COSTS AND BENEFITS OF THE URBAN MOBILITY TRANSITION

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EIT Urban Mobility – Mobility for more liveable urban spaces

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TRT

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Executive summary

This study simulates transition scenarios for European cities to meet the Green Deal objectives for the transport sector by 2030 and 2050. It is an update of a 2021 study, including more mobility measures, different impact dimensions, and a new baseline for the simulation. Based on twelve city prototypes of European cities, the study explores three scenarios (S01: *infrastructure and mobility services*, S02: *regulation and demand management*, S03: *zero-emissions*) and evaluate their costs and benefits for municipalities and users.

Among other indicators, the model estimates the CO_2 emission reduction as well as the investments and costs linked to the deployment of packages of sustainable mobility measures needed to reach the Green Deal objectives.

The simulated scenarios show that by 2030, technology improvements (i.e. increased penetration of new vehicle engine and powertrain technologies) alone are expected to lead to a 21% CO_2 emission reduction compared to 2022 levels, leaving a significant emission gap. Sustainable mobility measures simulated in the scenarios allow for further 14% - 44% reductions depending on the intensity of measures deployed. Only the most ambitious scenario (scenario 3) meets the Green Deal objective, but its realisation is unlikely due to the high acceptance and behaviour change it implies.

In 2050, all scenarios can reach the Green Deal target. The main drivers are technology innovations and vehicle fleet replacement (-73% CO_2), while the measures implemented in the scenarios contribute to a further 22%-25% CO_2 emission reduction. The effects of technology innovations and vehicle replacement in the long term shows the importance of national and European support for continuous investments in clean transport vehicles.

In the simulated scenarios by 2050, at least additional €1,5 trillion are needed to meet the Green Deal objectives for the transport sector in European cities. This corresponds to €500 billion in investments for implementation and management of the different measures and policies (generating about €300 billion in revenues), and €1,3 trillion in user costs. However, considering the internalisation of externalities, benefits outweigh costs in two out of three scenarios.

Results from the scenario modelling show a trade-off between the impact of the most efficient measures and their acceptability. Taking both into consideration, the combination of more attractive public transport and shared mobility with access restrictions constitute a credible mix of intervention: such combination brings the highest reduction in private car trips, and results in a 7% increase in public transport ridership by 2030, along with a slight increase in shared mobility and active modes (scenario 3).

Supply side measures – offering more mobility options – on their own are not sufficient to curb private motorised transport. The highest reduction in private car mode share (-16% in 2030) is achieved only when combining infrastructure rollout (e.g. public transport network, cycling infrastructure, charging points, etc.) and mobility services increase with access regulation and pricing measures such as low-emission zones. Nevertheless, it is unlikely that the transition to more sustainable urban mobility systems will lead to a large reduction in car ownership. Even if private car trips per inhabitants are expected to decrease in all scenarios, the number of cars per inhabitants will go down at a slower rate between 3% to 14,5% by mid-century, depending on the scenario.

The scenario assuming the highest reduction in car trips is also the one that bears the least costs for users. Achieving the strongest change in mobility habits away from private motorised transport towards more public transport and shared mobility leads to the highest cumulated cost savings of up to €2,900 per inhabitant in 2030, and €15,000 per inhabitant by 2050 (scenario 3). In scenarios 2 and 3, external cost savings are 60-150% higher than the total costs.

Shifting to public transport, shared mobility, and active modes of transport leads to cumulative health benefits of up to €1170 per capita by 2050, mainly due to the health benefits linked to more active lifestyles induced by people walking and cycling more often.

Across the scenarios, high user costs can be expected, reflecting the impact of transitioning to cleaner powertrains. This points to the need for flanking measures in the form of subsidies and highlights the role environmental bonuses for low-income households can play in the transition. Meanwhile, transport and urban planning need to go hand in hand to help reducing travel length and distances and therefore make trips by public transport and active modes more efficient and attractive.

Looking at other aspects of the transition, results show that combining vehicle fleet renewal and modal shift leads to the fastest decrease in particulate matter emissions (PM2,5) from transport, cutting levels by up to 61% in 2030 and up to 70% by 2050 (scenario 3). At the same time, road traffic deaths decrease as people switch to safer modes of transport such as metros, trams, and buses. In parallel, safer infrastructure reduces the number of road fatalities for pedestrians and cyclists. The role of technological innovations like intelligent transport systems also positively impacts road safety. The combination of all the measures above leads to a reduction in fatalities of up to 70% in 2050 compared to 2022.

Of all policy groups, *Access regulation and pricing* measures, achieve the highest savings in most city prototypes both in the mid and long term, because they require little investments compared to other measures. Such measures have a high political cost due to acceptance issues linked with habit changes but are a key enabler to meeting the Green Deal targets by 2030.

Electrification policies have the potential to achieve significant CO_2 reduction, albeit at a large cost, especially for users. *Public transport* within all city prototypes appears a particularly resilient policy group, with moderate costs and investments needed while reaching substantial CO_2 emission reduction. It stands out as an affordable option for inclusive and low-CO_2 mobility and should therefore be considered one of the most realistic and practicable approaches to the achievement of the Green Deal objectives in urban mobility.

The study's key recommendations are:

- The **regulatory framework** needs to allow cities to take the necessary sustainable mobility measures (eg. LEZ and road access regulation) required to meet decarbonization targets.
- Dedicated long-term **national and European funding** for investments in clean transport vehicles by private and public actors is needed to support the vehicle fleet renewal.
- Investments should prioritise the **provision of reliable, affordable and climate friendly alternatives,** such as walking and cycling, public and shared transport, cargo bikes and logistics hubs, etc.
- To support **modal shift toward public transport**, its quality and offer should be improved, including transport on demand services, to ensure service access as wide as possible.
- Improving the **efficiency of the freight delivery** is key, e.g. with delivery plans and distribution centers. Cargo-bikes are the safest and most sustainable option for the last-mile.
- Participatory processes and **stakeholder and citizen engagement** are crucial to influence the successful development, acceptance and implementation of effective sustainable transport.
- The close interrelation between transport and **urban planning should be better acknowledged** to help reducing travel length/distances, making trips by public transport and active modes more efficient and attractive.

1 Introduction

1.1 Study context

One of the most complex challenges facing city governments is the management of mobility issues. On one hand, citizens require to move in an efficient way. Conversely, there is an urgent need to address the negative externalities associated with mobility, including congestion, air pollution, noise, CO_2 emissions, accidents, and urban sprawl. Such pressing necessity is exacerbated by the fact that between 1990 and 2022, transport sector emissions have grown at an annual average rate of 1.7%.[1] Furthermore, cities are reported to be responsible for more than 70% of global GHG emissions, with transport and buildings being among the largest contributors.[2]

To overcome these challenges, cities must develop and implement coherent and challenging plans that are aligned with the EU's objectives for urban transport. The EU Green Deal[3] sets a target of reducing greenhouse gas emissions from transport by 90% by 2050, enabling the EU to become a climate neutral economy. This is in addition to the goal of achieving zero pollution for air, water and soil (COM/2021/400 final). However, the limited financial resources available to public administration mean that an integrated strategy must be prepared which is composed of sustainable mobility policies, evaluated in a scientific and measurable way, and flexible enough to accommodate for future changes.

In this context, the EIT Urban Mobility's *Costs and Benefits of the sustainable urban mobility transition study*[4] was carried out in 2021 with the purpose of assessing the impacts of different sustainable urban mobility scenarios in European cities while quantifying the costs and benefits of this transition in 2030 and 2050. The study simulated three potential scenarios, each one based on a different combination of policy measures, which were applied to 12 city prototypes to account for differences in terms of size, geography, transport infrastructures, and citizens' attitudes of 779 European cities with more than 50,000 inhabitants. The main outputs of each transition scenario consisted in a series of indicators from three domains: transport (modal split, car ownership), environment (CO_2 emissions, fatalities), and economy (city costs, revenues, and externalities). Also, a policy effectiveness comparison determined the best policy measures, in terms of associated cost/revenues and CO_2 reduction, according to different city sizes.

1 https://www.iea.org/energy-system/transport

2 https://www.unep.org/explore-topics/resource-efficiency/what-we-do/cities-and-climate-change

3 https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1596443911913&uri=CELEX%3A52019DC0640#document2

4 https://www.eiturbanmobility.eu/wp-content/uploads/2021/10/Final-report_Long-version.pdf

Results were generalized for the entire European context based in the number/size of cities belonging to each of the 12 prototypes.

The study was realized through the application of MOMOS, a strategic assessment tool that allows a comprehensive evaluation of policy scenarios through a scan between alternative hypothesis of intervention, and by providing the order of magnitude of the resources needed for their implementation as well as the expected impacts generated over different time horizons.

1.2 Objective of the study

This study consists in an update and improvement of the 2021 study. In particular, the key objectives of the update include:

- A refinement of the study's input data and of the definition of the city prototypes.
- An improvement of the policy measures: additional policies have been included in the simulation to better reflect the diversity of urban mobility options that cities can deploy. Also, there is a clearer and more accurate assignment of policies into the associated policy groups.
- A refinement of the intervention levels and targets of the policy measures, of the content of the transition scenarios, of the timeline of the policies implementation (including the simulation's base year).
- Based on the updated framework and assumptions, a new modelling simulation has quantified the expected costs and benefits of the sustainable urban mobility transition in European cities by 2030 and by 2050.
- According to the new results and insights obtained from the simulation, specific policy recommendations have been drafted for practitioners.

1.3 Methodology

The quantified analysis of the costs[5] and benefits of the transition to sustainable urban mobility in European cities by 2030 and 2050 has been obtained through the application of MOMOS, a quantitative tool which allows to simulate the impacts of different mobility transition scenarios in urban areas.

[5] The costs quantified in this study include: the measures' implementation and management costs sustained by the public administration, service providers and logistics operators, and the costs for the individual users. Further information is provided in **Section 3.2**.

The application of MOMOS enables the quantification of the transition to sustainable urban mobility taking into account the differences among European cities in terms of size, geographic location, transport infrastructures, citizens attitudes, average income, etc. The model runs until 2050, allowing for the simulation of different packages of sustainable policy measures.

The tool provides a quantification of results for three potential transition scenarios, each based on a specific combination of policy measures selected from important EU initiatives. These measures comprehensively cover the range of options that cities have available to lead the sustainable mobility transition. The policies assigned to each scenario determine their specific focus, namely: infrastructure and mobility services, regulation and demand management, zero-emissions mobility (as explained in section 2.4).

The three transition scenarios have been applied to "city prototypes" representing different dimensions (large, medium, and small) and geographic areas (Northern, Central, Southern, and Eastern Europe) of the cities they represent. A total of 12 city prototypes have been simulated. Finally, the model's output data have been generalized at EU level based on the number and size of EU cities that falls within each of the city prototypes considered.

Each city prototype has been defined using a set of real cities used as reference. For each of them, an in-depth data collection has been performed to reproduce the prototype's characteristics at the base year, including their socio-demographic aspects as well as mobility features (e.g., fleet composition, public transport infrastructure, availability of innovative/shared services, traffic management solutions, etc.). Nevertheless, additional data has been gathered for a diverse range of cities to ensure the prototypes are not influenced by specific circumstances in the real cities.

The simulation of the transition scenarios in MOMOS provides a series of quantitative indicators as outputs. Indicators are calculated for the three transition scenarios in two future years, i.e. the time horizons (2030 and 2050) and are compared to the base year (2022) values.

A comprehensive overview of the costs and benefits of the sustainable urban mobility transition is provided by assessing the impacts of the three transition scenarios on transport, environmental and social indicators (e.g., CO_2 emissions, air pollutants emissions, modal split, car ownership, road fatalities, etc.) as well as by quantifying their associated costs, monetary values, and revenues.

MOMOS (Sustainable Mobility Model)

Whereas the market offers several modelling tools that allow to simulate alternative policies and produce detailed answers about their possible impacts, they all come with a cost, complexity, and required level of specialist expertise that often make them difficult to implement. Instead, MOMOS is a strategic assessment tool that offers support to analyse policy scenarios for sustainable mobility in urban areas and can be applied to different urban contexts and geographic areas. The tool works at aggregated level, requires a limited amount of data, and can be applied within a short timeframe and with reduced costs. It also does not require sophisticated user skills. MOMOS allows to make a quick scan between alternative hypotheses of intervention providing the order of magnitude of the needed resources and expected impacts on yearly basis. The model provides 30 years of simulation (e.g., the period from 2020 to 2050) and offers a strategic evaluation of alternative solutions that is quantitative, theoretically sound, tailored to a specific context, and reasonably adaptable for limited time and resources. MOMOS is developed in Microsoft Excel environment and can be customised to represent different the impacts of transport policy scenarios in different urban contexts. To properly reproduce the city's (or prototype) characteristics at base year, the model requires a comprehensive set of input data to adapt the model to retrace the city circumstances, including both socio-demographic aspects and urban mobility features. MOMOS allows to design different scenarios, taking into account exogenous factors related to three domains: technology, energy, taxation. For each scenario, intervention policies and strategies can be defined through the selection of specific sustainable mobility measures. Quantitative results are estimated, to compare the impacts of the scenarios during the 30 years of simulation, by using indicators calculated on yearly basis related to the transport, environment and economy sector. More info available at https://www.momos-model.eu

1.4 Key differences compared to previous study

Whereas this study is an update of the one carried out in 2021, it is important to mention that some methodological changes have been implemented, particularly related to the MOMOS model, to the policy measures considered in the study and to the economic data guidelines.

The MOMOS Model

The current version of the model includes as relevant improvement the explicit modelling of the vehicle fleet. In fact, in the previous version all the vehicle fleets were read as exogenous data. Instead, the model now has its own vehicle fleet module, where each policy and related input influences dynamically the evolution of the vehicle fleet. Moreover, separate modules have been developed for private cars (resident and incoming), car-sharing, ride-hailing/taxi, public buses, Light Duty Vehicles (LDV), Heavy Duty Vehicles (HDV), and motorcycles.

One of the most important outcomes of this new implementation is the possibility to quantify the cost associated with the vehicle fleet. This includes both vehicle's ownership taxes and fuel consumption – already included in the previous study and now refined – as well as fleet renewal and scrapping. As mentioned above, the model is able to link any policy impact – such as a new access regulation in place in the city centre – with the volume of vehicles scrapped and purchased, segmented by fuel type and Euro Standard.

New policy measures

With respect to the previous study, the following new policy measures have been implemented and calibrated:

- **Uptake of electric vehicles.** This measure simulates a boost in the vehicle fleet renewal, inducing an increased uptake of electric vehicles in the stock. This applies to cars, LDV, HDV and motorcycles. The renewal is influenced by many policy measures but can be boosted directly if the city invests in it, e.g. with incentives for purchasing new electric vehicles, by scrapping an old internal combustion vehicle.
- **Phase-out of fossil fuel vehicles.** On the regulatory side, this policy measure aims to simulate European or national bans on fossil fuel vehicles. It is possible to set a different implementation year for each type of engine (for cars, LDV, and HDV).
- **Ride-hailing and taxi.** In combination with Public Transport and shared mobility, many cities have a not negligible ride-hailing or taxi fleet. The transport demand, the vehicle fleet, the pricing schemes and the related users' attitude are not the same as for car-sharing services. For this reason, a specific policy measure has been developed in the MOMOS model.
- **Moped sharing.** Similarly, moped sharing – previously simulated within bike-sharing – requires a specific policy measure, where the related fleet, pricing schemes and users' attitude are simulated. As the service typically uses electric vehicles, in most cases this service attracts new users where other transport modes are not allowed to circulate, e.g. in the Low Emission Zone, if the policy is in place.
- **Car-free days.** This measure simulates the car-free days, when the city does not allow private cars to circulate. Typically, this is not a systematic measure, but is implemented on specific days to provide an example of how the city can be without the circulation of private cars.

