CleanCities

Towards zero-emission transport in European cities:

Madrid

Final Report

TRT

This report has been produced by TRT Trasporti e Territorio for the Clean Cities Campaign.

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Date

24 / 11 / 2023

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This publication has been made possible thanks to the financial support of the Allianz Foundation.

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Acronym list

B2C	Business-to-consumer
BEV	Battery Electric Vehicle
C-ITS	Cooperative Intelligent Transport System
CNG	Compressed Natural Gas
CO	Carbon Monoxide
DRT	Demand-Responsive Transport
EU	European Union
EV	Electric Vehicle
GHG	Greenhouse Gases
HDV	Heavy Duty Vehicle
LDV	Light Duty Vehicle
LEZ	Low Emission Zone
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
LTZ	Limited Traffic Zone
MaaS	Mobility as a Service
NOx	Nitrogen oxides
PHEV	Plug-in Hybrid Electric Vehicle
pkm	Passengers-km
PM	Particulate Matter
PT	Public Transport
SUMP	Sustainable Urban Mobility Plan
vkm	Vehicle-km
VOC	Volatile Organic Compounds
ZEZ	Zero Emission Zone

1. Introduction

1.1 Study context and structure of the report

Between 1990 and 2019, greenhouse gas (GHG) emissions from transport have increased by around 24% in Europe [1] and urban transport is estimated to account for around 23% of all emissions from the EU transport sector [2].

Urban transport is not only a main driver of the climate emergency but is also directly responsible for a series of negative externalities at the city level, including air pollution, noise, and road traffic injuries/deaths. Many of these problems are expected to increase in the future without dedicated policy interventions, as cities continue to grow and face demographic changes such as ageing populations.

Different government levels have set distinct targets for sustainable urban transport to address these challenges. The 2019 *EU Green Deal* [3] mandates a 90% reduction in greenhouse gas emissions from transport for the EU to become a climate-neutral economy; this whilst working towards a zero-pollution ambition. The 2020 EC Communication *Smart and Sustainable Mobility Strategy* [4] calls for more sustainable, smart and resilient mobility. That includes boosting the uptake of zero-emission vehicles, making urban mobility healthier, stepping up safety and security across all modes, and providing better incentives for users to attain desirable changes in transport behaviour and choices.

In addition, 100 cities from the European Union and 12 cities from associated countries have been selected to join the *EU Mission for 100 Climate-neutral and smart cities by 2030* [5] to pursue ambitious goals to rapidly reduce emissions and implement innovative approaches with citizens and stakeholders.

Policymakers in European cities count on a broad set of options to achieve zero-emission transport. From offering more space for active mobility, improving public transport and scaling up shared mobility services to encouraging the transition to electric vehicles. The impact of these measures depends on the local context and the degree of combination of these alternatives. This has made it difficult for analysts and decision-makers to compare the routes through which European cities can achieve zero-emission urban mobility.

This is why the Clean Cities Campaign, a European coalition of more than 85 civil society organisations, has commissioned TRT to model scenarios that would enable European cities to achieve zero-emission urban mobility by around 2030.

The methodology and results of this analysis for Madrid are presented in this report. The report is organised as follows. First, the study objective and the context of the study are presented. Secondly, the methodology is summarised. This includes an explanation of how the MOMOS model and its calculation framework work. Also, the rationale behind the design of the transition scenarios is explained, including the input data collected, the definition of the different policy measures, the exogenous trends to account for, and the output indicators that the model generates. Finally, the results of the study are presented, and conclusions are drawn.

1.2 Objective of the study

Acknowledging both the magnitude of the challenge of the transition to sustainable urban mobility and its urgency, this study attempts to model transition scenarios towards zero-emission transport in European cities by around 2030. Each scenario is built on a different set of sustainable transport policies. The impacts of each set of policies are quantified through a series of indicators for each city and scenario.

As the target of zero-emission transport by around 2030 is very ambitious given the short timeframe, it is crucial to define a clear strategy. Through this exercise, it is possible to demonstrate to policymakers what efforts are needed and what the impact on citizens' mobility, the environment, and road safety will be. For the purpose of this study, zero emission urban transport is defined as mobility that emits zero tailpipe emissions from urban road and rail borne transport, including both passenger and freight transport. While upstream emissions from the production of fuels and vehicles should not be ignored and have been estimated in this study, these are usually outside of the cities' control and are therefore not in the focus of this study.

The research has been designed as a high-level analysis and the uncertainties and limitations are laid out in chapter 2.

It is important to stress that this study does not intend to present the most likely outcome nor attempt to forecast the future of urban mobility. Rather, it aims to define potential transition scenarios for the decarbonisation of urban transport and lays out what would be required to achieve this transition by around 2030 in a highly uncertain and constantly evolving context.

Five different metropolitan areas have been analysed for the study: the Brussels-Capital Region, the municipality of Madrid, the metropolitan county of Greater Manchester, as well as the municipalities of Milan and Warsaw. The cities have been chosen in order to have a representative set of large cities or metropolitan areas (more than 1 million inhabitants) from different parts of Europe and with different socio-economic and spatial characteristics. This report focuses on Madrid. The reports for the other cities will be made available on the website of the Clean Cities Campaign.

2. Methodology

2.1 General approach

This study focuses on the following research question: *What changes are needed to achieve zero-emission urban transport in selected European cities by around 2030?*

This question has been addressed through a high-level quantitative analysis of different sets of policy measures, which were summarised in scenarios. TRT used their assessment tool MOMOS (Sustainable Urban MObility MOdel) to simulate the outcomes of different mobility transition scenarios. This has made it possible to quantify the impact of the scenarios on mobility behaviour, the transport system, the environment and road safety; as well as to estimate the economic resources needed to drive such a shift.

There are four scenarios that have been simulated. Each one consists of a specific combination of policy measures (see 3.4). These measures have been selected based on which policies are being implemented or have been planned in European cities and taking into account their effectiveness in reducing GHG emissions. In addition, the main EU initiatives in terms of sustainable urban mobility were used to construct a baseline (e.g., CIVITAS [6], ELTIS [7]).

The first two scenarios have a narrower focus: Incentivising active and collective mobility (Scenario 01) and fleet electrification (Scenario 02) respectively. The third one (Scenario 03) combines all policy measures from the previous two scenarios. The fourth one (Scenario 04) applies all policy measures at the same time and extends their reach to estimate the order of magnitude of changes needed to achieve zero-emission urban mobility by around 2030.

All scenarios were applied to the aforementioned five European cities and metropolitan areas. Each one relied on in-depth data collection to reproduce the city's characteristics at the base year (2019), including socio-demographic data, the mobility features (e.g., fleet composition, public transport infrastructure, availability of innovative/shared services, traffic management solutions, etc.). When available, official sources were used. Where official sources were not available, the data has been interpolated or, where necessary, extrapolated. Other data – such as shared mobility services data – are not publicly available, and extrapolations were necessary.

The MOMOS simulation of the transition scenarios returns a series of quantitative output indicators. Results are provided for both the horizon year (2030) and the base year (2019) that is used as a reference point.

Greenhouse gas (GHG) emissions from transport, expressed in CO_2 equivalents, are the key output indicator. A total of 30 indicators is used to provide a thorough description of the possible mobility situation in 2030, and covers transport behaviour, transport activity, electric vehicle uptake, air pollutant emissions from transport and road safety. Both passenger and freight transport were included.

In addition, a multi-criteria economic analysis has been conducted to estimate the main costs and benefits associated with each scenario. These include costs (and revenues) for the city, the transport users, and freight operators as well as the external costs and savings resulting from reductions in GHG and air pollutant emissions, road traffic injuries/deaths, and noise.

2.2 The MOMOS model

TRT's assessment tool MOMOS (Sustainable Urban MObility MOdel) has been used for the simulation of the scenarios to evaluate the impact and pathway towards the goal of decarbonisation of urban transport in the selected cities and metropolitan areas.

The model was 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 2019 (base year) until 2030 (and beyond).

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. The tool has previously been used, for instance, to estimate the costs and benefits of the sustainable urban mobility transition in prototypes of 779 EU-27 cities in a study commissioned to TRT by EIT Urban Mobility [8].

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 it 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. 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.)

The calculation framework of the MOMOS model consists of several components, as shown in Figure 2. The core of the calculation framework consists of:

i) a component managing the estimation of transport demand for both passenger and freight (trips, modal split, passengers-km, tonne-km, etc),

ii) a (road) vehicle fleet component,

iii) a component related to transport cost, time and revenues

iv) a component where social and environmental impact are estimated (road traffic injuries/deaths, GHG and pollutant emissions and energy consumption). The calculations made within these modules are affected by the urban policy measures selected and set-up for simulating different scenarios.

