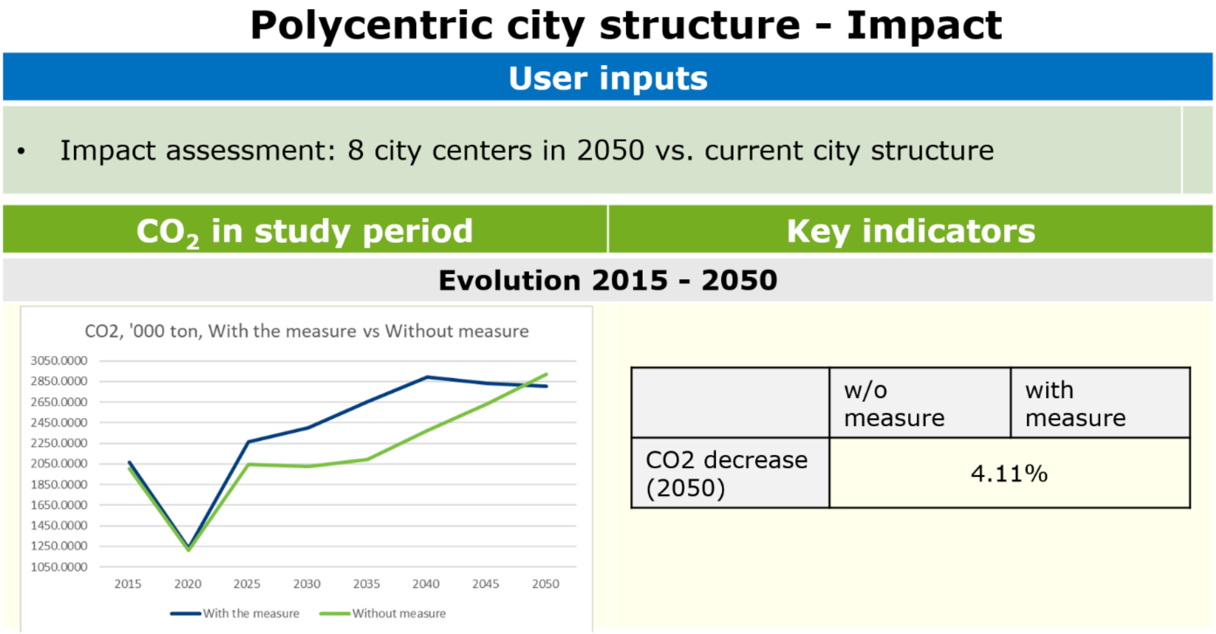
The model allows testing the polycentric city centre structure proposed in *'Baku Masterplan'*. According to the master plan, the city centre will consist of eight sub-centres in 2040. The details of the model representation for this scenario (‘Polycentric scenario’), as well as the baseline scenario with three centres (‘Baseline city centre development scenario’), are described in section Geographic scope.

The user sets the Polycentric scenario instead of the Baseline city centre development scenario. This affects the following model variables.

- The population, the area, and, consecutively, density of the city core

As the impact section shows, the polycentric structure leads to larger emissions than the current structure, until 2045. In 2050 the situation changes as the city centre stops growing in terms of area, but the population continues its growth, which eventually increases population density. Increased density leads to shorter trips and therefore higher shares of soft modes, which, in turn, leads to emission reduction.

Impact on CO2 and other indicators:



Polycentric city structure - Impact

User inputs

- Impact assessment: 8 city centers in 2050 vs. current city structure

CO_2 in study period | **Key indicators**

Evolution 2015 - 2050

	w/o measure	with measure
CO2 decrease (2050)	4.11%	