- **Online shopping.** Online shopping has become very popular in recent years. With a non-optimised delivery system, online shopping has a negative impact on traffic and emissions. However, with an efficient scheme, a large number of car trips for personal purposes can be avoided.
- **Low Emission Zone – LEZ.** One of the most effective policy measures in the short-term is the LEZ. On the other hand, it is not well accepted by citizens. However, many European cities are successfully implementing Low Emission Zones, and the MOMOS model is able to reproduce this considering different schemes by vehicle type for cars, LDV and HDV.
- **Cargo-bikes.** To reduce emissions and congestion in urban areas, cargo-bikes are one of the best solutions for last-mile logistics. The policy measure aims to encourage the use of cargo-bikes for this type of service. Of course, the policy works better if activated in combination with cycle lanes, urban delivery service, Low Emission zone, etc.

Economic data guidelines

Updated guidelines have been published since the previous study concerning the following economic values, affecting the estimation of costs and benefits.

- **The monetization** of GHG emissions is higher in this study, in line with the *EU Economic Appraisal Vademecum 2021-2027*,[6] which reports 83 €/ton in 2022, 259 €/ton in 2030, and 829 €/ton in 2050. Instead, in the previous study the values were taken from the EC's *Handbook on external costs of transport* 2019,[7] i.e. 100 €/ton until 2030, and 269 €/ton until 2050. This difference leads to a large gap in the economic assumptions.
- **The discount rate** is now the same for all the city prototypes (3%), in line with the *EU Economic Appraisal Vademecum 2021-2027*. In the previous study a discount rate of 4% was used for Southern city prototypes, 3% for Central and Northern, and 5% for Eastern ones, following the indications provided by the *EU Guide to Cost-Benefit Analysis of Investment Projects*.[8] From 2022 to 2050, even a small difference in the discount rate can lead to quite substantial differences in the economic results.

6 https://ec.europa.eu/regional_policy/en/information/publications/guides/2021/economic-appraisal-vademecum-2021-2027-general-principles-and-sector-applications

7 https://op.europa.eu/en/publication-detail/-/publication/e021854b-a451-11e9-9d01-01aa75ed71a1

8 https://ec.europa.eu/regional_policy/sources/studies/cba_guide.pdf

1.5 Structure of the report

The report is organised as follows. First, the methodological approach and the analytical framework of the study is illustrated, explaining the rationale behind the design of the three urban mobility scenarios and the policy measures implementation. Then, the quantification of the costs and benefits of the sustainable urban mobility transition is presented. Indicators are calculated for a series of city prototypes, necessary to summarize the entire EU27 context. These results are complemented with an analysis of policy measures effectiveness and with a series of recommendations and key messages that can be extrapolated from this study.

The report is accompanied by a series of Annexes (https://www.eiturbanmobility.eu/wp-content/uploads/2024/09/37-EIT-Study-on-costs-and-benefits-Annexes-v2a.pdf): Annex I provides some details on the calculation framework of the MOMOS model and its components. Annex II contains the full list of data used for the model simulation. The rationale and the intervention levels of the policy measures in the scenarios are reported in Annex III. Annex IV includes the list of cities used for the generalisation to the entire EU27 context.

Finally, the full list of output indicators, for each of the 12 city prototypes, is included in a dedicated separate document (https://www.eiturbanmobility.eu/wp-content/uploads/2024/09/2024_EIT_Costs-and-benefits-study_Full-results.pdf).

2 Methodological approach

2.1 Analytical framework

The study aims to evaluate policies and investments needed for European cities to transition to sustainable urban mobility by 2030 and 2050, assessing the revenues and benefits derived from it. This objective is addressed through a high-level quantitative analysis of different sets of policy measures, using the assessment tool MOMOS (Sustainable Urban MObility Model, see paragraph 2.2) to simulate the outcomes of three different mobility transition scenarios.

To quantify the impacts in European cities, different **city prototypes** have been designed to represent different urban conditions based on their dimension and the geographic localization. The prototype definition has followed the same rationale that has been successfully used in the previous study.

On the one hand, three types of **city dimensions** have been considered:

- Small (50,000 - 100,000 inhabitants)
- Medium (100,000 - 500,000 inhabitants)
- Large (more than 500,000 inhabitants)

Also, four **geographic areas** have been considered, to consider different income levels, motorisation rates, and transport infrastructure endowment across EU-27 Member States:

- *Northern Europe* (Denmark, Finland, Ireland, Sweden)
- *Central/Western Europe* (Austria, Belgium, France, Germany, Luxembourg, Netherlands)
- *Southern Europe* (Croatia, Cyprus, Greece, Italy, Malta, Portugal, Slovenia, Spain).
- *Eastern Europe* (Bulgaria, Czech Republic, Poland, Slovakia, Hungary, Romania, Estonia, Latvia, Lithuania)

Intersecting the three dimensions with the four geographic areas, 12 city prototypes have been generated to cover and **generalize the entire EU27 context**. Each prototype is representative of a set of cities in EU27 with specific mobility characteristics. The adaptation of the model for the application to the various prototypes is performed through as set of transport parameters, that allow the model to reproduce the most appropriate urban transport patterns. For example, small cities might have in general a reduced availability of public transport infrastructures compared to large cities, and so on. **Table 1** includes the cities (36, i.e. three per each prototype) that have been used as reference to define the city characteristics and transport parameters for each of the 12 city prototypes. For each of these cities, a set of input data related to socio-demographic aspects as well as mobility features have been gathered, as reported in paragraph 2.3. In selecting these examples, priority has been given to cities considered in the previous EIT Urban Mobility study. At the same time, all EU27 countries have at least one city to "represent" them, with the only exception of Malta.

	Southern Europe	Central/ Western Europe	Northern Europe	Eastern Europe
Small City	Lecce (IT) Faro (PT) Zadar (HR)	Klagenfurt (AT) Leuven (BE) La Rochelle (FR)	Lahti (FI) Galway (IR) Gavle (SE)	Zilina (SK) Tartu (EE) Daugavpils (LV)
Medium City	Lemesos (CY) Ljubjana (SI) Ravenna (IT)	Bielefeld (DE) Eindhoven (NL) Luxembourg (LU)	Uppsala (SE) Oulu (FI) Odense (DK)	Timisoara (RO) Szeged (HU) Klaipeda (LT)
Large City	Madrid (ES) Athens (GR) Milan (IT)	Bordeaux (FR) Munich (DE) Brussels (BE)	Dublin (IR) Copenhagen (DK) Goteborg (SE)	Sofia (BG) Prague (CZ) Warsaw (PL)

Source: Own elaboration

Table 1: List of reference cities for each of the 12 city prototypes

Although limited in number, the 12 city prototypes used in the simulation are fairly representative of the urban reality of EU27 context. In order to generalize to the European context, the actual number of Small/Medium/Large cities in Northern/Central-Western/Southern/Eastern Europe was taken into consideration.

The total number of EU cities was defined according to Eurostat definition of City: "A city is a local administrative unit (LAU) where the majority of the population lives in an urban center of at least 50,000 inhabitants". Data has been collected making reference to Eurostat and national statistics. In total, 1101[9] European cities have been considered, distributed as follows by prototypes. The full list of these cities, alongside the prototype they belong to, is available in Annex IV.

	Southern Europe	Central/ Western Europe	Northern Europe	Eastern Europe	Total
Small City	232	235	53	119	639
Medium City	126	168	29	78	401
Large City	17	27	5	12	61
Total	375	430	87	209	1101

Source: Own elaboration

Table 2: Number of cities for each of the 12 city prototypes

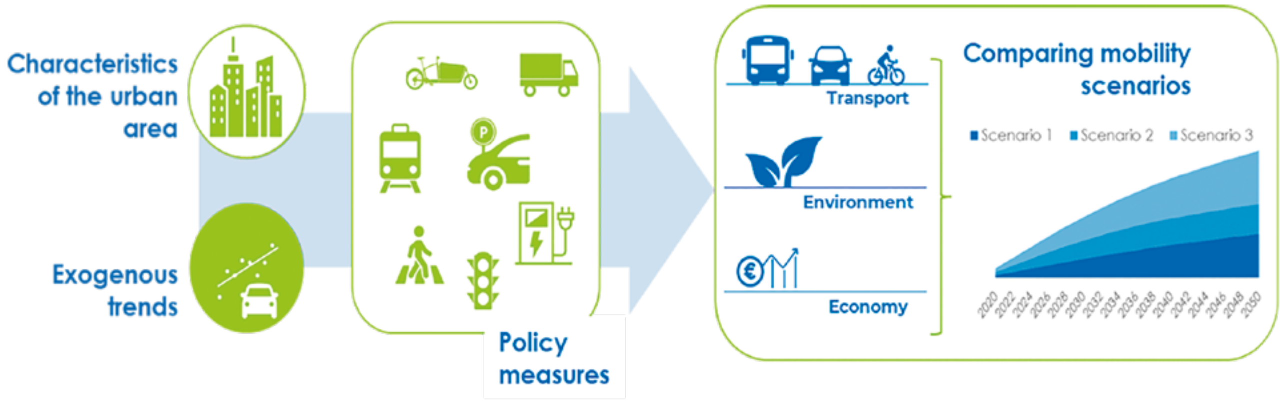
2.2 The MOMOS model

TRT's assessment tool MOMOS (Sustainable Urban MObility MOdel) has been used for the simulation of the potential transition scenarios to evaluate the impact and pathway towards the goal of decarbonisation of urban transport in the selected cities and metropolitan areas (https://www.momos-model.eu).

The model is developed in the MS Excel environment and provides estimations of mobility trends in urban areas quantifying transport, environmental and economic impacts of policy measures from 2022 (base year) until 2030 and 2050.

MOMOS is a strategic and aggregated model, that can be adapted to different city contexts in European countries (EU27, UK, Norway and Switzerland), and allows the user to rapidly identify, develop, screen, and assess different measures and policy scenarios. This tool does not intend to replace sophisticated and detailed transport models but allows the user to compare alternative solutions.

9 With comparison to the 2021 study, which considered 779 cities as per the Eurostat dataset, this update takes into account both Eurostat and national statistics datasets.



Source: TRT

Figure 1: Rationale and features of the MOMOS model

To represent the urban characteristics at the base year as well as exogenous trends that are outside of the scope of urban policies, MOMOS requires a set of input data to reproduce a specific city context. This namely includes socio-demographic aspects as well as mobility features (e.g., public transport infrastructure, innovative transport services, parking, traffic management solutions).

The model is calibrated, against observed data, to reproduce key urban mobility indicators (e.g., GHG emissions, energy consumption, trips by mode, road traffic injuries, etc.) at the base year in the study area.

MOMOS allows to evaluate different urban mobility policy measures, defining their intensity and temporal dimension. Policy measures can be simulated individually or can be used to build policy packages and scenarios combining multiple measures. A wide range of sustainable urban mobility measures of different nature is available in the model and can be adapted to the specific study context. The model also allows it to simulate different scenarios, which are designed independently and can be compared.

To assess the impact of mobility scenarios, the model estimates a set of output indicators, concerning different domains:

- **Transport** (modal split, vehicle fleet evolution, car ownership, etc.)
- **Environment and safety** (air pollutant and GHG emissions, energy consumption, road traffic injuries/deaths, etc.)
- **Economy** (cost and revenues for the city, monetisation of externalities, etc.)

MOMOS is designed to simulate scenarios under different exogenous assumptions related to three domains: technology, energy, policy. Technology mainly refers to innovative vehicle penetration trend and average vehicle fuel consumption by vehicle type. The evolution is inspired to different scenarios, such as the EU Reference scenario 2020 and the EU FitFor55 scenario. Energy trends are mainly related to fuel prices and energy mix for electricity generation. Policy trends include fuel duties and car ownership taxation.

More details on the calculation framework of the MOMOS model and its components are described in Annex I.

2.3 Input Data

To properly represent the characteristics at the base year 2022, as well as the trends in place in each city prototype, the modelling tool requires a comprehensive set of input data. Input data retrace, in the most accurate way possible, the city circumstances, including both socio-demographic aspects, and of course all urban mobility features. The collected input data include:

- **population** (age structure, growth, spatial distribution, etc.),
- **urban mobility features** (motorization rate, modal split, incoming trips, freight share, etc.),
- **transport infrastructure** (bike lanes, e-charging stations, Park & Ride, etc.),
- **public transport** (offer, ticket price, cost, speed, network length, prioritizing systems, etc.),
- **parking** (number of slots, tariff, etc.), sharing mobility (carsharing, bike sharing, moped sharing, micromobility),
- **traffic control and management** (LTZ passenger/freight, LEZ passenger/freight, pedestrian areas, traffic calming areas, etc.),
- and **vehicle fleet composition** (private cars, LDV/HDV, motorbikes, public buses, etc.)

The table in Annex II lists and describes all the data inputs that have been collected for the 36 reference cities and used to define the representative inputs of the 12 city prototypes. The base year refers to 2022.

Data were collected for the 36 cities, although for some inputs it was considered more appropriate to explore more comprehensive and generalised sources to achieve greater representativeness of the prototypes.

2.4 Design of the urban mobility scenarios

Having defined the analytical framework, it has been necessary to identify the policy measures to be used for the design of scenarios within the study.

MOMOS allows to simulate a wide range of sustainable urban mobility measures and to adapt them to the specific study context. The available measures are of different nature and comprehensively cover the range of options that cities currently have available to lead the transition to sustainable urban mobility. Also, they have been modelled considering recent and important European programs and projects such as CIVITAS, ELTIS, EIT Urban Mobility, etc.

Following the agreement with EIT Urban Mobility and the consultation with stakeholders, the following policy measures have been selected, organized into eight policy groups: *Public Transport, Active mobility, New Mobility Services, Access Regulation and Pricing, Urban Logistics, Electrification and alternative fuels, Cooperative Connected and Automated Mobility (CCAM), Transport Avoidance.*

For each measure, the input values are used to reflect the base year characteristics of the study area. Also, measures are assigned a proper **starting year**, to consider the temporal dimension while designing the intervention strategies, as well as a **ramp-up period** (if relevant), to consider the years required for its full implementation. In addition, some of the policy measures have been defined with a **two-step approach** to take account of the long-term horizon of 2050. In this way, the intensity of these measures has been modulated over time to contribute to the overall scenario strategy, considering the most appropriate temporal dimension of implementation. In this sense, each policy has been defined considering a specific rationale and a series of assumptions and target. These are explained in more detail in Annex III.

By differently combining the policy measures, three potential transition scenarios have been built through subsets of policies, whose combination and interaction define the scenario itself:

- **Scenario 1 "Infrastructure and mobility services"** is mostly based on inducing a more sustainable mobility behaviour of citizens through information, incentives to active mobility, enhancement of public transport services and facilities, cycling and pedestrian infrastructures, as well as the promotion of shared mobility services through incentives and regulation. The approach of this scenario is to provide integrated services and infrastructures to help citizens to change their mobility habits, accompanied by the renewal of private (and public) vehicle fleet. Policy measures aiming at discouraging and restricting car use are not included. Shared mobility services are promoted by enhancing their availability and integration with public transport.

- **Scenario 2 "Regulation and demand management"** In the short term, access to the city for private motorised vehicles is limited by Low Emission Zones and Limited Traffic Zones. In the longer term, a cleaner vehicle fleet makes the LEZ less impactful, so in medium and large cities road charging is introduced. In small cities instead, more space is given to sustainable modes and traffic calming, aiming to promote new mobility habits. In addition, pricing schemes, such as parking pricing, are introduced to discourage private motorised modes and push the shift towards sustainable modes. This scenario is complemented by transport avoidance measures to reduce transport demand, such as encouraging employees to work from home and other initiatives to reduce car dependency (*car free days*). It also includes policy measures related to freight urban logistics, with the objective of optimising the distribution and promoting more sustainable last-mile deliveries (cargo-bikes). In light of the implementation of regulations and pricing schemes, the issue of acceptability from citizens is to be considered.
- **Scenario 3 "Zero-emissions"** builds on the policies from previous scenarios and intensifies their reach to achieve the Green Deal targets of -55% of CO_2 emissions reduction by 2030 and -90% by 2050.[10] It is designed to drive substantial changes in urban mobility and significant shifts in the choice of how people move in addition to an enhanced trend of fleet decarbonisation. This is achieved through regulations and behavioural incentives as well as the provision of infrastructures and services. Economic instruments play a key role in this approach, with twofold roles. Firstly, they are used to change the behaviour of citizens by adopting the "user pays" or "polluter pays" principle (for example, road pricing policies are a cornerstone of this scenario). On the other hand, they are used to generate resources to support sustainable mobility by improving public transport, walking, and cycling facilities. The strategy of the scenario is designed considering temporal implementation, as well as the fact that policies are not completely additive to each other and in some cases might even cancel each other out.