The definition of specific urban characteristics within the calculation framework allows for a more accurate representation of the urban context, whilst considering differences that can affect the trend of mobility, especially the impact of the policies.

At the spatial level, the study area is divided into two types of zones generating transport demand: (i) the urban core and (ii) peripheral areas. The separation of zones is mainly done through an estimation of the population density within each district of the study area. The two types of zones are defined in Annex I: Study area and input data.

The urban core includes the inner centre of the city and the main urban area. Peripheral areas are generally suburbs or neighbourhoods which are, to an extent, distinct from the city (they can also be different municipalities surrounding the main city in a metropolitan area). Trips generated in each area are distinguished but without origin-destination details.

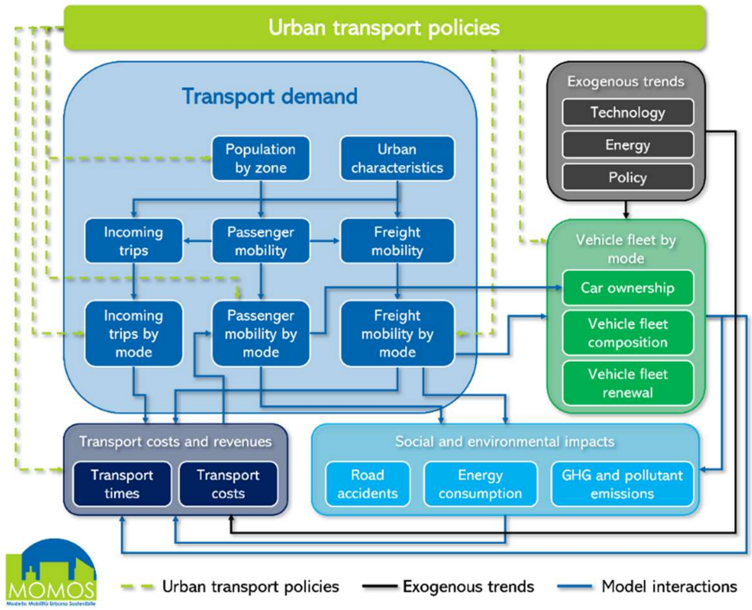

Figure 2: Calculation framework of the MOMOS model

Within the transport demand component, demographic developments by age group as well as the distribution of the population within the urban area, are simulated and used as the main inputs for passenger trips generation. Passenger demand segments are modelled by purpose (working, personal), period (peak, off-peak) and mode (pedestrian, bike, motorbike, car, bus, tram, metro, car sharing, bike sharing, e-scooter sharing and moped sharing). The mode split at the base year is based on the initial values - these differ by living area: i.e., within the urban core and the outskirts with a good level of public transport supply and the mode share of car is lower than in the outskirts with a poor level of public transport supply. Policy measures can change this trend and give rise to mode switches. Passenger-km numbers depend on average trip distances. Distances are different according to the living areas (shorter in the core urban area, longer in the outskirts). The estimation of vehicle-km depends on occupancy rates, which can also be affected by policies.

Passenger trips entering the city from other areas are treated separately in the model, as their relevance depends on the nature of the city. The share of multimodal trips (e.g., the use of public transport at urban level for the last leg of the trip) is explicitly taken into account. These trips are also included in the calculation of total passengers-km and vehicle-km by mode in the urban area (only the urban part of the overall trip distance is considered), and therefore affecting travel time, emissions and energy consumption.

Freight traffic in the urban area is calculated as a percentage of the total number of passenger car vehicles at the base year, evolving over time, based on growth rates. Freight demand is modelled considering the category of freight (distribution to retailers, mail services, for example movements of building materials), differentiated by vehicle type (light truck, heavy truck, and cargo-bike), and period (peak and off-peak). This distinction is introduced for two reasons. First, several measures are focussed on urban deliveries and therefore affect only one component of freight traffic. Second, the types of vehicles used for mail distribution are different from the vehicles used for transporting input to an industry.

The module also calculates the transhipments (at a platform within the urban area where freight is consolidated). At these platforms, LDV and cargo-bikes are used for the final leg of delivery. Lastly, performances related to vehicle-km are estimated considering the urban part of the overall trip distance.

Road vehicle fleets are segmented by fuel type (gasoline, diesel, CNG, LPG, LNG plug-in hybrid electric, battery electric, fuel cells) and emission standards (Pre-Euro and Euro 1/I, Euro 2/II, Euro 3/III, Euro 4/IV, Euro 5/V, Euro 6/VI, and post Euro 6/VI). For some modes only some of the segmentations are available. The private car fleet is distinguished by the car sharing fleet (where it exists).

Road traffic injuries and deaths are estimated based on injury/fatality rates by mode of transport applied to demand performance (vehicles-km). The injury/fatality rates evolve over time in accordance with mode-specific trends; taking into account technical developments as well as other circumstances (speed limits, infrastructure quality, etc.), which may arise also from the implementation of policy measures (such as traffic calming, infrastructure for pedestrians, etc).

Energy consumption is estimated by fuel / energy type (gasoline, diesel, CNG, LPG, LNG, electricity, hydrogen). Air pollutant emissions are estimated for $PM_{2.5}$, PM_{10}, CO, NOx and VOC related to exhaust emissions. For $PM_{2.5}$ and PM_{10}, as well as emissions from vehicle tyre, brake wear and surface wear are considered. Both estimates considered the EMEP/EEA air pollutant emission inventory guidebook 2019 [9]. Greenhouse gas emissions (CO_2 equivalent) are estimated as well, applying the related carbon content by fuel / energy.

The model allows it to consider in the calculation several exogenous trends related to three domains: technology, energy and policy. Technology mainly refers to powertrain market penetration trends and average vehicle fuel consumption by vehicle type. The evolution driven by the EU FitFor55 scenario is one of the trends integrated in the model. Energy trends are mainly related to fuel prices and the energy mix for electricity generation. Policy trends include fuel duties and car ownership taxation. More details about the exogenous trends are included in section 3.6.

3 Model Application in Madrid

3.1 Study area context

Source: Pixabay - Alex Azabache

The city of Madrid, the capital of Spain, is located in the centre of the country. With 3.286.662 inhabitants in 2022 [10], it is also the political, economic and cultural centre of the country. The related metropolitan area accounts for more than 6 million inhabitants, the 2nd largest in the European Union. In recent years, the city's economy has shifted toward the service sector, with a significant emphasis on finance, research, and technology. Madrid is now a major European financial center, with a diverse economy and a high standard of living, driven primarily by the service industry.

Recently, the city of Madrid has also implemented policies, plans and actions to reduce greenhouse gas (GHG) emissions. Usually, these actions have been associated with other municipal plans such as air quality, mobility or urban regeneration, using resources, developing synergies and trying to guide the different municipal policies in the same direction. The Roadmap to Climate Neutrality by 2050 of the City of Madrid aligns municipal policies with European and state policies. This Roadmap aims at reducing emissions in the city of Madrid by 65% by 2030, as compared to 1990, and to achieve climate neutrality by 2050.

But this journey does not start at this point in time; Madrid has already begun a path in this direction. This Roadmap adds to a set of commitments, plans and instruments that make up the climate planning of the city of Madrid, a living plan that is in constant evolution and expansion with the addition of new initiatives. Furthermore, Madrid is among the 100 cities in the EU 'Mission for climate-neutral and smart cities by 2030', taking the opportunity to scale and speed up climate actions, learning also from other cities to meet the challenge.

The city of Madrid has one of the most extensive public-transport networks in Europe, spanning a total length of almost 2,250 km in 2021 [11], as well as one of the most competitive systems thanks to its diversity of ticket options and fares. In 2022, the city recorded almost 200 km of public transport reserved lanes [12] and around 284 km of bike lanes in 2023 [13]. As a result, the 2018 mobility survey in Madrid Metropolitan area reports that about 2.4 million trips are made by Public Transport on a typical weekday within the city of Madrid [14].

It is worth noting that Madrid attracts a large amount of people from the surrounding metropolitan area, accounting for about a quarter of the total mobility within the area. Recently, more and more mechanisms are under development to handle this kind of trips. In this respect, Park&Ride policies have been implemented, encouraging car drivers to leave the car at the almost 7,000 parking slots at the border of the city (most of them free of charge) and take advantage of the highly developed public transport network.

Nevertheless, supporting multimodality toward more sustainable urban mobility is achieved not only by empowering the public transport service but also enlarging the availability of shared mobility. Madrid has a large shared vehicle fleet, comprising about 2,700 cars, 4,000 bikes, 5,000 moped, and 6,300 scooters according to 2019 data.