Nevertheless, some of the policies are expected to be implemented in all scenarios, given their relevance in current and planned sustainable mobility strategies. Consequently, when they are not part of the main focus of the scenario, their application is introduced with a smooth intensity. Table 3 lists all the measures that contribute to the definition of each scenario.

Also, policy measures are applied and modulated within each scenario according to different implementation patterns and roadmaps, whose ultimate objective is to address the zero emission and sustainable mobility goals.

[10] With respect to 1990 level of GHG emissions.

Table 4, **Table 5**, and **Table 6** summarize the initial year in which each policy is put into effect, as well as the ramp-up years needed to fully implement the measure. Where implemented, the two-steps approach is highlighted as reported in the legend below. Otherwise, once the policy is fully implemented, it is considered to stay in place until the scenario's last year (2050).

Legend

First step	Second step	Colour legend
		Years of policy implementation
		Years of policy full activation
		Years of policy implementation (background level)
		Years of policy full activation (background level)

Table 3: List of policy measures associated to each scenario

Policy Group	Policy Measure	S01	S02	S03
Public Transport	Green public fleet	X	X	X
	Demand-Responsive Transport (DRT)	X		X
	Bus network and facilities *	X		X
	Tram network and facilities **	X		X
	Metro network and facilities	X		X
	Public transport fare		X	X
	Prioritizing public transport	X		X
Active mobility	Cycling networks and facilities	X		X
	Incentives to sustainable modes		X	X
	Pedestrian Areas	X		X
New Mobility Services	Bike sharing	X		X
	Car sharing	X		X
	Ride-hailing	X		X
	Moped sharing	X		X
	e-scooter sharing	X		X
	Legal and regulatory framework of new mobility services	X		X
	Mobility as a Service (MaaS)	X		X
	Multimodal mobility hubs	X		X
Access Regulation and Pricing	Limited Traffic Zones (LTZ)		X	X
	Low Emission Zones (LEZ)		X	X
	Road Charging *		X	X
	Parking pricing		X	X
	Traffic calming zones		X	X
Urban Logistics	Green freight fleet	X		X
	Delivery and servicing plan		X	X
	Cargo bikes	X		X
	Urban Delivery Centres and logistics facilities *		X	X
	Legal and regulatory framework of urban logistics		X	X
Electrification and alternative fuels	Uptake of electric cars	X	X	X
	Phase-out of fossil fuel vehicles	X	X	X
	Electric energy refuelling infrastructure	X		X
	Hydrogen energy refuelling infrastructure	X		X
CCAM	Autonomous bus vehicles (DRT)	X		X
	Shared autonomous car vehicles	X		X
	Cooperative ITS		X	X
Transport Avoidance	Working from home		X	X
	Car-free days		X	X
	Online shopping		X	X

** Not applied in small city prototypes. ** Not applied in small and medium city prototypes*

Table 4: Policy measures implementation overview for Scenario 1 – Public transport and mobility services

Policy Measure	2022	2025	2030	2040	2050
Green public fleet					
Demand-Responsive Transport (DRT)					
Bus network and facilities					
Tram network and facilities *					
Metro network and facilities **					
Public transport fare					
Prioritizing public transport					
Cycling networks and facilities					
Incentives to sustainable modes					
Pedestrian Areas					
Bike sharing					
Car sharing					
Ride-hailing					
Moped sharing					
e-scooter sharing					
Legal and regulatory framework of new mobility services					
Mobility as a Service (MaaS)					
Multimodal mobility hubs					
Limited Traffic Zones (LTZ)					
Low Emission Zones (LEZ) - Passengers					
Low Emission Zones (LEZ) - Freights					
Road Charging *					
Parking pricing					
Traffic calming zones					
Green freight fleet					
Delivery and servicing plan					
Cargo bikes					
Urban Delivery Centres and logistics facilities *					
Legal and regulatory framework of urban logistics					
Uptake of electric cars					
Phase-out of fossil fuel vehicles					
Electric energy refuelling infrastructure					
Hydrogen energy refuelling infrastructure					
Autonomous bus vehicles (DRT)					
Shared autonomous car vehicles					
Cooperative ITS					
Working from home					
Car-free days					
Online shopping					

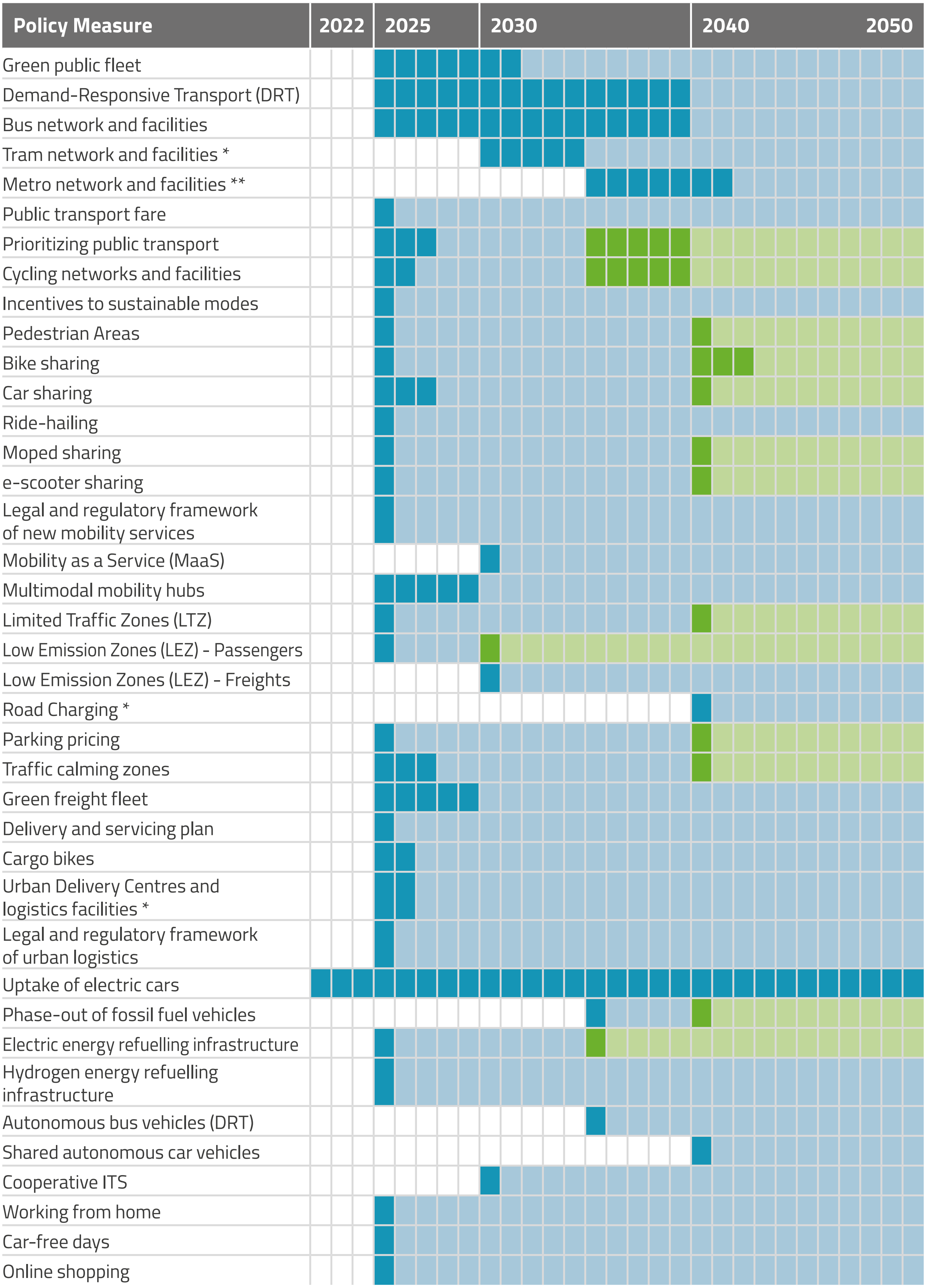
** Not applied in small city prototypes. ** Not applied in small and medium city prototypes*

Table 5: Policy measures implementation overview for Scenario 2 – Regulation and demand management

Policy Measure	2022	2025	2030	2040	2050
Green public fleet					
Demand-Responsive Transport (DRT)					
Bus network and facilities					
Tram network and facilities *					
Metro network and facilities **					
Public transport fare					
Prioritizing public transport					
Cycling networks and facilities					
Incentives to sustainable modes					
Pedestrian Areas					
Bike sharing					
Car sharing					
Ride-hailing					
Moped sharing					
e-scooter sharing					
Legal and regulatory framework of new mobility services					
Mobility as a Service (MaaS)					
Multimodal mobility hubs					
Limited Traffic Zones (LTZ)					
Low Emission Zones (LEZ) - Passengers					
Low Emission Zones (LEZ) - Freights					
Road Charging *					
Parking pricing					
Traffic calming zones					
Green freight fleet					
Delivery and servicing plan					
Cargo bikes					
Urban Delivery Centres and logistics facilities *					
Legal and regulatory framework of urban logistics					
Uptake of electric cars					
Phase-out of fossil fuel vehicles					
Electric energy refuelling infrastructure					
Hydrogen energy refuelling infrastructure					
Autonomous bus vehicles (DRT)					
Shared autonomous car vehicles					
Cooperative ITS					
Working from home					
Car-free days					
Online shopping					

** Not applied in small city prototypes. ** Not applied in small and medium city prototypes*

Table 6: Policy measures implementation overview for Scenario 3 – Zero emissions



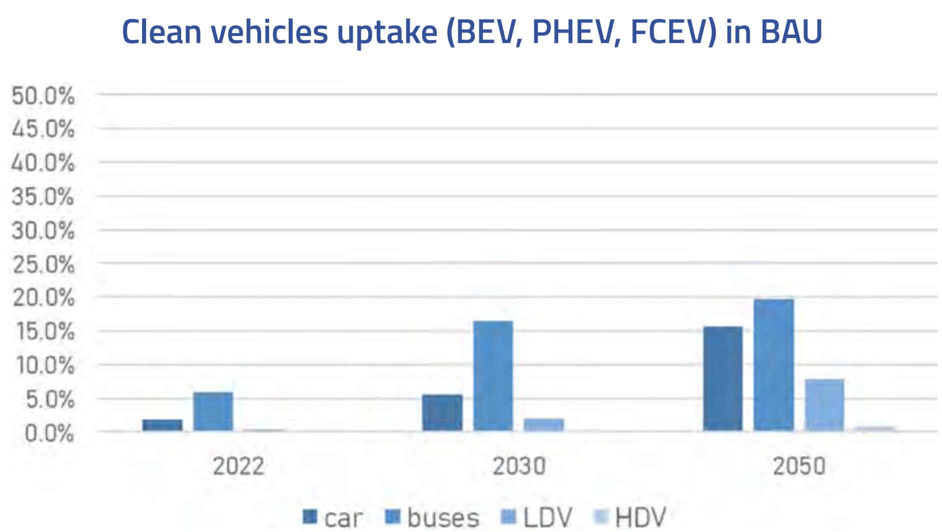
** Not applied in small city prototypes. ** Not applied in small and medium city prototypes*

2.5 Exogenous assumptions

As mentioned in **section 2.2**, MOMOS is designed to simulate scenarios under different **exogenous assumptions** which are not influenced, or only partially, by policies at the urban level. Assumptions related to **technology** concern the evolution of vehicle fleet composition driving the uptake of new vehicle engine and the improvement of their efficiency over time.

For the assessment of the impacts in monetary terms, the scenarios' results have been compared with the **Business-As-Usual (BAU)** scenario. The assumptions of the BAU scenario are rather conservative, assuming that fleet renewal and innovative vehicle uptake is slowly evolving with respect to the current situation. An improvement of vehicle efficiency is expected (about -1.3%/year for cars and vans and -0.7%/year for HDVs, considering both new and existing vehicles). Within the BAU, no policy measures are applied.

The choice to compare the modelled scenarios with the BAU scenario is explained by the aim to assess the whole additional effort needed for the transition, also including national/EU policies even if they are not necessarily under the responsibility of local authorities. The figure below provides the share of innovative vehicles (PHEV, BEV and FCEV) in the total stock, at base year 2022 and in 2030 and 2050 in EU27 in the BAU scenario.



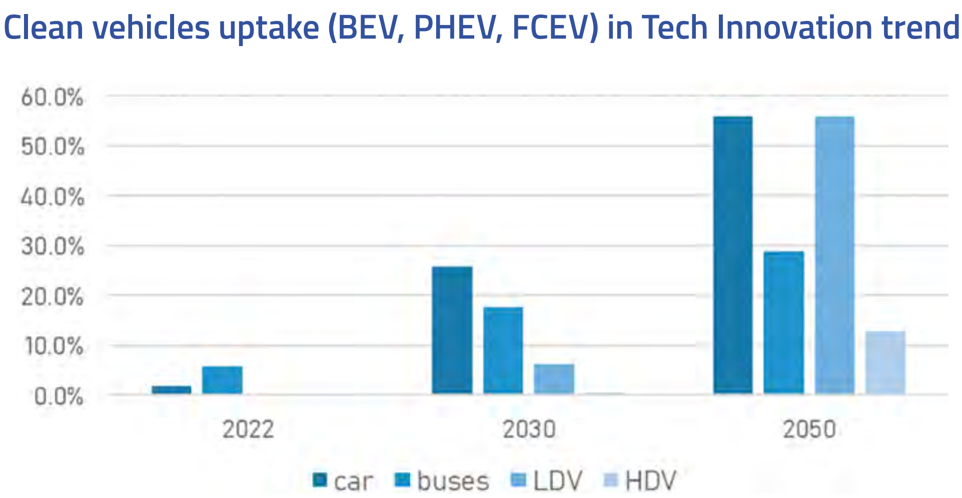
Source: MOMOS Model

Figure 2: Clean vehicles uptake (PHEV, BEV and FCEV) in total stock in BAU scenario, exogenous trend

The transition scenarios simulated in this study build on the assumptions related to the vehicle fleet composition with an **increasing penetration** of new vehicle technologies. The evolution of vehicle fleet composition is based on the assumptions of the **EU Reference Scenario 2020.**[11] These assumptions on the composition of the fleet are the same basis for all three transition scenarios, mentioned in the analysis as **'Technological innovation scenario'**.

11 https://ec.europa.eu/energy/data-analysis/energy-modelling/eu-reference-scenario-2020_en

Figure 3 shows the share of innovative vehicles (PHEV, BEV and FCEV), at base year and in 2030 and 2050 in EU27 in the Technological innovation scenario, building on the EU reference scenario 2020.



Source: MOMOS Model

Figure 3: Clean vehicles uptake (PHEV, BEV and FCEV) in total stock in Technological innovation scenario, exogenous trend

On top of this exogenous trend, the model considers the impact of the simulated policies toward the objectives of **FitFor55 package**,[12] aligned also with the implementation of the regulation on CO_2 emission standards for Light Duty Vehicles (LDVs) and heavy-duty vehicles (HDVs), resulting in more fuel-efficient vehicles being introduced into the market. Furthermore, when simulating the scenarios, it is assumed that a significant reduction of the internal combustion engine vehicles takes place in the long-term, by replacing them with hybrid and zero-emission vehicles (decarbonisation).

On the **energy** side, assumptions related to the fuel prices follow the EU Reference Scenario trend, applied to base year 2022 values related to the geographical areas (Northern, Central, Southern, and Eastern Europe). The same trend is assumed also in the BAU scenario.

The model also allows to consider the uptake of **biofuels** and **e-fuels** in the medium to long term with exogenous assumptions. In this respect, the BAU scenario assumes that by 2050 about half of the petrol and diesel cars on the road will be running on biofuels. The technological innovation trend, on the other hand, assumes that both e-fuels and biofuels will be widely used by 2050, replacing more than 90% of conventional fuels.

Concerning **electricity** price and recharging of private electric vehicles, it is assumed that the share of recharging at home is about 85%,[13] while at charging point the price is about triple with respect to household price.[14] The assumption is the same in all scenarios and kept constant over time.

[12] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en

[13] TRT assumption. Elaboration on https://www.sciencedirect.com/science/article/pii/S1364032121010066

[14] https://alternative-fuels-observatory.ec.europa.eu/consumer-portal/electric-vehicle-recharging-prices

3 Results of the Study

3.1 Quantification of costs and benefits of the sustainable urban mobility transition

This chapter presents the results of the simulations through a set of indicators that quantify the costs and benefits of the sustainable urban mobility transition in European cities by the years 2030 and 2050. The results of the three potential scenarios are estimated separately for the 12 city prototypes, which synthesise the differences of European cities in terms of geography (Southern, Central/Western, Northern, and Eastern Europe) and dimension (Small, Medium, and Large cities). Then, considering the number of actual cities that fall into each prototype category (e.g., Small Southern, Large Central/Western, Medium Eastern, etc.), results are generalized for the entire EU27 context.

Importantly, in quantifying the costs and benefits of the sustainable urban mobility transition, the study considers the cost of externalities.[15] These costs are estimated taking into account CO_2 emissions (tank-to-wheel), air pollutant emissions (considering NOx, VOC, CO and PM2.5), noise and accidents (fatalities and injured people). The applied monetary values are those adopted by the European Commission (EC)'s *Handbook on external costs of transport* of 2019 (Sustainable Transport Infrastructure Charging and Internalisation of Transport Externalities), as reported in Table 7. For climate change costs (CO_2) the EU Economic Appraisal Vademecum 2021-2027 has been used, taking into account the different values increasing over time (up to 829 €/ton in 2050). The values of externalities are adjusted in Euro 2021 (applying deflator where needed).

To compare the three scenarios, all the costs considered, including the externalities, have been discounted at a yearly discount rate of 3% for all EU geographical areas, as recommended by the EU Economic Appraisal Vademecum 2021-2027.

Whereas the following section focus on the key outputs for the EU27 context, the whole set of output indicators for each city prototype is available in the study full results doc (https://www.eiturbanmobility.eu/wp-content/uploads/2024/09/2024_EIT_Costs-and-benefits-study_Full-results.pdf).

[15] The value of time savings, which is often included in transport projects' cost-benefit analysis, has not been included among the economic results of this study. Indeed, the current nature of the MOMOS model does not allow an accurate estimate of such savings.

			Marginal costs			
			Southern Europe	Central Europe	Northern Europe	Eastern Europe
GHG	CO_2	[€/ton]	83 €/ton in 2022, 259 €/ton in 2030, 829 €/ton in 2050			
Air Pollutants	$PM_{2.5}$ (cities < 500,000 inhab.)	[€/ton]	208,231	389,872	460,490	264,979
	$PM_{2.5}$ (non-exhaust emissions)	[€/ton]	97,770	173,871	148,144	97,151
	$PM_{2.5}$ (cities > 500,000 inhab.)	[€/ton]	26,612	21,117	14,063	15,678
	CO	[€/ton]	10	10	10	10
	NOx	[€/ton]	12,043	38,814	12,587	16,714
	VOC	[€/ton]	699	3,142	1,114	622
Accidents	Fatalities	[€/person]	2,584,106	4,109,907	4,045,181	2,667,926
	Serious injuries	[€/person]	395,812	636,433	623,716	377,785
Noise	Motorbike	[€/pkm]	0.102			
	Car	[€/pkm]	0.009			
	Bus	[€/vkm]	0.113			
	Tram	[€/vkm]	0.107			
	Metro	[€/vkm]	0.107			
	Car sharing	[€/pkm]	0.009			
	HDV	[€/tkm]	0.104			
	LDV	[€/tkm]	0.021			

Sources: EU Economic Appraisal Vademecum 2021-2027, EC's Handbook on external costs of transport of 2019

Table 7: Monetary values for externalities (in Euro 2021)

3.2 Results overview for the EU27 context

This chapter focuses on the generalization of the prototypes results for the entire EU27 context. As already explained, this generalization is obtained by combining altogether the results of the 12 city prototypes and considering the number of EU27 cities that fall into each prototype category. The results are reported with the values of the indicators for **the three policy scenarios** (S01 – Infrastructure and mobility services, S02 – Regulation and demand management and S03 – Zero emissions) for the year **2030 and 2050**, in comparison with the base year 2022.

Transport behaviour and passenger activity

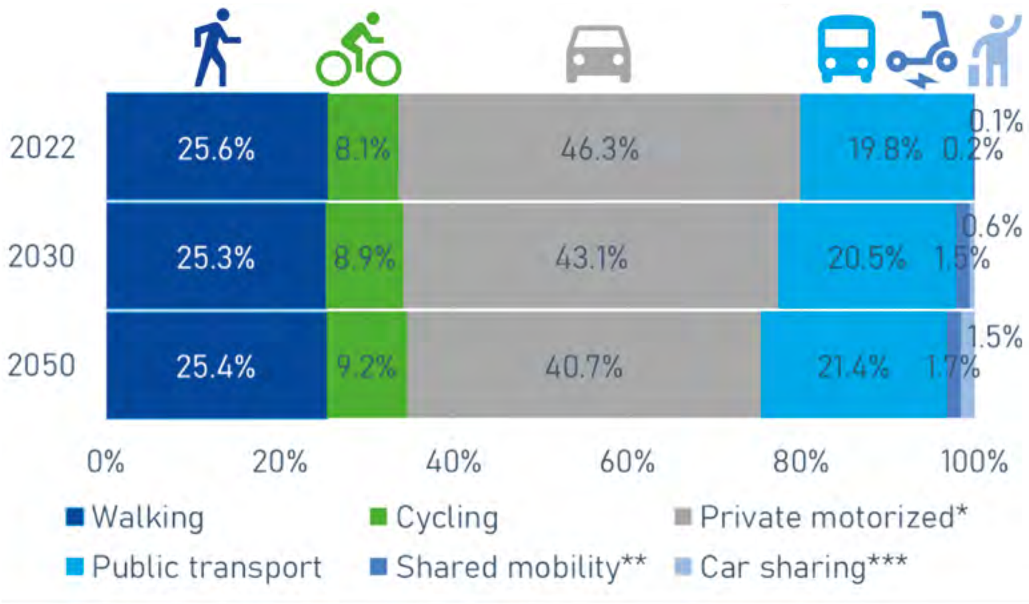
The design and implementation of the policy scenarios aim to shape new sustainable mobility habits in urban areas to improve quality of life while contributing to achieve decarbonisation targets. On the passenger side, one of the most important indicators to analyse transport choice and mobility patterns is **modal split**, computed in MOMOS both on trips and passenger-km. In the following charts, results are presented with transport modes aggregated into six categories: **Pedestrian**, **Bike**, **Private Motorized** (private cars, both as driver or passenger, and motorbikes), **Public Transport** (metro, tram, buses, and DRT, when implemented), **Shared mobility** (shared bikes, e-scooters, and mopeds) and **Car sharing** (car sharing, ride hailing and taxi).

The following Figure 4, Figure 5, and Figure 6 presents the impacts on modal split (estimated on trips of residents of the study area) simulated in the three scenarios.

Aiming to reduce car dependency, it can be noticed that **private motorized** modal share decreases in all three scenarios with respect to the base year 2022, but with an important differentiation: while S01 shows a moderate reduction of -3% in 2030 and -6% in 2050, higher reductions are estimated in both S02 and S03 (up to -16% in S03). In fact, in S01 a mix of new or improved transport infrastructures and mobility services is provided, making public transport, sharing mobility and active modes more attractive. However, these policy measures are not sufficient on their own to bring about major changes in mobility habits, and private motorized modes keep their predominant role in urban mobility. Instead, in S02 and S03, the reduction of car dependency is mainly driven by access regulation and pricing measures, raising some acceptability issues but effectively inducing a more consistent mode shift toward alternative and more sustainable modes. In the short term, the implementation of a Low Emission Zone (LEZ), which restricts access to cleaner vehicles, is one of the main drivers of this change, encouraging car users to shift to an alternative mode of transport, to replace their vehicle with a less polluting one or to even forgo the trip altogether.

In both scenarios, travelling by private cars is also made more time-consuming due to traffic regulations (e.g., traffic calming) and more expensive due to parking pricing. In the long-term, in medium-large cities road charging is implemented to complement the strategy discouraging the use of private motorised vehicles. Nevertheless, there is a slight increase in the mode share of private cars by 2050. The reason for this is that the vehicle fleet evolves over time due to other policies and technological development, which makes the effect of the LEZ less relevant and results in more private cars being on the road.

Scenario S01: Infrastructure and mobility services



*includes cars (as both driver and passenger) and motorbikes
**includes shared bikes, e-scooters, and e-mopeds
***includes car sharing, ride hailing and taxi

Figure 4: Modal split (number of trips) change in EU27 context for Scenario S01

Based on the focus of each scenario and the policy measures applied, the use of modes alternative to private cars evolves differently. **Scenario S01**, providing improved sharing mobility services, an enhancement of public transport service and infrastructure, as well as improved cycling facilities, shows a moderate increase in all alternative transport modes with respect to the base year: about 1% in cycling, 1.5% in public transport, car sharing and shared mobility by 2050. Walking remains almost constant.

Scenarios **S02 and S03**, as mentioned above, show a larger reduction in private motorized modes already in the short-term. In S02, the reduction of private motorised transport is accompanied by the increase of cycling (from 8.1% in 2022 to 11.6% in 2030 and 12.1% in 2050) and public transport (from 19.8% to 24.1% in 2030 and 22% in 2050). In the longer term, a slight increase in traveling by active modes (pedestrian and bikes) as well as by private cars results in a small reduction in the share of trips made by collective modes.

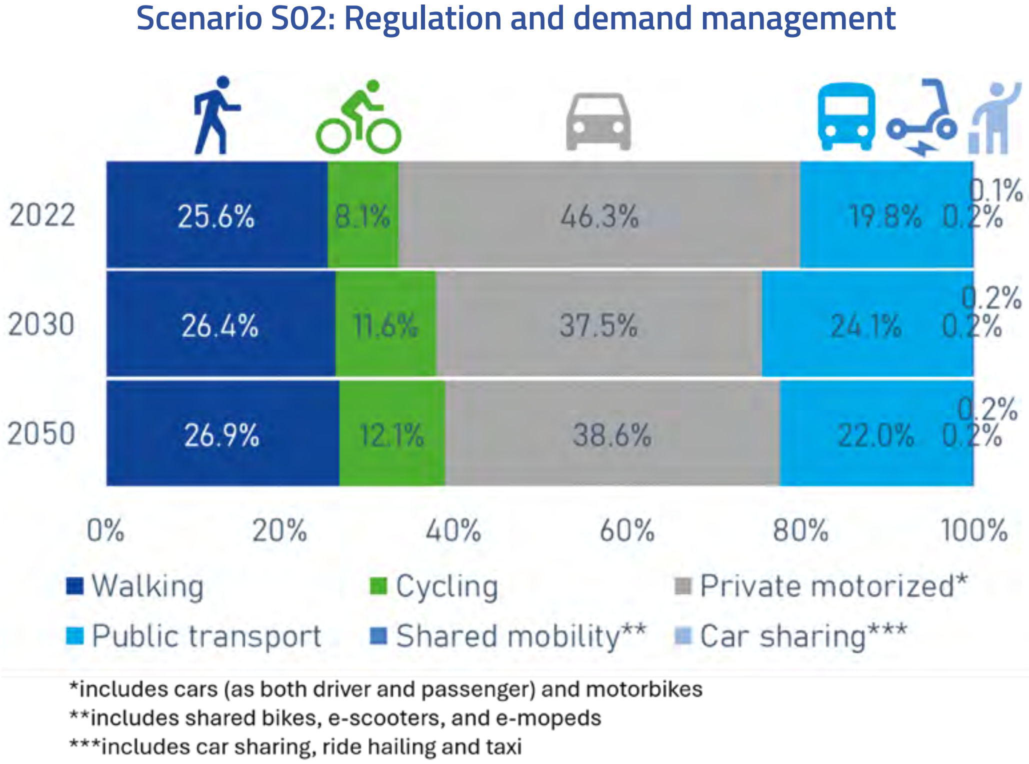


Figure 5: Modal split (number of trips) change in EU27 context for Scenario 2

Looking at the modal split in **S03** a very high reduction in the use of the private cars is observed already in 2030, with a shift towards all the other modes. These trips shift mostly to public transport (+7% in 2030 and + 5% in 2050) but also to walking and cycling (respectively +1-2% and +4-5%), sharing mobility (+2%) and car sharing (+1%). Again, in the longer term the “clean” evolution of cars’ fleet makes the effects of some policies less relevant (e.g., the LEZ) and therefore a slight increase of private vehicles is shown.

In this scenario, all policy measures are implemented and therefore the overall strategy allows, on the one hand, to discourage the use of private motorized vehicles, and, on the other hand, to provide improved mobility services and better sustainable alternatives for travelling in urban areas.

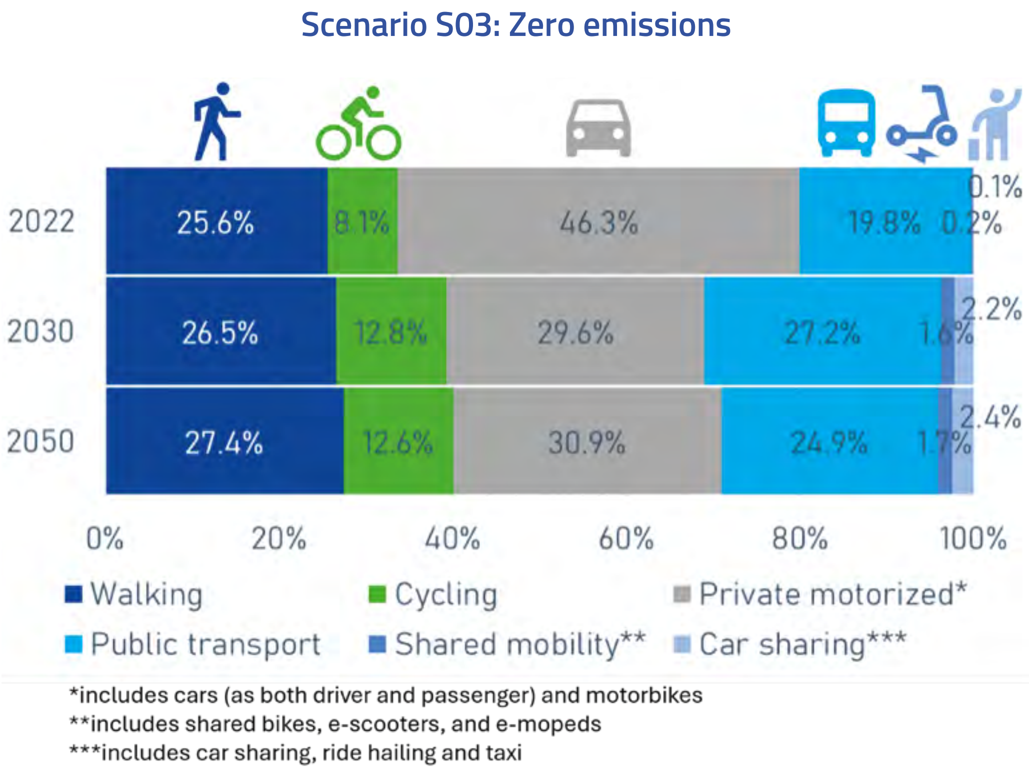


Figure 6: Modal split (number of trips) change in EU27 context for Scenario 3

As mentioned above, reducing car dependency in urban areas can improve the liveability of cities and provides many (co-)benefits. These include reduced GHG emissions, to achieve decarbonisation targets, but also lower levels of air and noise pollution, less congestion and road fatalities. However, it is worth to mention that the modal shift simulated in the model and the potential reduction in average distances call into question the only partially free choice of destinations. Someone who now drives 20 km to work cannot freely choose to cycle 5 km to work, because work does not change location, and if it does, it is more likely to move away (or away from housing, displaced by gentrification). In short, what in the model are variations in certain parameters, in real-life would be revolutions not only in behaviour, but also in income distribution and urban planning.[16]

Similar trends in terms of mode split are observed in the city prototypes. As expected, depending on the situation at the base year some differences are observed. Furthermore, the strategy of scenarios has been designed taking into account city size and selecting the appropriate policy measures. As an example, in medium and large cities the road charging scheme is introduced in the long term. Instead, in small city prototypes, it doesn't seem appropriate to introduce this kind of scheme in some parts of the city and it has been decided to replace it with a more stringent

[16] This concept has been addressed from different points of view in literature, a few examples include: https://www.sciencedirect.com/science/article/pii/S0967070X21003693, https://metropolitics.org/Gentrification-or-ghetto-making-sense-of-an-intellectual-impasse.html

parking pricing policy and focus more on enlarging pedestrian areas. As a result, both cycling and pedestrian trips are incentivised, in a context where travel distances are short and the capillarity and frequency of public transport might not be as developed as in medium and large cities.