On the other hand, when it comes to traffic regulations, in Madrid a Limited Traffic Zone (LTZ) was implemented for freight vehicles (over 12t) as of 2019, as well as a Low Emission zone (LEZ) for passenger cars. Both apply to 22% of the core urban area (Madrid Central). About 85% of the core urban area is subject to a speed limit of 30 km/h. This way, the accident and fatality rates have been highly reduced, allowing for a safer mobility for all transport modes.

3.2 Input data

To properly represent the study area's characteristics at base year, the MOMOS tool requires a comprehensive set of input data. Data has been collected for the base year (2019) from official sources, where available. Otherwise, input parameters were either extrapolated from previous years or interpolated from similar city contexts.

The collected input data includes the following groups:

- 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, pricing, etc.)
- Carsharing (fleet, pricing, etc.)
- Bike sharing (fleet, pricing, area coverage, etc.)
- Moped sharing (fleet, pricing, area coverage, etc.)
- Micromobility (fleet, pricing, etc.)
- Traffic control and management (low-traffic zones for passenger/freight, low-emission zones for passenger/freight, pedestrian areas, traffic-calming areas, etc.)
- Vehicle fleet composition (private cars, LDV/HDV, motorbikes, public buses, etc.)

As mentioned in the previous section, the study area is differentiated at the spatial level with two types of zones, mainly accounting for differences in the population density of each district. This allows for a more precise simulation, as the model endogenously estimates both the trips generated and the modal split separately for each zone. Policy input and characteristics at the base year also require such differentiation.

Table 8 (included in Annex I: Study area and input data) defines the area categorisation that has been assigned to each district of the study area.

The full list of collected input data is shown in Table 9. Each data is accompanied by a description, categorisation, value(s), and the source(s) used.

Finally, Table 10 lists the input unitary costs used for the monetization of externalities in the study area (referring to national values)

3.3 Policy measures

One of the core elements of the MOMOS model is the possibility to select from a wide range of sustainable urban mobility measures and adapt them to the specific study context.

The available measures are of a different nature and comprehensively cover the range of options that cities currently have available to promote the transition to sustainable urban mobility. The selection takes into account what is being implemented and planned in European cities, their effectiveness in reducing GHG emissions, as well as recent and important EU programmes and projects.

Table 1 illustrates the mobility measures that have been considered in this study and categorises them into seven groups. Also, it is worth noting that measures have been selected considering the time horizon of the study's simulation (2030). Therefore, a few innovative options (e.g., autonomous vehicles, hydrogen refuelling infrastructure) have not been included, as their full implementation is (in most cases) not foreseen within the relatively short timeframe of the study. Their future roll-out and impact on urban mobility are subject to significant uncertainty.

For each measure, the input values are used to reflect the base year characteristics of the study area. MOMOS provides pre-set reference values for missing inputs according to the specific geographic/demographic/mobility context.

Also, measures are assigned a specific starting year, to take into account 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[1].

Finally, each policy is designed considering a specific rationale and related assumptions. These are explained in more detail in Table 11 included in Annex II: Policy measures rationale.

[1] Within this study, all policies have been assigned 2023 as starting year. In addition, it is expected that all policies run out their ramp-up period (i.e., are fully implemented) by 2030.

Table 1: List of policy measures available for the simulation

Vehicle fleet and charging infrastructure
Electric vehicle uptake
Electric vehicle charging infrastructure
Green public transport fleet
Green logistics fleet
Cooperative ITS
Innovative and shared mobility services
Bike sharing
Car sharing
Moped sharing
E-scooter sharing
Mobility-as-a-Service (MaaS)
Demand-responsive transport (DRT)
Transport infrastructure
Cycling network expansion
Bus network expansion
Tram network expansion
Metro network expansion
Park & Ride infrastructure

Traffic management and control
Prioritizing public transport
Limited traffic zones (LTZ)
Low-emission zones (LEZ)
Traffic calming
Pedestrian areas
Transport avoidance
Working from home
Car-free days
Pricing schemes
Congestion and pollution charging
Parking pricing
Public transport fare reduction
Urban logistics
Urban delivery centers
Delivery and servicing plan
Cargo bikes

The model allows simulating policy packages, selecting and designing the intensity and timeline of different measures in a comprehensive strategy. When combined, there is a correlation in how they affect the same variables in the model (e.g., transport cost, transport time, modal split, vehicle stock, etc.). This can reduce or amplify the impact with respect to the case in which the policy is applied in isolation. For example, an increase of a cycling network would be beneficial and support the impact of expanding bike sharing services. Also, there is a correlation between public transport services and car sharing, due to their competition and attractiveness for similar passenger segments.

There might also be an indirect correlation among measures. For instance, low-emission zones have an impact on modal shift from private cars to other transport modes depending on the vehicle fleet composition, based on the access regulations in place. If the renewal of vehicles fleet is boosted by other measures supporting, for example, the EV uptake, the related impact on modal shift will be smaller.

To summarise, it is important to point out that the combination of different policies would not necessarily lead to adding up the impacts of individual policies due to the reasons explained above.

3.4 Transition scenarios

The study has simulated potential transition scenarios, each one building on different sets of sustainable policy measures. Four scenarios have been modelled:

- Scenario 1 (S01) "Active and Collective": this scenario aims to induce more sustainable travel behaviour by improving the public transport system, providing more and better walking and cycling infrastructure and encouraging shared mobility. This includes measures to discourage and restrict car use, such as parking and traffic management - as well as measures to improve urban logistics.
- Scenario 2 (S02) "All-electric": this scenario is mainly focused on fleet electrification. It increases the uptake of e-vehicles in private, public, and logistics fleets and assumes the widespread creation of charging infrastructure. In addition, regulation and pricing policies that affect vehicles with internal combustion engines (e.g., LEZ) are also applied.
- Scenario 3 (S03) "Everything all at once": this scenario combines all the available policy measures implemented in the previous two scenarios. Whereas one might assume that the results of this scenario could be the sum of S01 and S02, policies are not completely additive to each other and in some cases even cancel each other out (see above).
- Scenario 4 (S04) "(E)Mission: Zero": this last scenario not only applies all the measures included in scenario 3, but also pushes them to the limits of feasibility for each policy, with the aim of getting as close as possible to the target of zero-emission urban mobility by 2030.

The following policies have been applied in all scenarios as they are widely used and represent cross-cutting interventions: green public transport, working from home, low-emission zones (LEZ) and parking pricing.

Table 2 shows the composition of the four transition scenarios with the set of policies implemented in each of them.

Table 2: Policy composition of the four transition scenarios

Group	Policy	S01	S02	S03	S04
Vehicle fleet and charging infrastructure	Electric vehicle (EV) uptake		✓	✓	✓
	EV charging infrastructure		✓	✓	✓
	Green public transport fleet	✓	✓	✓	✓
	Green logistics fleet		✓	✓	✓
	Cooperative ITS		✓	✓	✓
Innovative and shared mobility services	Bike sharing	✓		✓	✓
	Car sharing	✓		✓	✓
	Moped sharing	✓		✓	✓
	E-scooter sharing	✓		✓	✓
	Mobility-as-a-Service (MaaS)	✓		✓	✓
	Demand-responsive transport (DRT)	✓		✓	✓
Transport infrastructure	Cycling network expansion	✓		✓	✓
	Bus network expansion	✓		✓	✓
	Tram network expansion	✓		✓	✓
	Park & Ride	✓		✓	✓
Traffic management and control	Prioritizing public transport	✓		✓	✓
	Limited traffic zones (LTZ)	✓		✓	✓
	Low-emission zones (LEZ)	✓	✓	✓	✓
	Traffic calming	✓		✓	✓
	Pedestrian areas	✓		✓	✓
Transport avoidance	Working from home	✓	✓	✓	✓
	Car-free days	✓		✓	✓
Pricing schemes	Parking pricing	✓	✓	✓	✓
	Public transport fare reduction	✓		✓	✓
Urban logistics	Urban delivery centers	✓		✓	✓
	Delivery and servicing plan	✓		✓	✓
	Cargo bikes	✓		✓	✓

3.5 Intervention levels of the policies

To assess the sustainable urban mobility transition driven by the scenarios, each policy needs to be defined and constructed using a series of parameters and pre-identified intervention levels. These levels have been set by considering what cities aim for in terms of their future mobility (e.g., SUMP objectives, specific goals, fleet evolution forecasts, etc.), as well as what is needed to reach the overall aim of the study (i.e., zero-emission urban mobility by 2030).