As shown in **Figure 7**, the **car ownership** trend and modal split of motorised transport are interconnected. Nevertheless, the scenarios generate moderate reductions in the number of cars owned over the years. In fact, at least in the short term, even if users could change their daily mobility habits, the models shows that a smaller proportion is willing to give up the private car. Indeed, a car may continue to be a necessity for certain types of trips (e.g. long trips, where no alternative can offer the same level of flexibility as the private car). Compared to 2022, in S01 car ownership decreases by less than 3% by 2050, whereas the reduction in the private cars per inhabitants by 2050 is higher in S02 (-7%) and especially S03 (-14.5%), where all the policy measures are applied.

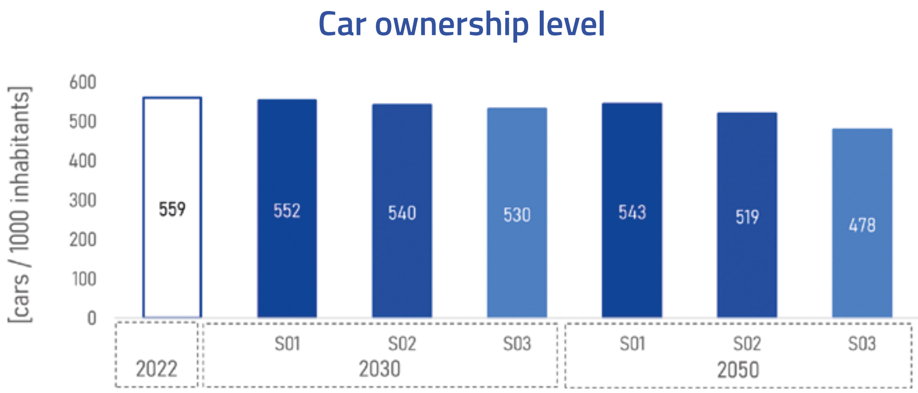


Figure 7: Car ownership level in EU27 context

Freight transport activity

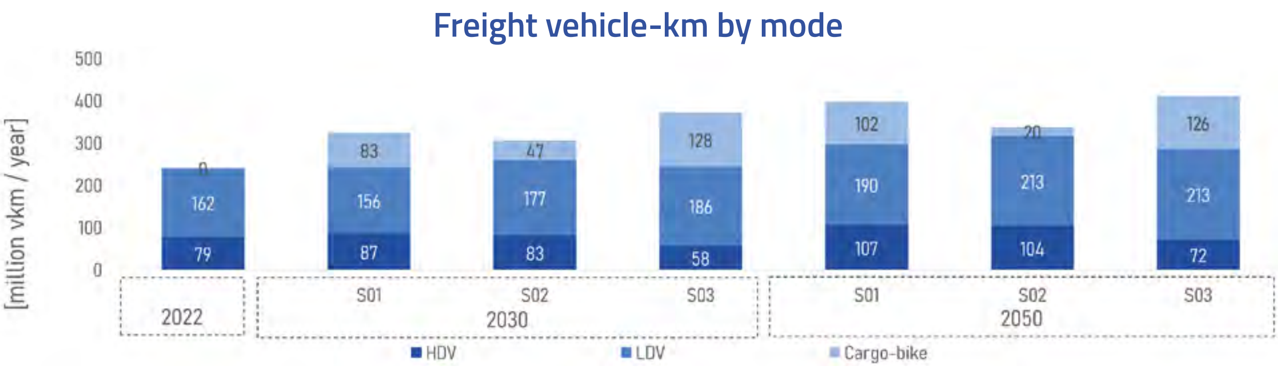


Figure 8: Freight transport activity by mode in EU27 context

Freight vehicles are segmented by **LDV** (Light Duty Vehicles), **HDV** (Heavy Duty Vehicles) and **cargo-bikes**. Although great efforts have been made in recent years to optimise the delivery system, LDV and HVD traffic in the urban context causes congestion and pollution.

On one hand, the vehicle technology is improved, and the efficiency is increased with policy measures such as the *Urban Delivery Systems*. On the other hand, the last-mile logistics need a mode shift towards the cargo-bikes. With this kind of vehicles, it is possible to deliver freights also in area banned from cars. Moreover, these deliveries are zero-emission, and in some cases are more optimized than the same made with an LDV.

Despite having a dedicated policy in place to incentivize the uptake of cargo-bikes, their number is even more increased – in the short-term – through the introduction of the Low Emission Zone for freight vehicles, in S02 and S03. In fact, when the polluting vehicle fleet is banned from the city, deliveries can be made either changing vehicle technology or changing vehicle type and moving to cargo-bikes.

The first solution (changing vehicle technology) leads to an investment in new HDV and LDV with cleaner engines. This is accompanied by an optimization of the load factor to keep delivery costs as low as possible. The second solution leads to a stronger shift towards cargo-bikes, instead of LDVs, for the urban segment of the delivery.

In 2050, when the overall vehicle fleet is cleaner, the deliveries with LDV rise again, lowering the number of cargo-bikes compared to the short-term when a strong LEZ scheme is applied. Eventually, the LDV/cargo-bike usage in the long term could be balanced with more restrictive regulations (e.g. road charging schemes).

While across the city prototypes the same pattern can be observed, there is a small difference between S01 and the other two scenarios. In fact, by providing services, infrastructures and specific targets for cargo-bikes, S01 achieve an increase in cargo-bikes both in 2030 and in 2050. Instead, in S02 and S03 the increase in cargo-bikes is also largely driven by policy constraints in using LDV and HDV vehicles, becoming less effective as soon as the vehicle fleet is cleaner in the long term.

Fleet evolution and decarbonization

In MOMOS, the evolution and renewal (both in terms of efficiency and type of engine) of vehicle fleet is simulated. In particular, the model considers the fleet of private cars, LDV, HDV, public buses, and motorbikes.

The model considers a base renewal trend to simulate the Business-As-Usual scenario, in which, also without the application of policy measures, citizens continue to change their vehicles/ technology, also considering various factors like national and EU subsidies, evolution of technology or the implementation of specific rules.

In the three policy scenarios, the uptake of "clean" **private cars** follows a very similar trend, boosted by different policy measures applied in each scenario. In particular, the Plug-In Hybrid Electric Vehicles (PHEVs) show a peak in 2030, when the technology for Battery Electric Vehicles (BEVs) still keeps improving. By 2050, it is foreseen that almost the totality of the vehicle stock becomes clean (94% in S01, 96% in S02 and 99% in S03), with the larger part made by BEVs.

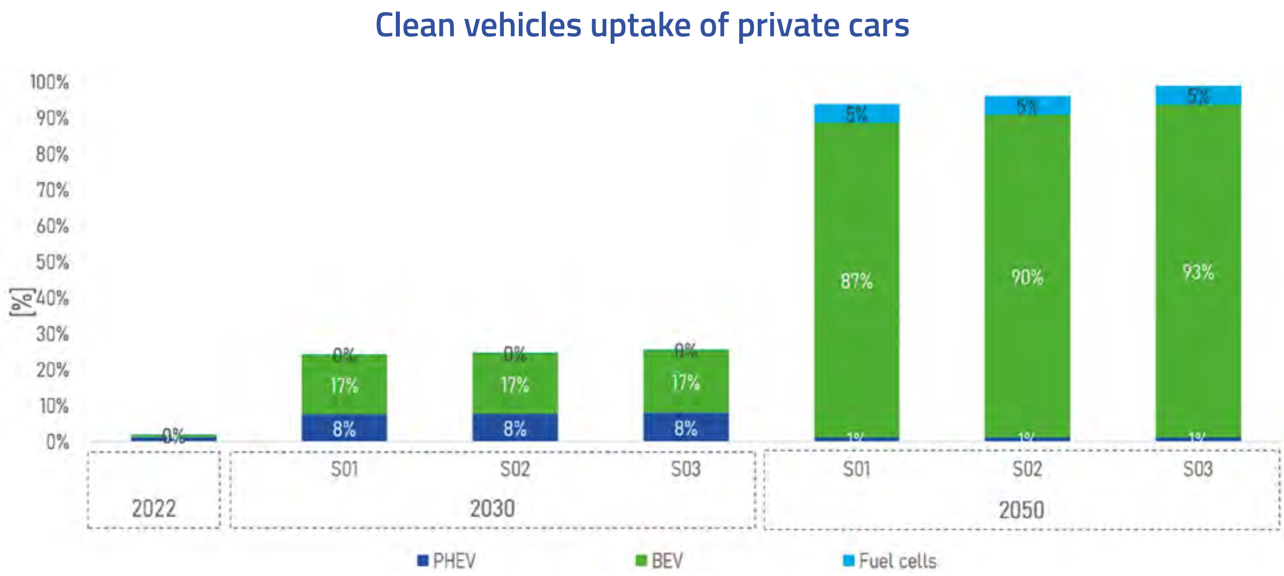


Figure 9: Clean vehicles uptake of private cars in EU27 context

A faster growth trend is expected for **public buses**, with about 95% of BEV and 3% of PHEV in 2030, and the whole stock of buses composed by BEV in 2030.

The nature of the public transport service, with fixed urban routes and the possibility to recharge in bus depots, as well as the incentivization of cities to "green" their bus fleets make the shift towards electric vehicles easier than the private cars', where a strong and capillary energy refuelling infrastructure is needed in order to boost their BEV stock.

In Figure 10 and Figure 11 clean vehicles uptake of LDV and HDV are also shown. While the LDV stock follows a similar trend to the cars' one, for HDV the pattern is different. First, the cost of a single HDV vehicle is much higher than the one associated with a private car or an LDV. So, the renewal of its vehicle stock is slower. Moreover, the model simulates that the technology uptake is less developed for HDVs, so only 21% to 23% of BEV HDVs is foreseen in 2050, accompanied by a similar portion of Fuel cell vehicles and about 11-12% of LNG vehicles. The result builds on the trend of EU reference scenario 2020, with the assumption of CO_2 emission standards for heavy-duty vehicles becoming effective later than for private cars and Light Duty vehicles.

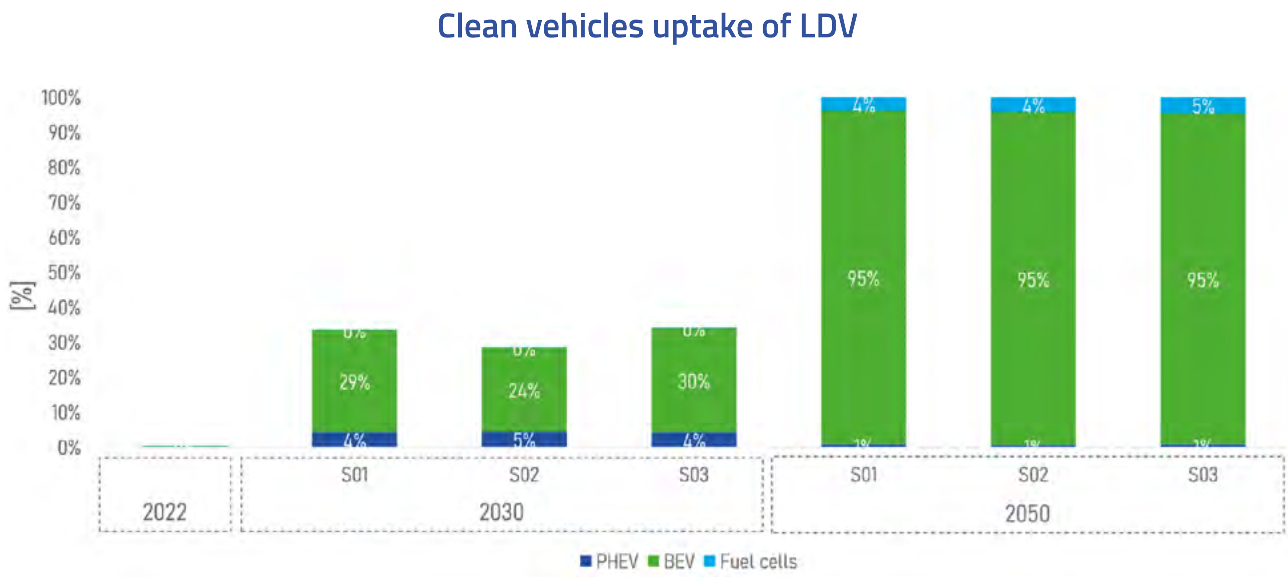


Figure 10: Clean vehicle uptake of LDVs in EU27 context

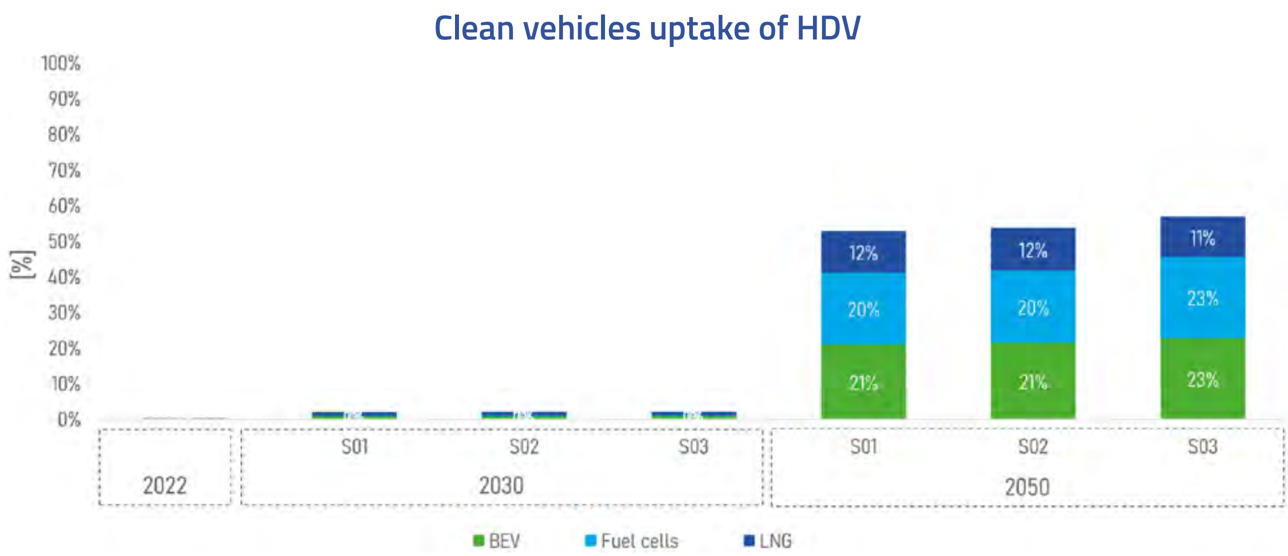


Figure 11: Clean vehicles uptake of HDV in EU27 context

Air pollutant emissions from transport

Together with the GHG emissions, also other air pollutants are modelled in the three policy scenarios, namely PM2.5, NOx, VOC and CO. In Figure 12, it is possible to see the consistent reduction of PM2.5 by 2030 and by 2050. NOx, VOC and CO show an even higher reduction in 2050, mainly due to the vehicle technology improvement of LDVs and HDVs.

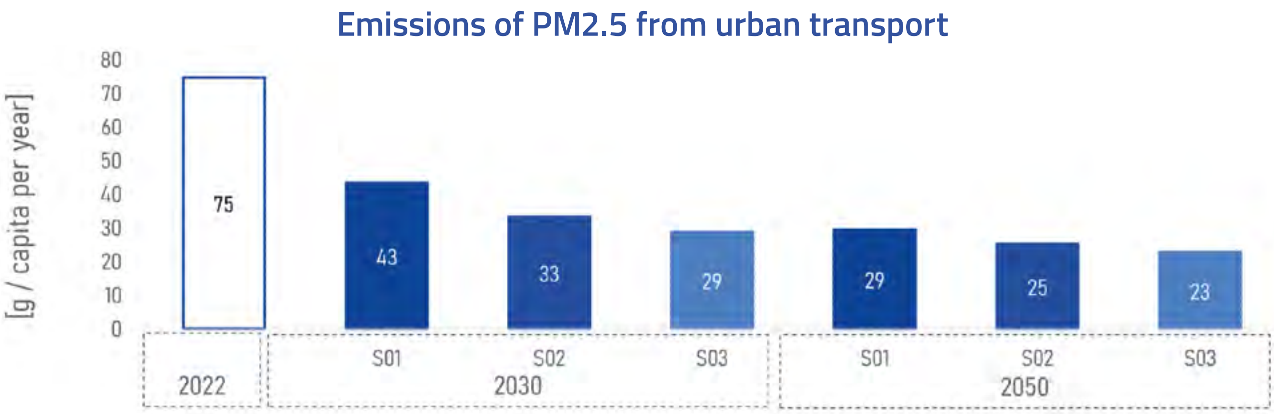
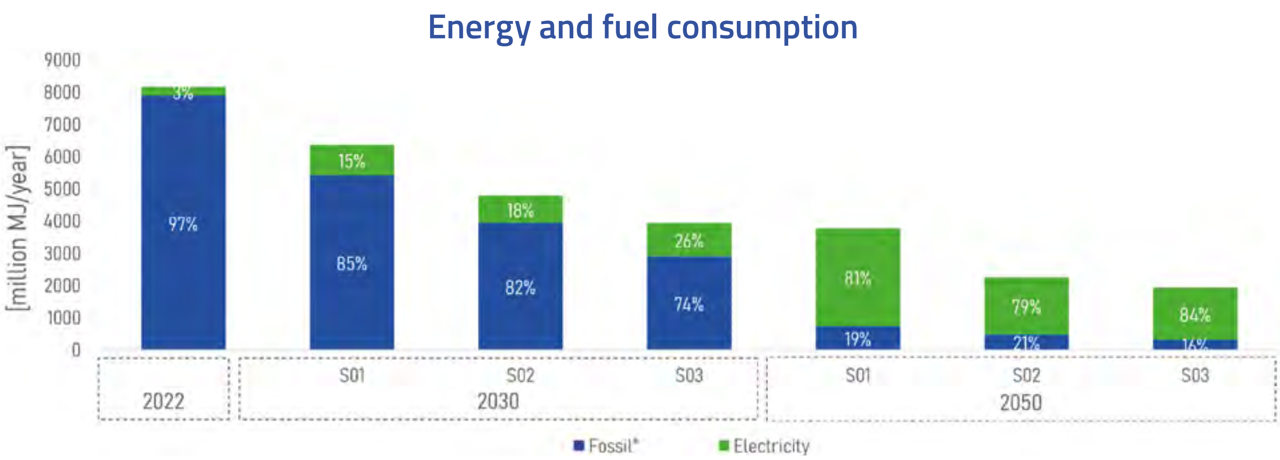


Figure 12: Emissions of pM2.5 from urban transport

This result can also be explained by the energy and fuel consumption evolution in urban areas, as shown in the following figure. While at base year fossil fuels accounts for 97% of the energy consumed, in 2030 the share of fossil fuels starts decreasing, whereas electricity rises. In 2050, fossil fuels are used only for one fifth of the total energy consumed. Also, the total energy consumed is much lower than in the base year (-76% from base year in S03).



*Including synthetic and biofuels

Figure 13: Energy and fuel consumption in EU27 context

It is important to note that the Energy and fuel consumption indicator considers both fossil fuels and electricity. On the other hand, the results associated with the GHG emissions only consider the tank-to-wheel segment, and therefore the emissions related to electricity are excluded.

Indeed, electricity' GHG emissions mainly depend on national and international development of the electric energy production, which is not strictly related to or influenced by the urban context.

Greenhouse Gases Emissions from transport

The core objective of this study is to simulate pathways to achieve the Green Deal transport CO_2 emission reduction targets in urban mobility.[17] As greenhouse gas emissions in the transport sector have been growing by around 19.5% between 1990 and 2022, the objective is to reduce the amount of CO_2 by -62.3% in 2030 and by -91.6% in 2050 if the comparison is made with the simulation's base year (2022).

The study focuses on GHG tank-to-wheel emissions (i.e., only the emissions related to the burning and usage of a fuel in a vehicle) from all transport modes, considering trips within the urban area of residents, incoming city users and freight transport. The main indicator is reported in the following **Figure 14** in terms of per capita GHG emissions, as ratio with the inhabitants of the urban area.

The figure highlights the respective contribution of both the technology innovation trend and the scenarios in 2030 and 2050. It can be observed that a reduction of about 21% is achieved by the technology innovation trend (described in **chapter 2.5**). This accounts for a reduction of yearly emissions (compared with 2022) thanks to both vehicle fleet renewal and vehicle efficiency improvements. The policy scenarios are responsible for the remaining reductions, playing a significant role in the short term and contributing to the achievement of the target in the long term.

By 2050, all three policy scenarios are able to gradually reach and go beyond the Green Deal target. However, their pathway toward the goal is not the same and only Scenario 03 allows to achieve the objective also by 2030. This is explained by the application of a comprehensive mix of policy measures, intensified where needed and resulting in substantial change in the modal split. In S03 the combination of policies and the related timing is designed to discourage car dependency already in the short term (through policy measures related to access restrictions and pricing, then modulated over time) combined with the improvement of public transport services, sharing mobility and the implementation of measures incentivising active modes. The different roadmap of the scenarios is further underlined when looking at the **cumulated per capita GHG emissions** from 2022 to 2050: scenario S01 and S02 account respectively for 8.8 tons CO_2/capita and 7.0 tons CO_2/capita, whereas in S03 it is 5.8 tons CO_2/capita.

[17] -55% and -90% greenhouse gas reduction in the transport sector by 2030 and 2050, compared to 1990's levels.

By 2030, Scenario 02 gets quite close to the target (0.33 tons CO_2/capita), thanks to the consistent change in mode split driven by access restrictions and pricing measures, whereas in Scenario 01 yearly GHG emissions per capita are reduced by about 35% from 2022 (0.44 tons CO_2/capita). By 2050, the three scenarios attain CO_2 emissions reductions ranging from about -95% to -98% (compared to 2022 levels).

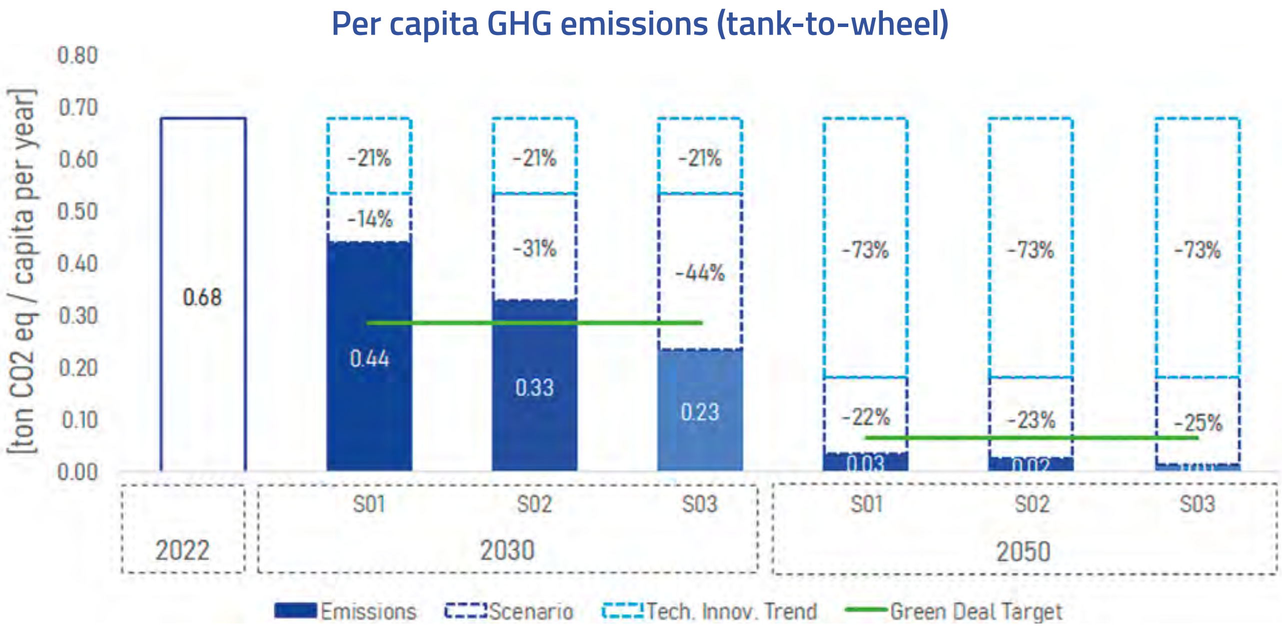


Figure 14: GHG emissions per capita in EU27 context

All these results include both passengers and freight mobility. At the base year 2022, passengers' mobility accounts for about 81% of GHG emissions. By 2030, thanks to the focus of the policies and the improvement in vehicle fleet assuming larger uptake on the passenger side, the contribution related to passenger ranges from 67% in S03 to 77% in S01. In the long term, by 2050 only about 8% of the remaining emissions are related to passengers' mobility in S03, 13% in S02 and 34% in S01. This is largely due to the clean vehicle uptake of car and buses, becoming more than 90% of the fleet.

Considering the 12 prototypes (https://www.eiturbanmobility.eu/wp-content/uploads/2024/09/2024_EIT_Costs-and-benefits-study_Full-results.pdf) the results show similar trends, with all three policy scenarios reaching the Green Deal target in 2050, and Scenario S03 doing it also in 2030.

The lowest values of CO_2 per capita is estimated in small cities in northern and southern Europe in S03, where in 2050 each citizen will be responsible for the emission of as low as 0,006 t per year of greenhouse gases. Overall, the lowest cumulated CO_2 emissions per capita is estimated in small cities in Northern Europe, with about 2.5 t per capita over the period 2022-2050.

Road safety

According to the Sustainable and Smart Mobility Strategy,[18] road traffic deaths should eventually tend towards zero by 2050, although the recent trends and situation at the base year 2022 show stalling progress in reducing road fatalities in many European countries.

In all scenarios, road traffic deaths are reduced over time as a combined effect of policies aiming to increase safety and an overall reduction of road motorised traffic. Two main components are influencing this trend. On the one hand, the reduction in road traffic (private cars and trucks) reduces the number of road deaths as more people switch to safer modes of transport such as buses and metros. In addition, the construction of dedicated infrastructure (cycle lanes or pedestrian areas) and the implementation of traffic calming measures can improve the safety of pedestrians and cyclists. However, on the other hand, cyclists are the most vulnerable road users with the highest fatality rate. Therefore, the expected reduction in road deaths is limited by the fact that more people are using bicycles as a means of transport and the infrastructure is generally safer.

In S02, traffic calming, pedestrian areas and cooperative ITS are the drivers of improved road safety, benefiting also from a reduction of road traffic and achieving a reduction of -68% in 2050. In S01 instead, the implementation of cycling network is providing safer paths, therefore reducing the fatality rates for cyclists and enhancing the use of bikes (obtaining a reduction of about -41% at 2050). In S03 all the policies above are implemented, resulting in further slight decrease of road traffic deaths (-70% in 2050 with respect to 2022).

The trend of road traffic injuries (available in https://www.eiturbanmobility.eu/wp-content/uploads/2024/09/2024_EIT_Costs-and-benefits-study_Full-results.pdfc) shows similar decrease in the scenarios.

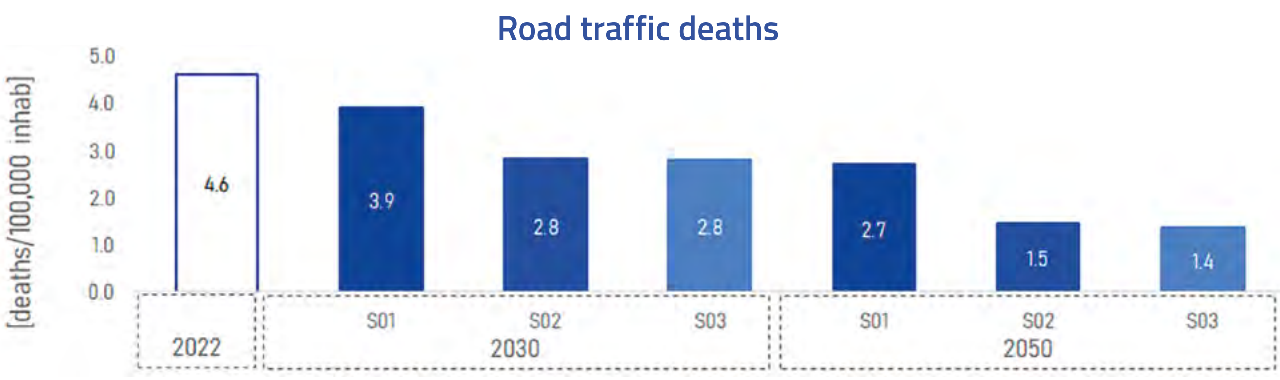


Figure 15: Road traffic deaths per 100,000 inhabitants in EU27 context

[18] https://eur-lex.europa.eu/resource.html?uri=cellar:5e601657-3b06-11eb-b27b-01aa75ed71a1.0001.02/DOC_1&format=PDF

The previous chart reports results on total road traffic deaths in relation to the population size. However, the total amount of road traffic deaths also reflects the shift toward more vulnerable modes (especially cycling) related to the increase in the number of kilometres travelled. Therefore, to complement the analysis, the fatality rate (as ratio between road traffic deaths and kilometres travelled) is reported below for all modes (as average) and for cycling.