In principle, the same intervention levels have been applied to the five European cities modelled in this study. Nevertheless, specific circumstances have been taken into account for some policies (e.g., moped sharing services were not always implemented depending on the current mode share). This means that each policy implementation leads to different results, varying from city to city, depending also on the base year situation.

It is also worth underlining that there is a notable difference in the specific intervention levels depending on the scenario they are applied to. Policies in the first three scenarios are set at very ambitious, but clearly attainable levels, which are mostly in line with what has been defined in the mobility plans of various European cities. For example, the target for the cycling network has been set looking at the current values of trailblazing cities such as Amsterdam or Copenhagen.

Scenario 4 contains the same policies as scenario 3 but goes further in the implementation levels by implementing these policies with much higher levels of ambition in order to get as close as possible to zero-emission urban mobility in 2030.

In scenarios 1, 2, and 3, policies have been constructed to attain the following intervention levels in Madrid:

Vehicle fleet and charging infrastructure.

- It simulated that an additional increase in electric cars penetration is accompanied by at least 1 charging point for every 8 EVs. Of these charging points, at least 50% are set up for fast charging.
- Public transport is set to be 100% electric by 2030.
- An additional increase in electric LDV penetration is foreseen.
- Implementing Intelligent Transport Systems (ITS) will also increase safety and efficiency in road transport. It is important to note that, across all policy targets, increases or reductions always refer to a change compared to the situation at the base year (2019).

Innovative and shared mobility services

Shared mobility fleets are all set to expand and grow. The assumed intervention level is to have at least:

- 6 bikes for every 1,000 inhabitants in the bike sharing system

- 2 cars for every 1,000 inhabitants in the car sharing system
- 1 moped for every 1,000 inhabitants in the moped sharing system
- 4 e-scooters for every 1,000 inhabitants in the shared e-scooters fleet
- An increased integration between services (PT, sharing, etc.) and improved efficiency as a result of a Mobility-as-a-Service (MaaS) solution.
- The implementation of a Demand-Responsive Transport (DRT) system will cover at least 10% of the core urban area and 50% of peripheral areas.

Transport infrastructure

In terms of transport infrastructure, both network and service offer will be improved:

- Bike lanes are extended to have at least 200m of bike lanes for every 1,000 inhabitants.
- 90% of the bus network will have a 4-minute average frequency.
- 80% of the tram network will have a 5-minute average frequency.
- There will be at least 5 Park & Ride spaces per 1,000 inhabitants.

Transport avoidance

- Incentivizing working from home will reduce transport demand by 20% for work-related trips.
- In addition, 1 car-free day per month will be established.

Pricing schemes

- Parking fees will be increased by 30%. At the same time, the number of parking spaces will be reduced to not exceed 2 per 10 inhabitants.
- In addition, a 20% reduction of the public transport fare is simulated for both young people (<18) and the elderly (>65)

Traffic management and control

As far as traffic management and control concerns, different targets have been set for passengers and freights:

- The implementation of Limited Traffic Zones (LTZs), for both passenger and freight, is set to cover at least 20% of the core urban area and 5% of peripheral areas.
- Besides that, a low-emission zone (LEZ) will cover 100% of the total area. Passenger vehicles are banned up to EURO5 (gasoline) and up to EURO6 (diesel). Freight vehicles (both LDV and HDV) are banned up to EURO6.
- In terms of traffic calming, a 30km/h speed limit is applied to at least 85% of the core urban area and 30% of peripheral areas.

- Pedestrian areas are implemented on at least 5% of the core urban area and 1% of peripheral areas.
- Reserved public transport lanes and prioritizing systems will cover, respectively, at least 15% and 30% of the public transport network.

Urban logistics

- In terms of urban logistics, urban delivery centres will see an increase of 25% in terms of managed freight.
- At the same time, delivery and servicing plan will reduce freight movements for retail by 10% (LDV) and by 5% (HDV).
- Finally, an increased share of freight is delivered by cargo bikes: up to 5% (B2C) and 0.5% (Retail).

As anticipated above, in scenario 4, the intervention level of a few policies has been extended to achieve even more ambitious targets. These "boosted" policies have been selected by keeping into account their individual potential to reduce GHG emissions. All other policies keep the same targets and parameters presented for Scenario 1 ,2 and 3.

The extended policy intervention levels include:

- at least 1 charging point for every 5 EVs
- An additional increase of 30% in bike lanes (compared to the target of scenario 1,2, and 3)
- Establish 1 car-free day per week.
- Triple parking fees (compared to the price at base year)
- Reduce by 50% public transport fares for young people (<18) and the elderly (>65)
- Have reserved public transport lanes and prioritizing systems covering, respectively, at least 25% and at least 40% of the public transport network.
- Implement Limited Traffic Zones (LTZs), for both passenger and freight, covering at least 40% of the core urban area and 10% of peripheral areas
- Implement a zero-emission zone covering 100% of study area, where only fuel cell, PHEV and BEV are allowed to circulate for both cars and trucks while granting exemptions to certain groups and on certain roads[2]. By 2030, the % of fleet that can circulate corresponds to: 54% for cars, 80% for LDV and 42% for HDV.

[2] Exemptions are granted for residents with special permits (e.g., disabilities) or emergency vehicles. Moreover, certain main roads and park and ride facilities remain available for traffic from or towards areas outside the zero-emission zone.

Full details about the policy targets, including the key values of the policies at base year and the expected values in 2030 are included in Table 12 in Annex III: Intervention levels in the scenarios.

3.6 Exogenous trends: technology and energy

As mentioned in the calculation framework, MOMOS is designed to simulate scenarios under different exogenous assumptions related to technology, concerning the evolution of vehicle fleet composition over time. This aspect is relevant for driving the penetration of new technologies, influenced only partially by policies at the urban level.

Concerning vehicle technology, for the purpose of the assessment of the impacts in monetary terms, the transition 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. A moderate improvement of vehicle efficiency is expected (about -7% in 2030 with respect to 2019 for cars and vans and -4% for HDVs). 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 effort needed for the transition, also including national/EU policies even if they are not necessarily under the responsibility of local authorities. Table 3 provides the share of PHEV and BEV vehicles, at base year and in 2030, in the BAU scenario.

Table 3: Madrid's EV uptake (PHEV and BEV) in Business-as-Usual (BAU) scenario, exogenous trend

Vehicle	2019	2030
		BAU
Car	0.6%	3.0%
Light-duty vehicle (LDV)	0.5%	4.2%
Heavy-duty vehicle (HDV)	0.0%	0.0%

Source: MOMOS Model

The transition scenarios simulated in this study build on the assumptions related to the vehicle fleet composition with an ambitious penetration of new vehicle technologies. The evolution of vehicle fleet composition is based on the assumptions of the EU "Fit for 55" strategy [15]. In this EU Scenario, 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 (fleet decarbonisation).

This exogenous trend assumes large improvements in energy efficiency of vehicles, resulting in a fuel consumption reduction of about 20% for ICE cars and LDV and of about 12% for HDV (considering both new and existing vehicles) between 2030 and 2019.

This trend is aligned with the implementation of the regulation on CO_2 emission standards for Light Duty Vehicles (LDVs) [16] and heavy-duty vehicles (HDVs) [17], resulting in more fuel-efficient vehicles being introduced into the market. These assumptions on the composition of the fleet are the same basis for all four transition scenarios, mentioned in the analysis as 'Technological innovation trend'. For Spain, the values of battery electric vehicles (BEV) stock shares in the model are based on forecasts of T&E's European Union Transportation Roadmap Model (EUTRM) [18]. As far as PHEV (plug-in hybrid vehicles) are concerned, the values are based on the EU Reference Scenario [19] projections. Thus, in Spain PHEV and BEV in 2030 account for 16.8% for cars, 12.8% for LDVs and 3.3% for HDVs.

On top of this exogenous trend, the model considers the impact of the simulated policies on the speed of EV uptake and fleet renewal.

On the energy side, assumptions related to the fuel prices[3] and energy mix for power generation are included to estimate the emissions on a well-to-wheel basis. The energy mix changes over time at the country level according to the exogenous energy trend: the transition scenarios simulated in this study considers both the current energy mix shares as well as the needed increase to reach the 69% renewables target, as set in the REPowerEU plan [20]. The same trend is assumed also in the BAU scenario.

3.7 Output indicators

The outcome of the MOMOS simulation consists of a series of quantitative indicators. Indicators are calculated for each scenario at the simulation's horizon year (2030) as well as compared to the values at base year (2019).