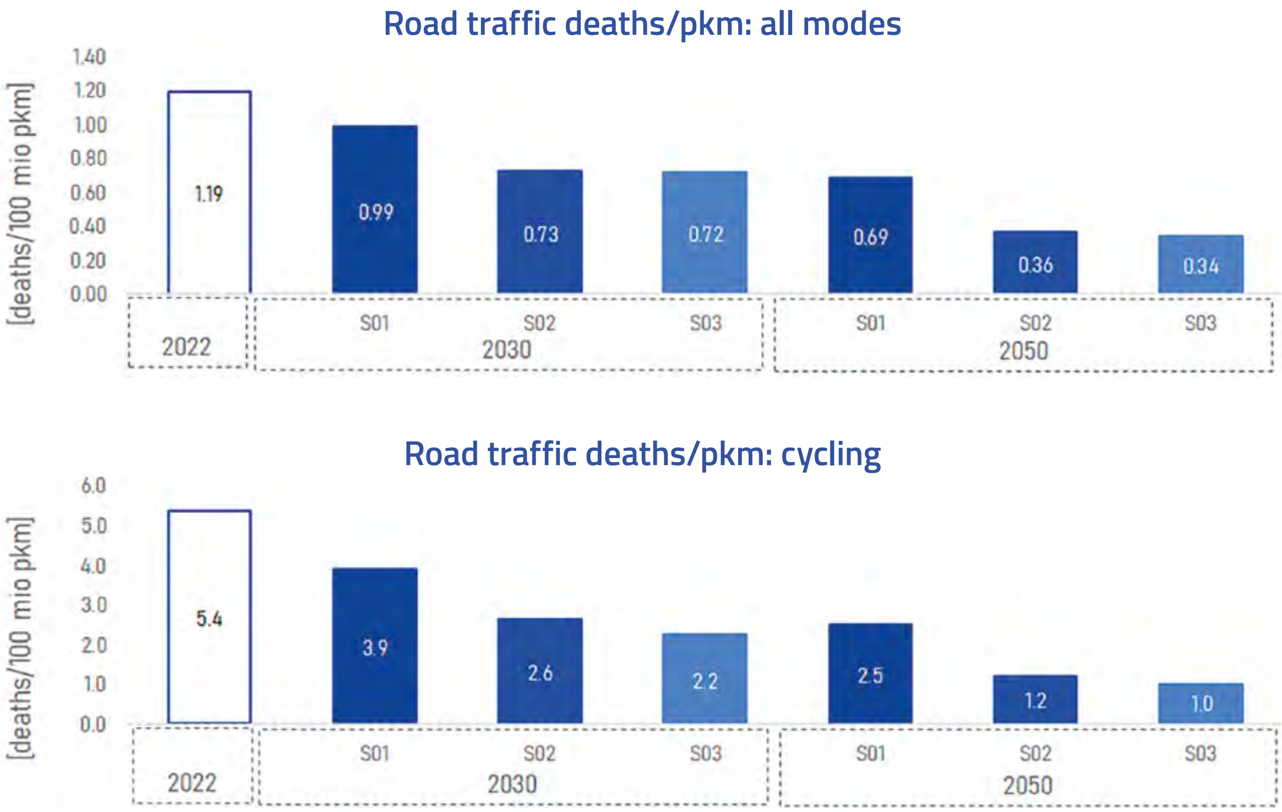


Figure 16: Average (all modes) and cycling fatality rates per pkm in EU27 context

Looking at the city prototypes (see https://www.eiturbanmobility.eu/wp-content/uploads/2024/09/2024_EIT_Costs-and-benefits-study_Full-results.pdf), it is possible to notice that in several prototypes the transition scenarios, thanks to combination of safety-addressing policy measures, bring the number of urban fatalities to less than 1 every 100,000 inhabitants. The best results are obtained in small cities, where active mobility is more encouraged.

Economic results

As explained in **paragraph 3.1**, costs (and revenues if relevant) are estimated in the model for each policy measure, considering both their implementation and management phase. Furthermore, user costs in terms of transport expenditures (including operating and ownership cost of private vehicles) are estimated. Therefore, the model allows to understand the overall costs and revenues for each scenario simulated, considering the different actors in the urban context. The economic indicators are computed on a yearly basis and cumulated over the simulation period, discounted over time, and compared to the Business-As-Usual scenario.

In fact, costs and revenues **are the incremental ones associated with the implemented policies and technology trend,** compared to the **Business-as-Usual Scenario** (BAU) scenario, in which no policy measures are activated. Anyhow, the BAU scenario is associated with costs and revenues of the related base trend. For example, the vehicle fleet base renewal rate, the associated fuel consumption or the vehicle fleet management are accounted in the BAU. Thus, costs and revenues do not represent the total costs and revenues, but only the incremental ones related to the specific set of policies, and those related to the fleet renewal of the technology innovation trend. Therefore, the costs have been computed as cumulated, discounted (3% per year), and compared to Business-As-Usual scenario.

To have a wide representation of the impacts in monetary terms, four categories have been used:

- **Implementation and management costs**, including costs incurred by the public administration, service providers and freight operators. This group includes all costs related to the implementation of a new service (e.g.: carsharing service boosted, new metro line, etc.), as well as the management of the existing and new services are considered. Fleet management and renewal are also considered. For example, if the logistic vehicle fleet needs to be renewed due to new access regulations, the associated cost is considered in this group.
- **Revenues**, earned by the public administration (e.g.: Parking fees) and service providers (e.g.: carsharing tariffs).
- **User costs,** including both transport expenditure for services (e.g. Public Transport ticket, carsharing), and private vehicle operating costs (including charges), ownership and purchase. User costs include transport expenditure of residents of the study area, as well as those borne by incoming users for their mobility within the study area.
- **Total net costs**, computed as the sum of implementation and management costs, user costs, minus revenues. It is important to note that some of the user costs (e.g.: parking fees) are also included in the revenues, from the public administration perspective.

It is worth to mention that subsidies are not considered explicitly in the model: national subsidies for public transport services (which could potentially reduce the costs) neither subsidy for renewal of vehicle fleet nor the uptake of electric transport.

The sustainable urban mobility transition generates savings in terms of external costs. In this study, the following are considered:

- **GHG** emissions (tank-to-wheel).
- **Air pollutants** emissions, considering PM2.5, PM10, VOC, CO and NOx.
- Urban road traffic **injuries** and **deaths**.
- **Noise** related to transport sources.

The externalities are monetized as reported in **Section 3.1**.

In **Table 8**, costs and revenues are reported for the three policy scenarios.

Looking at the implementation and management costs, the distribution over time and the effort required can be compared between the scenarios. S01 is lower than the other scenarios over the whole period, although it is twice as high as S02 in the short term. The policy costs in this scenario are mainly related to public transport, fleet renewal (PT and freight operators), cycling and walking infrastructure and shared mobility. In S02, the additional amount of money required is lower than in S01 in the short term and higher until 2050. In this scenario, the costs are related to more expensive policies such as access regulation and pricing in large parts of cities, urban logistics facilities, incentives for active modes, as well as PT fleet renewal. Finally, S03 is the most demanding in terms of investment and management costs due to the large package of policies implemented.

The user costs of the scenarios are not so different in the short term, because of the obvious economic effort required by the renewal of private vehicles. However, in S02 and S03, the greater reduction in car trips replaced by alternative modes allows a reduction in user costs compared to S01. This is also observed in the long term, where S02 and S03 are largely cheaper from a user perspective.

Looking at the results in terms of total net costs (calculated as the difference between total revenues and costs) and excluding external costs, scenario S02 shows the lowest values. Instead, S01 and S03 have similar total net costs, mainly due to higher user costs.

Costs and revenues – Average per capita						
[euro / capita]	**2022 – 2030**			**2022 – 2050**		
	S01	**S02**	**S03**	**S01**	**S02**	**S03**
Implementation and management costs	815	364	1,080	1,735	2,746	5,771
Revenues	460	375	752	1,991	1,751	2,955
User costs	1,551	971	1,206	9,317	6,645	6,998
Total net costs	**1,906**	**960**	**1,534**	**9,061**	**7,639**	**9,815**

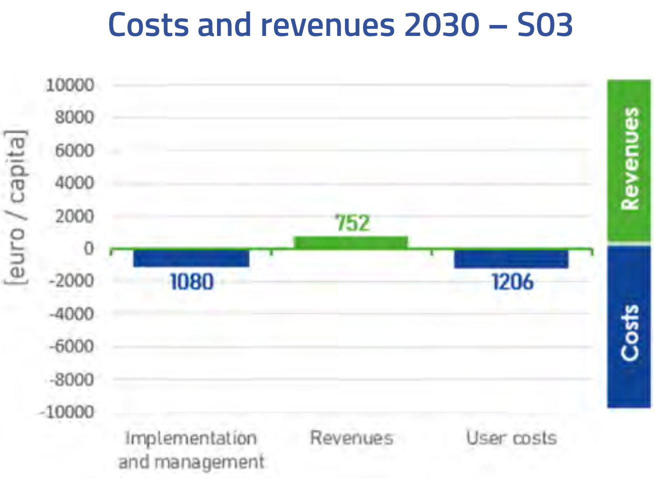
Table 8: Average per capita costs and revenues for the EU27 city prototype

Due to the different unitary costs, the external cost savings are of different magnitudes. Road traffic injuries/deaths account for the largest share of the savings, followed by greenhouse gas emissions reductions and noise reductions (see **Table 9**). S02 and S03 are quite similar in terms of total savings up to 2030, but S03 is more effective in the long term, as might be expected from the more ambitious target set in this scenario. Instead, S02 shows a lower overall result in both 2030 and 2050. This scenario achieves less pronounced changes in mobility habits, with a smaller reduction in the private car share, which is also reflected in a smaller reduction in externalities.

External cost savings – Average per capita						
[euro / capita]	2022 – 2030			2022 – 2050		
	S01	S02	S03	S01	S02	S03
GHG	115	205	261	1,949	2,409	2,734
Air pollutants	39	105	117	177	324	364
Injuries / death	672	2,049	2,365	3,691	9,562	10,983
Noise	33	72	157	535	679	1,393
Total external costs savings	**859**	**2,431**	**2,900**	**6,351**	**12,974**	**15,474**

Table 9: Average per capita External costs savings for the EU27 city prototype

Comparing **Table 8** and **Table 9**, it emerges that in scenarios S02 and S03 the total savings from externalities reduction outweigh the total net costs. Instead, S01 is the only scenario where the external cost savings are lower than the costs for implementing the scenario. In fact, S01 requires less investments and management costs with respect to S03 but achieves only about one third of the external costs savings. Across the city prototypes, the same scheme is observed, with differences proportioned to the city size.



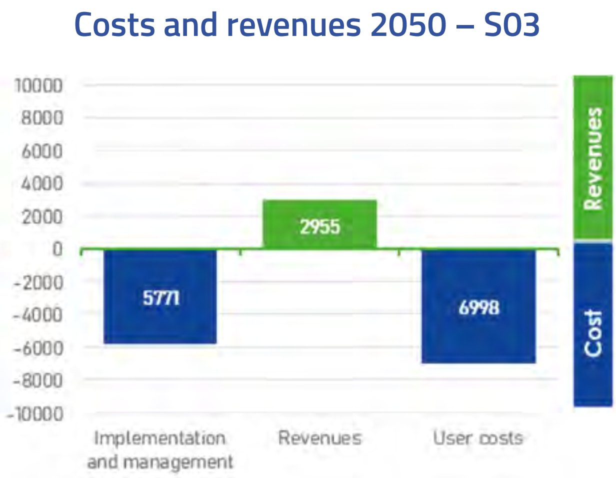


Figure 17: Costs and revenues for Scenario 3, in the EU27 context

Should we look at the totality of all EU27 cities considered in the studies (Table 10), the total net costs of the three scenarios range between 194 billion € and 385 billion € by 2030. By 2050, the scenarios' cumulated net cost surpasses 1,500 billion in the three scenarios. On the other hand, the total external costs savings exceeds the total net costs in S02 and S03 in both the short and the long term. In particular, such savings reach peak values in S03, accounting for a little less than 600 billion by 2030 and more than 3,000 billion by 2050.

Total net costs & Total external costs savings in all EU27 cities						
Billion euro	2022 – 2030			2022 – 2050		
	S01	S02	S03	S01	S02	S03
Total net costs	385	194	310	1,830	1,543	1,982
Total external costs savings	174	491	586	1,283	2,620	3,125

Table 10: Total net costs and total external costs savings in all EU27 cities

As thoroughly explained both in section 1.4 and in section 3.1, the calculation of the external costs savings generated by GHG emissions reduction has been made using the values of the EU Economic Appraisal Vademecum 2021-2027. Had the monetization values[19] from the EC's *Handbook on external costs of transport* of 2019 been used, the GHG-related savings would have been lower (approximately half of the euro/capita).

[19] 83€/ton in 2022, 104€/ton from 2025, and 279€/ton from 2040.

Still, the overall outcome of the economic comparison between costs/revenues and external costs savings of the three scenarios would not have changed. **Table 11** provides the comparison between the GHG external costs savings calculated with the "Vademecum" monetization values and with the "Handbook" monetization values.

External cost savings GHG – Vademecum vs Handbook						
[euro / capita]	2022 – 2030			2022 – 2050		
	S01	S02	S03	S01	S02	S03
GHG (Vademecum)	115	205	261	1,949	2,409	2,734
GHG (Handbook)	78	143	182	986	1,294	1,477

Table 11: External cost savings GHG – Vademecum vs Handbook

Experimental health benefits assessment

This section presents an experimental assessment[20] of the health benefits of active transport (i.e. cycling and walking) associated with the transition scenarios, based on results from the MOMOS model.

Transport can influence levels of physical activity. There is a strong evidence base for the health benefits of physical activity. The World Health Organization has developed the Health Economic Assessment Tool (HEAT) to provide an economic assessment of the health benefits of walking and cycling and to support their inclusion in valuations (WHO, 2007, 2011 & 2014). It estimates the value of the reduced risk of death for a given amount of walking or cycling. It is assumed that there is a dose-response effect, with greater levels of activity yielding greater benefits for individuals, particularly those who are induced into active modes from relatively inactive lifestyles. In 2016, the UK Department for Transport commissioned research to assess the health impact of active modes of transport. This work included a literature review of the science on physical activity and health, and a summary of current methodologies used by TAG (2022) and the World Health Organisation Health Economic Assessment Tools (WHO HEAT). Based on this, the TAG report proposed an updated methodology for calculating the physical health benefits of walking and cycling, which was used as the basis for the experimental evaluation in this section.

The method recommended by the TAG for assessing the health impact of active travel is based on estimating the change in premature death (mortality) resulting from a change in the number of people walking or cycling, i.e. the health benefit of gaining more years of life. An intervention that increases the number of active users is expected to reduce the relative risk of all-cause mortality. This can be monetised by estimating the number of deaths averted, converting to years of life lost (YLLs) and then multiplying by the value of a quality-adjusted life year (QALY).

In this study, this has been assessed using the same approach to externalities: the benefits associated with walking or cycling have been accumulated over the simulation period, discounted at 3% per year and compared with the BAU scenario. However, it is important to emphasise that a number of assumptions about the level of physical activity of individuals and the characteristics and mobility habits of people travelling by active modes are key drivers of the assessment and can only be treated in an aggregated way in the current version of the MOMOS model.

[20] Due to the experimental nature of this assessment, the health benefits have not been taken into account in the overall results of the study presented above.

Based on the simulations, the average cumulative health benefits of active transport modes by 2050 amount to about 200 to 300 Euros per capita in S01, 500 to 680 Euros in S02 and 850 to 1,170 Euros in S03. Of course, the results depend on the number of trips shifted to active modes in the different scenarios. The range of results is similar to the benefits in terms of noise reduction.

Health benefits – Average per capita						
[euro / capita]	2022 – 2030			2022 – 2050		
	S01	S02	S03	S01	S02	S03
Range of benefits (min/max)	53	107	193	221	495	850
	72	147	265	304	681	1,168

Table 12: Average per capita Health benefit for the EU27 city prototype

Further research into the relationship between physical activity and health is ongoing. In addition, further details should be included in the model to improve the representation and estimation of the relevant aspects affecting quantification. Therefore, the values derived from the application of the methodology should be taken as indicative of the magnitude of the expected effect rather than as precise estimates. However, it should also be emphasised that this approach only captures the benefit of reduced premature mortality and does not capture the impact on quality of life.