As the overall objective of the study is to simulate transition scenarios towards a zero-emission urban mobility by around 2030, the key indicator is the reduction in GHG emissions. In addition, a series of core indicators provide a more complete picture of the scenario simulations by outlining their effects on the transport, environment, social, and economic spheres.

Table 4 lists all the output indicators that have been calculated in the study.

[3] Fuel prices follow the EU Reference Scenario [19] trend.

Table 4: List of output indicators

Group	Indicator	Unit of measure
GHG emissions from transport	Total GHG emissions (tank-to-wheel, TTW) Total GHG emissions from all transport modes, considering trips within the urban area of residents, incoming city users and freight transport. Tank to wheel considers only the emissions related to the burning/usage of a fuel in a vehicle.	[kton CO2 eq / year]
	Per capita GHG emissions (tank-to-wheel) Ratio between total GHG emissions TTW (residents, incoming city users and freight transport) and inhabitants of the urban area.	[ton CO2 eq / capita per year]
	GHG emissions (well-to-wheel, WTW) Total GHG emissions from all transport modes, considering trips within the urban area of residents, incoming city users and freight transport. Well-to-wheel considers all the emissions, including related to the cascade of steps required to produce and distribute the energy carrier (starting from the primary energy resource), including vehicle refuelling.	[kton CO2 eq / year]
	Per capita GHG emissions (well-to-wheel) Ratio between total GHG emissions WTW (residents, incoming city users and freight transport) and inhabitants of the urban area.	[ton CO2 eq / capita per year]
	GHG emissions by sector (tank-to-wheel) (passenger and freight) Total GHG emissions TTW related to passengers (residents, incoming city users) and freight transport	[kton CO2 eq / year]
	GHG emissions by sector (well-to-wheel) (passenger and freight) Total GHG emissions WTW related to passengers (residents, incoming city users) and freight transport	[kton CO2 eq / year]
Transport behaviour	Aggregated internal modal split based on pkm Modal split estimated based on passenger-km within the urban area of residents only	[%]
	Aggregated internal modal split based on trips Modal split estimated based on the number of trips within the urban area of residents only	[%]
	Car ownership level Ownership of private cars compared to residents in the urban area, per 1,000 inhabitants	[cars/1,000 inhab]
	Private car vehicle-km Vehicle-km driven within the urban area by private cars, considering trips of both residents and incoming city users	[million vkm/year]

Group	Indicator	Unit of measure
Transport activity - Passenger	Total Passenger-km Passenger-km travelling within the urban area by any mode, considering trips of both residents and incoming city users (urban segment only)	[million pkm/year]
	Total travel time Total time spent travelling within the urban area for all passenger trips related to both residents and incoming city users (urban segment)	[million h / year]
	Average travel time Average travel time related to passenger trips within the urban area for both residents and incoming city users (urban segment)	[min / trip]
	Total trips Total passenger trips related to both residents and incoming city users (urban segment)	[million trips / year]
Transport activity - Freight	Total vkm Total vehicle-km driven within the urban area by any type of freight vehicles	[million vkm/year]
	Vkm by mode (HDV, LDV, Cargo-bike) Vehicle-km driven within the urban area by freight vehicles (HDV, LDV, Cargo-bike)	[million vkm / year]
Electric vehicles uptake	EV uptake of private cars Share of electric vehicles (PHEV, BEV) in the total stock of private cars (related to residents)	[%]
	EV uptake of public buses Share of Electric vehicles (PHEV, BEV) in the total stock of buses for PT service	[%]
	EV uptake of freight vehicles (LDV) Share of Electric vehicles (PHEV, BEV) in the total stock of LDV	[%]
	EV uptake of freight vehicles (HDV) Share of Electric vehicles (PHEV, BEV and FCEV) in the total stock of HDV	[%]
	EV uptake of private motorbikes Share of Electric vehicles (BEV) in the total stock of private motorbikes	[%]
Air pollutant emissions	Emissions of PM2.5 Sum of total particulate matter (PM2.5) emissions from exhaust and brake and tyre wear, from all transport modes considering trips within the urban area of residents, incoming city users and freight transport.	[g / capita]

Group	Indicator	Unit of measure
from transport	Emissions of NOx Total exhaust emissions of NOx, from to all transport modes considering trips within the urban area of residents, incoming city users and freight transport.	[g / capita]
	Emissions of CO Total exhaust emissions of CO, from to all transport modes considering trips within the urban area of residents, incoming city users and freight transport.	[g / capita]
	Emissions of VOC Total exhaust emissions of VOC, from all transport modes considering trips within the urban area of residents, incoming city users and freight transport.	[g / capita]
Energy	Energy and fuel consumption Total energy and fuel consumption, related to all transport modes and fuel/energy type considering trips within the urban area of residents, incoming city users and freight transport.	[million MJ/year]
Road Safety	Road traffic deaths Ratio between persons killed in a road traffic crash, immediately or dying within 30 days, and the inhabitants of the urban area	[road traffic deaths /100,000 inhab.]
	Road traffic injuries Ratio between persons injured in a road traffic crash, who was hospitalised for a period of more than 24 hours., and the inhabitants of the urban area	[road traffic injuries /100,000 inhab.]
	Road traffic deaths/pkm: All Modes Ratio between road traffic deaths and total amount of passenger-km for all modes	[road traffic deaths /1,000,000 pkm]
	Road traffic deaths/pkm: Cycling Ratio between road traffic deaths related to injury accidents involving bike and total passenger-km for cycling	[road traffic deaths /1,000,000 pkm]
Costs and savings	City Costs Cost sustained by the city (including public administration, service providers, etc.) associated to the implementation of the transition scenario. All costs are cumulated (2019 - 2030), discounted (3%), and compared to BAU scenario	[million €] [€/capita]
	City Revenues Revenues obtained by the city (including public administration, service providers, etc.) associated to the implementation of the transition scenario. All revenues are cumulated (2019 - 2030), discounted (3%), and compared to BAU scenario	[million €] [€/capita]

Group	Indicator	Unit of measure
	User Costs Cost sustained by the private user associated to the implementation of the transition scenario. All costs are cumulated (2019 - 2030), discounted (3%), and compared to BAU scenario	[million €] [€/capita]
	Freight Operators Costs Cost sustained by freight operators associated to the implementation of the transition scenario. All costs are cumulated (2019 - 2030), discounted (3%), and compared to BAU scenario	[million €] [€/capita]
	External Costs Savings Savings generated by a reduction of externalities associated to the implementation of the transition scenario. Externalities include: CO_2, air pollutants, road traffic injuries, and noise. All savings are cumulated (2019 - 2030), discounted (3%), and compared to BAU scenario	[million €] [€/capita]

4 Results of the study

In this section, the main results of the study for Madrid are presented and commented on. The full results, with the complete list of tables and figures, are included in Annex IV: Full results of the study.

4.1 GHG emissions

The core indicator of this study is GHG emissions. The model estimates both GHG tank-to-wheel emissions (i.e., only the emissions related to the burning/usage of a fuel in a vehicle) and well-to-wheel emissions (i.e., all the emissions related to the steps required to produce and distribute the energy carrier).

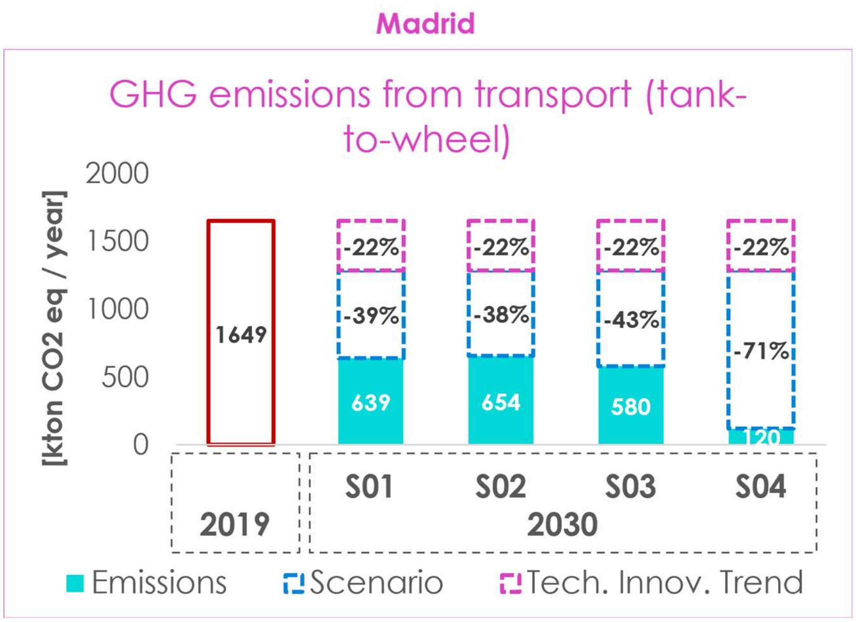

Figure 3: Tank-to-wheel greenhouse gases emissions from urban transport in Madrid

Looking at the tank-to-wheel GHG emissions, it is possible to see the respective contribution of both the technology innovation trend and of the policy scenarios.