3.3 Policy measures groups effectiveness

While the results presented above consider the urban mobility transition scenarios in their totality (i.e., with the activation of the entire package of measures associated with each scenario), it is also possible to evaluate costs and revenues of single policy groups (e.g., Public Transport, Active mobility, etc.), as well as the CO_2 reduction that is attributable to it. In particular, these calculations are performed by comparing the Technological Innovation Trend scenario (see **section 2.5**), and scenarios in which each group of policy measures is activated separately. This way, it is possible to make an estimation[21] of how much each group of policy measures is responsible in terms of reduction of CO_2 emission. Also, it is possible to assess the Net Financial Balance of the specific policy group implementation. In order to consider all policies in all prototypes, the policy targets of S03 have been used.

Looking at the results of the effectiveness analysis in 2030 **(Figure 18)** and in 2050 **(Figure 19)** it is possible to see a similar pattern of how the different policy measure groups perform in terms of CO_2 emissions reduction and costs associated with. In particular, two policy groups stand out when considering the two variables used for the analysis: *Access regulation and pricing* and *Electrification and alternative fuels.*

Access regulation and pricing is the policy group that achieves the best result in terms of CO_2 reduction, especially in medium and large city prototypes. Nevertheless, it is also the one with highest savings in medium and large city prototypes (in 2030) and in small and larger city prototypes (in 2050). In 2030, *Active mobility* is the second-best group in terms of greenhouse gas emissions reduction for all three prototypes sizes, whereas in 2050, *Electrification and alternative fuels* becomes the best alternative to *Access regulation and pricing.*

Looking at the net financial balance, *Electrification and alternative fuels* policy group is the most expensive in all prototypes sizes. This is due to the high cost associated with the fleet renewal and with the refuelling infrastructures. In addition, by activating this policy group alone, citizens are strongly encouraged to change their vehicles, as per the lack of alternatives.

Also, *Urban Logistics*, *Public Transport*, *New Mobility Services* and *CCAM* require more investments than the savings they are able to attain. Indeed, all these policy groups include technological development and large economic investments. On the contrary, *Active mobility, Transport avoidance,* and *Access regulation and pricing* generally need smaller investments, so that they generally have positive financial balance in the three prototypes sizes.

[21] It is important to remember that the results obtained in the policy measures effectiveness might differ than the ones obtained in the policy scenarios simulation. This is because each individual policy measure interacts with all the others included in the scenario, achieving different results, sometimes higher, other times lower. Therefore, the policy measures groups effectiveness analysis is only a theoretical exercise in which a single policy group is simulated without the activation of any other policy, except for those in that group.

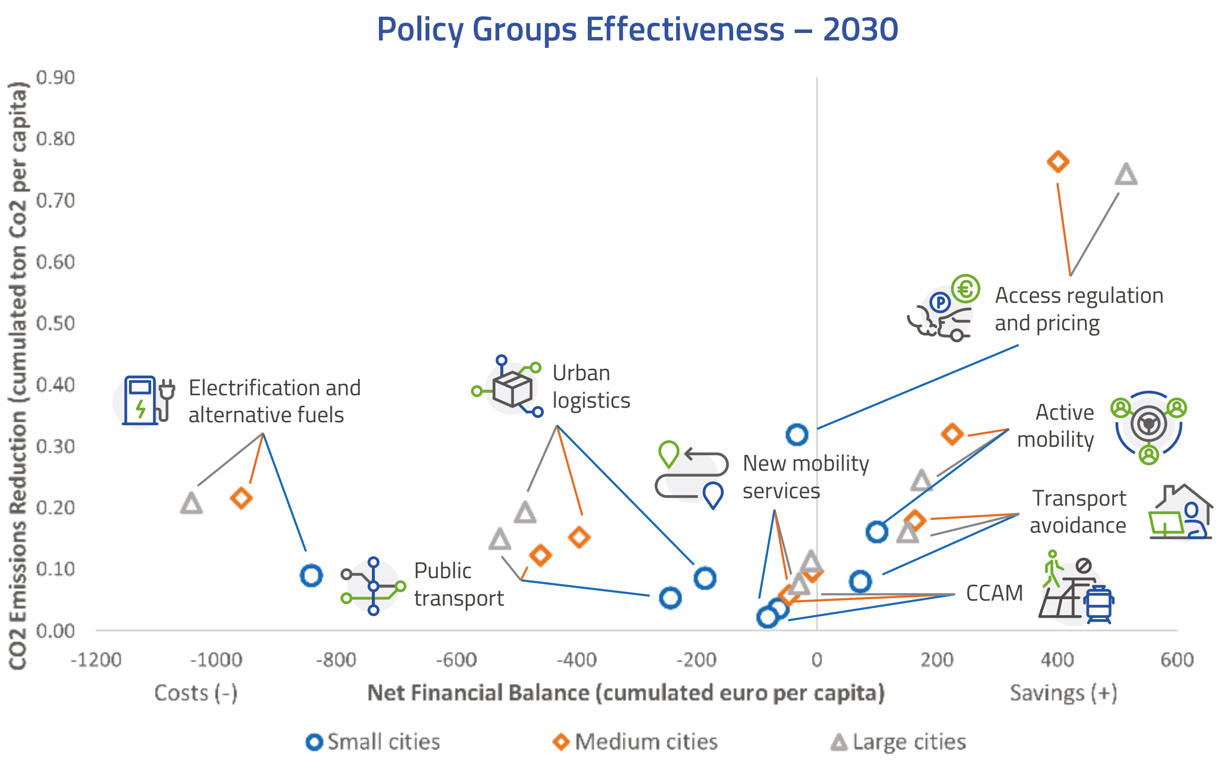


Figure 18: Policy group effectiveness – 2030

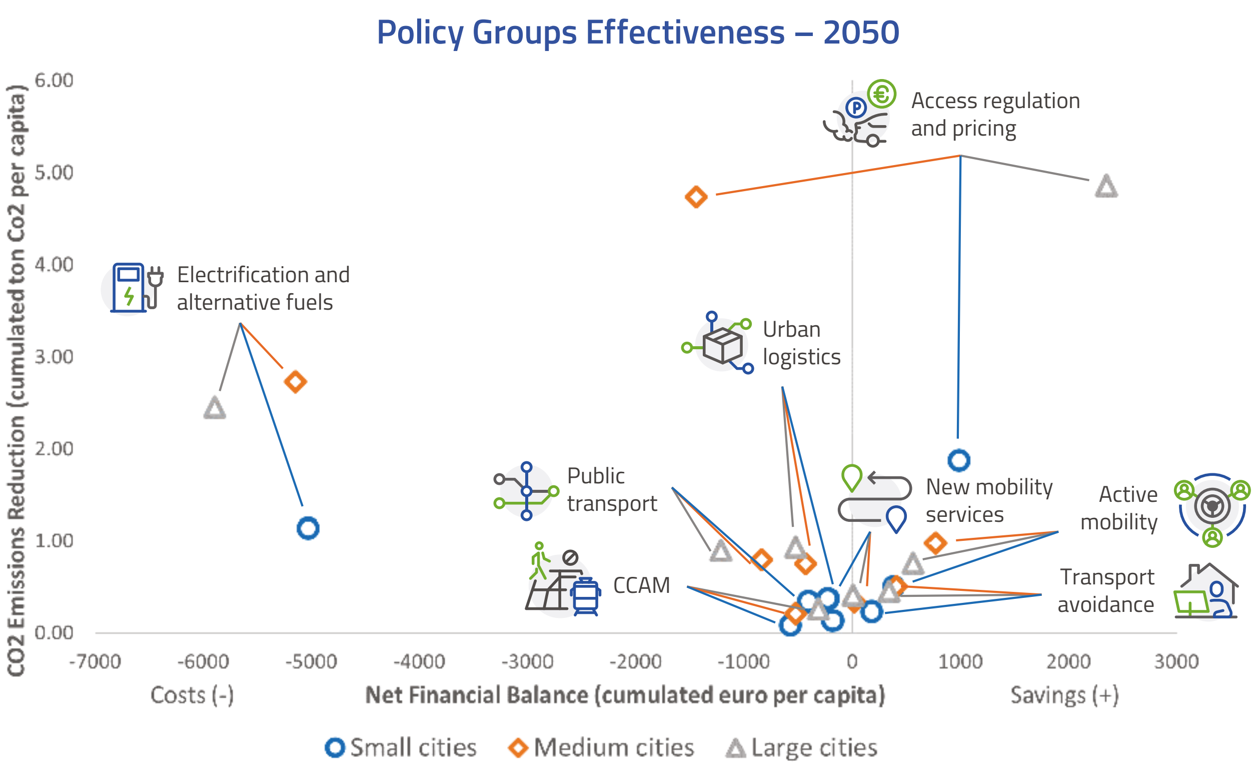


Figure 19: Policy group effectiveness – 2050

4 Conclusions and Recommendations

The study has **assessed the impacts of the sustainable urban mobility transition of European cities** through the quantification of costs and benefits associated to three potential policy scenarios: S01 **"Infrastructure and mobility services"**, S02 **"Regulation and demand management"**, and S03 **"Zero-emissions"**.

The simulation of the three potential scenarios for 12 city prototypes has allowed to fairly represent the entire EU27 context while taking into account differences among cities in terms of size and geography, as well as per capita income, motorization rates, fleet composition, energy prices, and value of travel time among other indicators. In addition, the input data collection for the correspondent reference cities has allowed to consider the urban and transport parameters that characterize each single city prototype at base year.

Looking at the results of the study, the first thing to point out is that **each scenario has been capable of reaching the Green Deal target in terms of greenhouse gas emissions by 2050,** even if with a different approach. However, reaching the target for CO_2 emissions reduction set for the year 2030 seems to be more complicated. In fact, only Scenario S03 can achieve the target in the short term, bringing quite drastic changes both in terms of vehicle fleets composition – and with the high costs associated – and in citizens' mobility habits.

Indeed, in S03, the **modal split** requires a **significant change** by 2030, with a reduction in the private motorized modes about -16%. Also, a fast turnover in all the vehicle fleets is needed to have a higher share of clean vehicles circulating. The high costs associated with this scenario – especially in the short-term – indicate that municipal, national or even European subsidies are fundamental to reduce the citizens' investments for the fleet turnover.

Looking only at the long-term (2050), also **S01 and S02 can reach the target**. The first one leaves the choice to the citizens, providing services and infrastructures, but without severe restrictions. The second one works stronger on the regulation side, introducing LEZ, LTZ, transport avoidance schemes, etc. This way the users are forced to change their vehicles, or their mobility habits (i.e., the modal split changes more in S02 than in S01). Other important outcomes associated to S02 include a lower cost for the public administration and service providers, higher cost for the users, and a GHG reduction higher with respect to S01. Overall, this scenario has a high probability of **not being easily acceptable to citizens**.

Whereas S01 invests on public transport, sharing mobility and all kind of services or infrastructures to help citizens change their mobility habits, it is only with strong access restrictions (like in S02) that it is possible to obtain wider changes in mobility habits.

In terms of **economic results of the policy scenarios, which consider costs, revenues, and the external costs savings generated by the implementation of sustainable policy measures,** scenarios S02 and S03 have higher external costs savings than costs associated with. Instead, S01 results in a negative balance, with higher costs and less external costs savings.

It is also important to look at the **safety** aspects: S02 and S03 achieve a higher reduction in injuries and deaths. One of the main reasons is the implementation of traffic calming measures, which is the single policy with the highest impact on safety.

Finally, it is interesting to look at the **costs/revenues and the CO_2 monetization attributable to each policy group** (policy effectiveness). Both in short and long term, *electrification and alternative fuels* lead to high costs, and an intermediate reduction in the GHG emissions. *Access regulation and pricing* instead, have the highest reduction in GHG emissions associated, with a positive economic balance between costs (vehicle fleet renovation, investments, etc.) and savings (fuel consumption saved, ownership taxes avoided with less private cars, etc.). While all policy measures reduce CO_2 emissions, *Active mobility* and *Transport avoidance* are also convenient from an economic perspective.

A notable mention is needed for *Public Transport.* The group does not attain the most "effective" result in terms of costs associated vs emissions reduction. This is mainly due to the high investments that are generally needed to improve the system and to expand its network. However, having a reliable, efficient, and capillary **public transport system** represent the backbone of a well-functioning and affordable urban mobility system and an indispensable element to complement all the other policy measures targeted to the transition towards a less car-dependent and more sustainable urban mobility.

It is important to remind that the model used for this study (MOMOS) is a **strategic and aggregated** one, adaptable under several assumptions to different city circumstances in different European countries, and enabling for a rapid identification, development, screening, and assessment of different measures and policy scenarios and of their expected impacts. Whereas the tool allows an evaluation of alternative solutions, it does not intend to replace sophisticated transport models. Also, its structural limitations does not allow to accurately represent some aspects (e.g., computation of travel time, change of destination and related distances, etc.).

To conclude, the study has been able to demonstrate what is needed for a transition towards sustainable urban mobility. Whereas this study **does not intend to present the most likely outcome** nor wants to forecast the future of urban mobility, it aims to define **potential transition scenarios** for the **decarbonisation of urban transport** and lays out what would be required to achieve this transition in a highly uncertain and constantly evolving context.

Recommendations

Based on the results of the study, some policy recommendations can be formulated. Importantly, the study points out that it is imperative to put in place a **regulatory framework** to accelerate cities' transition towards zero emission transport, in particular to allow the introduction of specific measures driving the path towards decarbonization targets.

To achieve the decarbonization targets, the contribution of **technological innovation and vehicle renewal** is necessary. Therefore, dedicated long-term national and European funding for investments in clean transport vehicles is needed to support the different actors (public transport operators, private citizens, freight operators) in renewing the vehicle fleet.

As far as cities are concerned, here below some key recommendations:

- Among the various policy measures, in the short-term **LEZ and road access regulation** have a particularly strong impact on mode shift and therefore air pollutant and GHG emissions. By limiting access to the zone to compliant vehicles, motorized transport in cities is curbed and alternative modes of transport are considered. These measures should be therefore accompanied with improved services and infrastructure to make active modes, public transport and shared mobility a valuable and attractive alternative.
- The interaction between **car sharing** (especially free-floating services) and **public transport** should be carefully considered and designed, to avoid competition between the two services. Their interaction is increasingly important for the planning of sustainable urban transport systems and car sharing should be designed as complement of public transport by serving access and egress trips in the light of a multimodal integrated service.
- The transition toward zero-emission mobility and the achievement of Green Deal targets cannot be foreseen without planning appropriate **investments** to prioritise the provision of **reliable, affordable and climate friendly alternatives**, such as walking and cycling infrastructure, public and shared transport, cargo bikes and logistics hubs, etc.
- To support modal shift toward **public transport**, its **quality** and **offer** should be improved, including transport on demand services, to ensure a wider access to the service. Appropriate **service capacity** is crucial to make public transport a reliable and attractive alternative to private cars.
- Together with the passenger mobility, the **freight delivery system** has a crucial role too. First of all, a relevant **fleet renewal** is needed, to make the circulating vehicles less polluting. Secondly, it is very important to work on the **efficiency** of the freight delivery, for example using delivery plans and distribution centers. Finally, the **last-mile logistics** can be made more sustainable through **cargo-bikes**, who are able to reduce congestion and pollution, but also injuries and fatalities.

- Being aware of the **acceptance** issue of some policy measures suggested for the achievement of decarbonisation target, it is crucial to implement **participatory processes** and engage stakeholder and citizens. These are relevant factors that influence the successful development, acceptance and implementation of effective sustainable transport.
- The analysis of costs and environmental and social benefits in different contexts suggests the importance of **designing tailored policies** that address issues and are reinforced by the strength of the specific local context. In particular, transport policies should be accompanied by **urban planning considerations** to help reducing travel length/distances (i.e. the 15-minute city concept) and therefore making trips by public transport and active modes more efficient and attractive.

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