A reduction of about 22% is achieved by the technology innovation trend (described in chapter 3.6). This accounts for a reduction of about 362 kilotons of CO_2-equivalents in terms of yearly emissions (when comparing 2030 with 2019), thanks to vehicle fleet renewal and vehicle efficiency improvements.

The policy scenarios are responsible for the remaining reductions. In S01 and S02, they account for 39% and 38% respectively, leading to an overall 61% and 60% reduction in CO2-equivalents. The policies in S03 add a 43% reduction, reaching a total reduction of 65%. In this respect, it seems possible to achieve similar results by either investing in behavioural change (S01) or in cleaner vehicles (S02). By combining these two approaches, a further reduction can be achieved as shown in S03.

Still, it is necessary to point out that the results of S03, which combines all the policies of S01 and S02, do not equal the sum of the results of the first two scenarios (see explanations in 3.3).

Despite these strong reductions in GHG emissions, none of the first three scenarios gets close to the zero-emission target. Based on the modelling, only when pushing these policies to the limits of feasibility in S04 (see 3.5) that it is possible to reach a reduction of about 93% of CO_2 emissions in 2030.

All these results include both passengers and freight mobility. To better understand the contribution of each segment, it is worth underlining that about 55% of the remaining emissions in 2030 are related to passengers' mobility, and the remaining 45% to freight transport.

Looking at the well-to-wheel emissions, a slightly lower result is reached in terms of reduction compared to 2019. In Madrid, assuming the exogenous renewable electricity target (see section 3.6), a reduction of 59% is estimated in S01 and 58% in S02, which becomes 62% in S03, and 84% in S04.

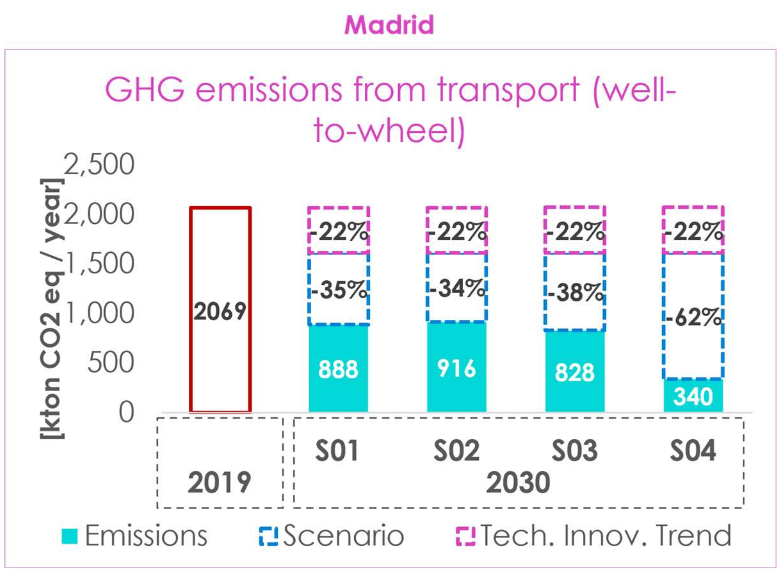

Figure 4: Well-to-wheel greenhouse gases emissions from urban transport in Madrid

4.2 Transport

One of the other key transport output indicators is the modal split (or modal share). This indicator captures the mobility patterns of residents of the study area. The modal split is calculated based on the share of passenger-km travelled by each mode. Only trips occurring within the study area are taken into account, thereby excluding trips originating outside of it. The four scenarios affect the modal split in different ways, and by shifting trips to low carbon modes, it contributes to the reduction of GHG emissions.

Transport modes are aggregated in four categories: Private Motorized (private cars, both as driver or passenger, and motorbikes), Public Transport (metro, tram, buses, and DRT, where implemented), Active Modes (walking, cycling and micro-mobility), and Shared Mobility (car, bike, moped and e-scooter sharing). Detailed results by mode are reported in Annex IV.

With respect to the base year 2019, S01 and S03 indicate about 12 and 11 percentage points of reduction in the share of private cars and motorbikes. This reduction is mainly driven by traffic management measures, by improved accessibility, and by increased attractiveness of alternative modes, in line with the *Avoid-Shift-Improve* paradigm.

On the one hand, travelling by private cars is made more time-consuming due to traffic regulations (e.g., traffic calming) and more expensive due to parking pricing. On the other hand, people are encouraged to use more public transport thanks to measures that enhance and prioritize the service as well as lower its cost.

Additionally, active modes are made more attractive thanks to larger pedestrian areas and improved cycle paths, thus making it more comfortable and safer to use the bike or to walk. In particular, the bike modal share rises from 0.5% in 2019 to 3.31% in 2030 in both S01 and S03. It is worth underlining that bike sharing users are accounted for in the shared mobility category. Therefore, the actual number of people using a bike as their main mode of transport is actually even higher than shown in the active modes indicator.

In addition, there is an increased use of shared mobility (including car, bike, moped and e-scooter sharing), achieved through service improvements (i.e., more vehicles/devices available in the study area).

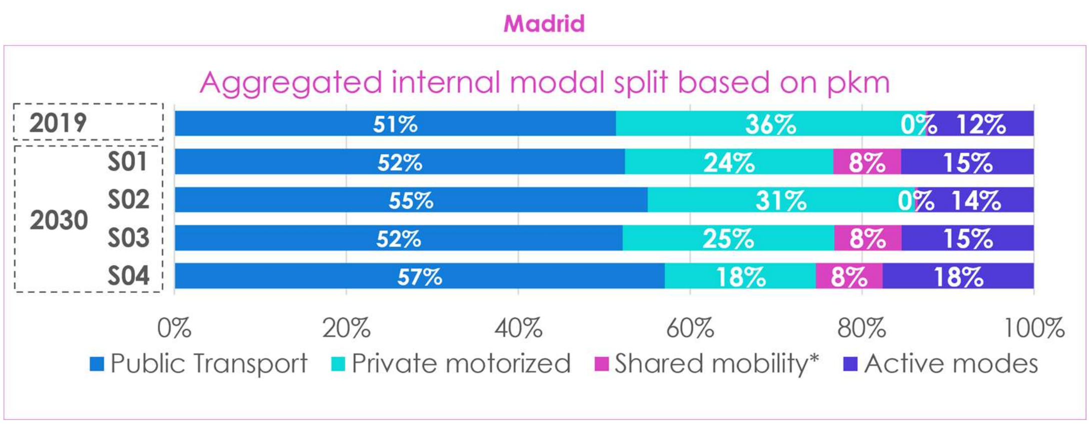

Figure 5: Aggregated internal modal split based on passengers-km in Madrid.

*Shared mobility includes car, bike, moped and scooter sharing.

A slightly different result is achieved in S02. Since this scenario's main focus is on the renewal of the vehicle fleet and the acceleration of the EV uptake, smaller variations in the modal split are obtained. Shared mobility, public transport and active modes are not strongly incentivized. Nevertheless, a small reduction of 5 percentage points of the modal share of private cars is observed. This is mainly caused by the implementation of a low-emission zone (LEZ) over the whole urban area, which restricts access to cleaner vehicles only. The LEZ is the driver of 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.

This measure is implemented in all scenarios. Nevertheless, with respect to S01 and S03, the impact on modal split is less strong, because in S02, other policies also contribute to faster fleet renewal and EV uptake. The accelerated uptake of BEV and PHEV means that fewer vehicles are affected by the access restrictions imposed through the LEZ and, as a consequence, a smaller modal shift away from the car is observed in Scenario 2.

Looking at the modal split in S04, a very strong change in the mobility behaviour is expected. From 2019 to 2030, the share of private cars and motorbikes decreases by 18 percentage points. These trips shift mostly to shared mobility (+7.5 percentage points) but also to public transport (+5.5 percentage points) and walking and cycling (+5 percentage points).

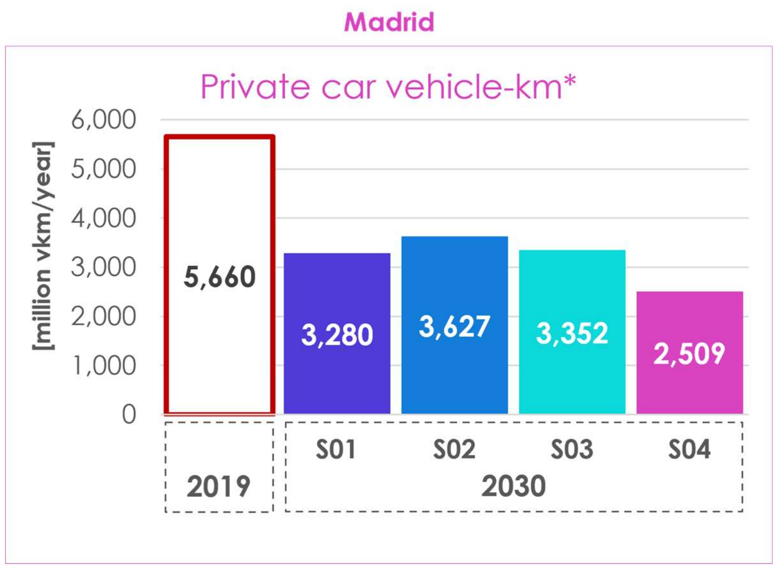

Figure 6: Private car vehicle-km in Madrid

*Including both internal and incoming trips (city segment only)

Reducing car dependency in urban areas can improve the liveability of cities and provides many (co-)benefits. These include reduced GHG emissions (as seen in the previous section), lower levels of air and noise pollution, less congestion and road traffic crashes. In this sense, an important indicator is also the number of car vehicle-km travelled in the study area (including both internal and incoming trips).

S02, which is mainly focused on the renewal of the vehicle fleet, has the lowest reduction with -36% vehicle-km with respect to the base year. In S01 and S03, a larger reduction (-42% and -41%) is achieved, which is even larger in the ambitious S04 (-56%). S04's substantial reduction is mainly due to the impact of this scenario on incoming trips (modal shift, increased multimodality through Park&Ride facilities, diffusion of car-pooling and increased car-occupancy, and trips avoidance). In fact, it is worth noting that incoming trips contribute significantly to urban traffic in the Madrid municipality, being estimated as about 23% of total trips in the area. As already mentioned for the modal split, S04 requires drastic changes in how people move, resulting in a higher reduction of private car usage.

Whereas the modal split of motorised transport, car-vehicle km, and car ownership are all interconnected, the scenarios generate smaller reductions in the number of cars owned over the years by residents in the urban area. In fact, at least in the short term, even if users might change their daily mobility habits, a smaller proportion is ready to abandon private cars. Indeed, a car might continue to be a necessity for certain types of trips (e.g., extra-urban, day trips, etc. where no alternative options can offer the same level of flexibility as the private vehicle). Compared to 2019, the level of car ownership decreases by about 6% in S02, and 10% in S01 and S03. On the other hand, S04 reaches a remarkable -27% of cars owned by 2030.

Modal shift and changes in private car usage also affect travel time[4]. Two different indicators are reported on this aspect: the average travel time per trip and the total travel time. The first one is affected by the mobility choices in terms of transport mode used, time performances of the services provided (also in terms of waiting time or time to pick up a shared vehicle) and road congestion. On the other hand, total travel time also considers the overall number of trips made within the city (considering both internal and city segments of incoming trips).

As a result of a shift towards (generally) slower transport modes, average time per trip increases in S02 (1.6%) and S04 (0.7%). On the other hand, in S01 and S03 the average travel time decreases by -1.8% and -1.2%. Indeed, the implementation of traffic-calming measures (expected to cover 85% of the core urban area in 2030) means slightly lower speed and higher travel times also for private cars. Nevertheless, S01 and S03 contain policies focused on the enhancement of public transport and alternative modes.

Total travel time decreases with respect to the base year (between -1% and -5%). However, in this result, two components that act in opposite directions need to be considered. On the one hand, transport demand is growing over time as a direct

[4] Due to the aggregated nature of the model, not including a detailed transport network and traffic assignment process, travel times are the results of an approximated approach.

impact of population growth. On the other hand, the implementation of working from home policies reduces the number of commuting trips made.

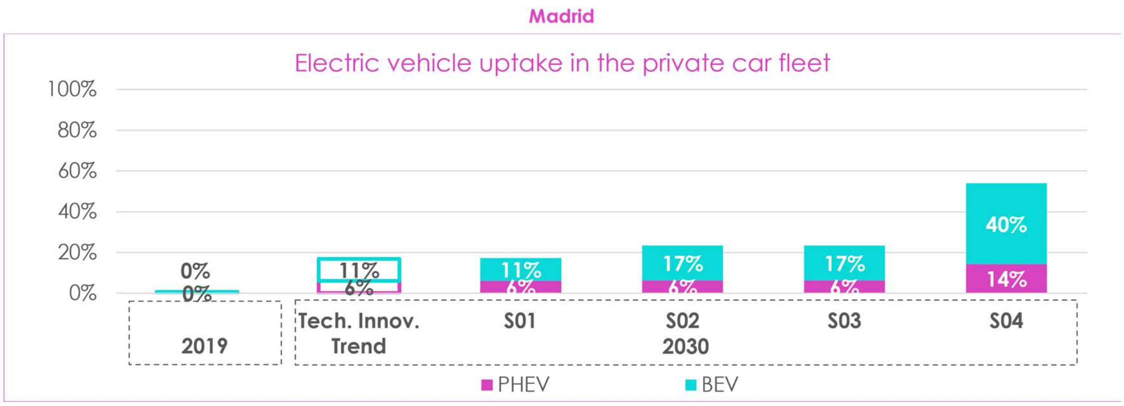

Figure 7: Electric Vehicles uptake in the private car fleet in Madrid

As already mentioned, S02 is focused on fleet electrification and renewal as the core element for a sustainable transition. Therefore, it reaches a higher uptake of electric private cars with respect to S01. The uptake of electric vehicles reaches 17% and 6% for BEV and PHEV respectively in 2030. The same result is also achieved in S03, where the same measures to incentivise electrification are applied. The Technological Innovation Trend contributes to a strong uptake of electric vehicles, resulting in a 11% share of BEV and a 6% share of PHEV with respect to the total stock.

An even larger uptake of electric vehicles is achieved in S04, where the zero-emission zone (ZEZ) alongside more ambitious policies supporting vehicle electrification are implemented. In this scenario, the share of BEV and PHEV in 2030 rises to 40% and 14% respectively. In the longer term and beyond 2030, it is expected that the share of PHEV will decrease, in favour of an even larger uptake of BEV vehicles.

Beside the passenger sector, freight transport is also relevant when it comes to analysing the impacts of a sustainable transition in urban mobility. In Madrid, an estimated 25% of CO_2 emissions from transport was emitted by road freight vehicles in 2019.

Generally, two ways can be taken to reduce emissions and congestion from freight: one is fleet renewal and modal split change, the other is the efficiency increases. Dedicated policies (e.g., urban delivery services) help optimise goods per vehicles and reduce the number of shipments by increasing their efficiency. Additionally, freight vehicles can be pushed towards a greener fleet with the low-emission zone, and with specific policies for the renewal of the vehicle fleet.

Also, to avoid high investment costs, one can choose to move goods with alternative and more sustainable services (e.g., cargo-bikes). However, it is important to point out that not all categories of goods can be moved by cargo-bikes and therefore in these cases the shift from HDV or LDV is limited.

In MOMOS, freight transport is simulated considering shipments by both trucks (LDV and HDV) and cargo-bikes. When looking at the results of freight vehicle-km, it is important to keep in mind the very different load factors according to the type of vehicle. Indeed, the shift from one vehicle to the other (especially if towards cargo-bikes) can lead to strong increase in the number of vehicles with lower capacity.

Madrid

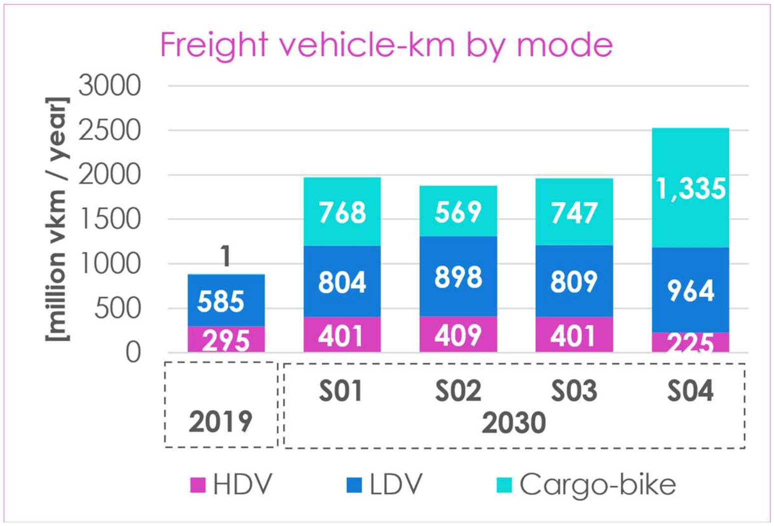

Figure 8: Freight vehicle-km by mode in Madrid

Looking at the scenario results, all of them assume the diffusion of cargo-bike delivery services at different rates: S01 and S03 show similar values of vehicle-km for cargo-bike and LDV, resulting from several policies boosting the mode shift (e.g., LEZ) and promoting the uptake of cargo-bikes. The difference between S01 and S02 in the number of vehicle-km by cargo-bike is due to two factors. Firstly, in S02 there is no dedicated policy to further increase this typology of freight vehicles. Secondly, the higher vehicle fleet renewal and electrification of S02 (also affecting LDVs and HDVs) means that fewer freight vehicles are affected by the LEZ restrictions. With the boosted policies associated with S04, both freight vehicles electrification and cargo-bike vehicle-km significantly rise, whereas LDV and HDV vehicle-km are slightly decreased thanks also to the assumed enhanced optimization of load factors.

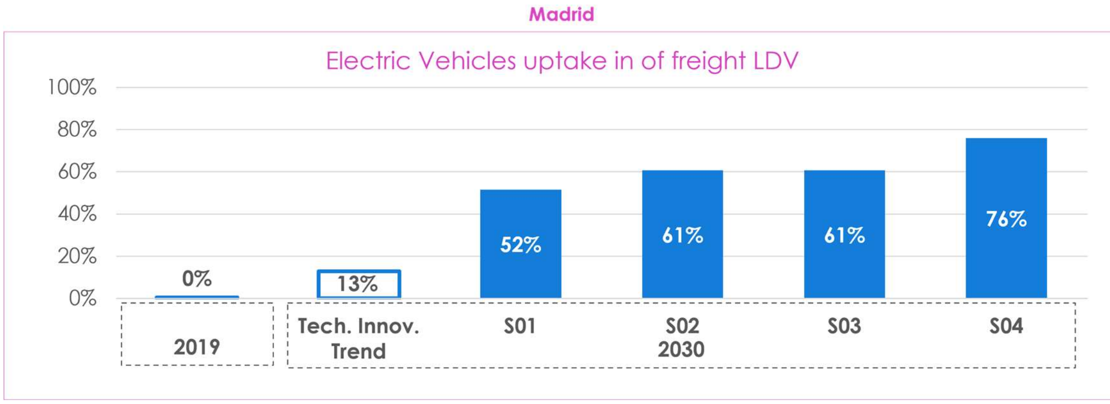

Figure 9: Electric Vehicles uptake in freight LDV in Madrid

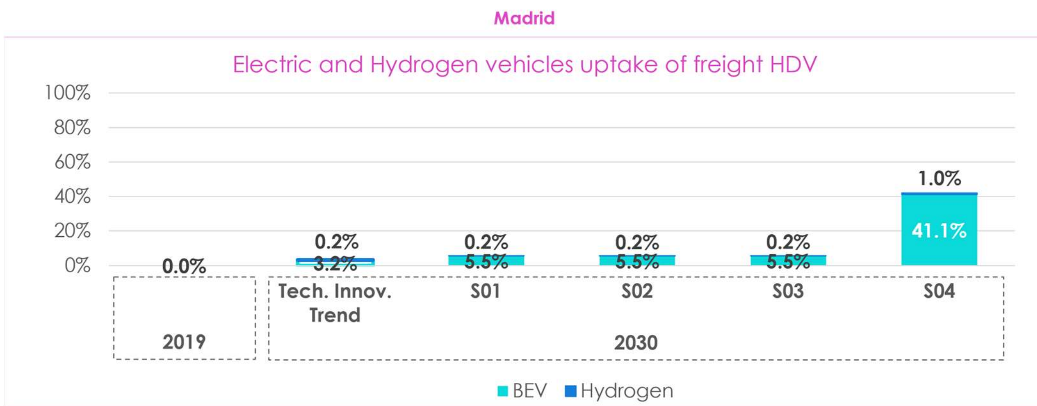

Figure 10: Electric and Hydrogen vehicles uptake of freight HDV in Madrid

Across the four policy scenarios, the trend towards electric Light Duty Vehicles (LDV) is similar to the one in private cars: in 2030, S01 achieves a share of about 52% for PHEV/BEV LDV. S02 and S03 show a higher increase (61%), while in S04 an even larger EV uptake is expected (76%). The exogenous Technological Innovation Trend is responsible for about 13% of the electric share for LDV.

For High Duty Vehicles (HDV), both battery electric and hydrogen vehicles are worth mentioning in 2030. In the first three scenarios, these types of vehicles account for about 9% of the total fleet. With the more restrictive LEZ regulations of S04, the BEV share grows to 41% and the hydrogen' share to 1%.

Overall, these shares are higher with respect to passenger cars, assuming that commercial operators could be more receptive to renewing their fleet and to the shift caused by the implementation of an LEZ (and a ZEZ in S04). Of course, the model is simulating a very demanding renewal rate and investments on the LDV side. Additionally, compared to private cars, freight and logistic operators have fewer alternatives to keep moving goods inside the city context. Thus, in case of traffic restrictions, besides replacing a portion of vehicles with cargo-bikes, the only alternative is a forced change to the vehicle technology with BEV (of PHEV) trucks.

The energy and fuel consumption is mainly driven by trends in transport demand and technology. From 2019 to 2030, the total energy consumption almost halves in the first three scenarios (-49% in S01, -46% in S02, -51% in S03) and decreases by 70% in S04. This result is the consequence of fleet renewal, traffic reduction, but also efficiency improvements of internal combustion engine vehicles (see 3.6).

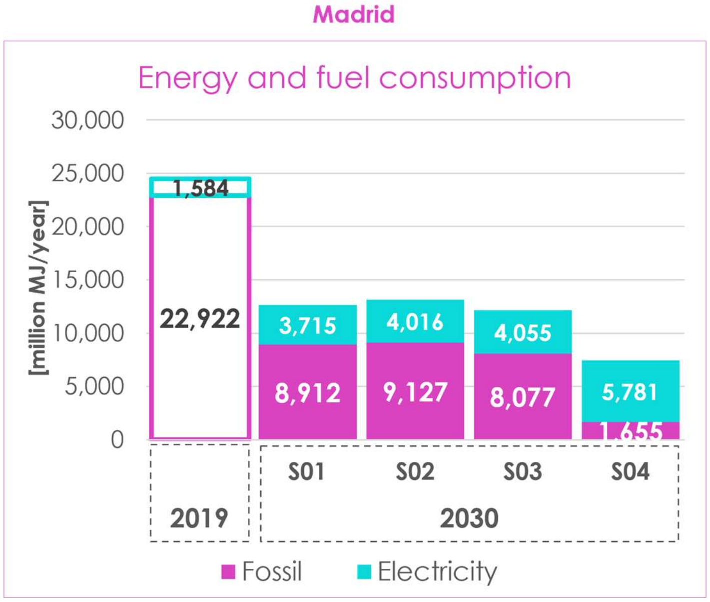

Figure 11: Energy and fuel consumption in Madrid

It is also worth noting that, at the base year, only 6.5% of the energy consumed comes from electricity, while 93.5% comes from fossil fuels. In 2030, in turn, electricity will account for about 30% in S01, S02 and S03, and 78% in S04.

4.3 Air pollutant emissions

Beside GHG emissions, urban mobility generates air pollutant emissions that pose a risk to the health of citizens. For this reason, the model simulated emissions from road transport, including of PM2.5 (Particulate Matter), NOx (Nitrogen Oxides), VOC (Volatile Organic Compound) and CO (Carbon Monoxide).

For what concerns PM2.5, all scenarios are expected to reduce PM2.5 emissions (considering both exhaust and non-exhaust components). S02 is less effective than the others. In fact, PM2.5 emissions are caused not only from fuel combustion, but also from tyre and brake wear. This way, an electric vehicle continues to produce PM2.5 emissions, especially due to tyre war (brake wear can be reduced thanks to regenerative braking system).

Moreover, air pollutant emissions also depend on traffic demand. Combining fleet renewal, mode share change, and a drop in traffic demand, it is possible to explain the results obtained. The reductions range from -53% in S02 to -65% in S04. In this respect, fleet renewal and EV uptake are responsible for reductions of about -19% in PM2.5 emissions between 2019 and 2030.

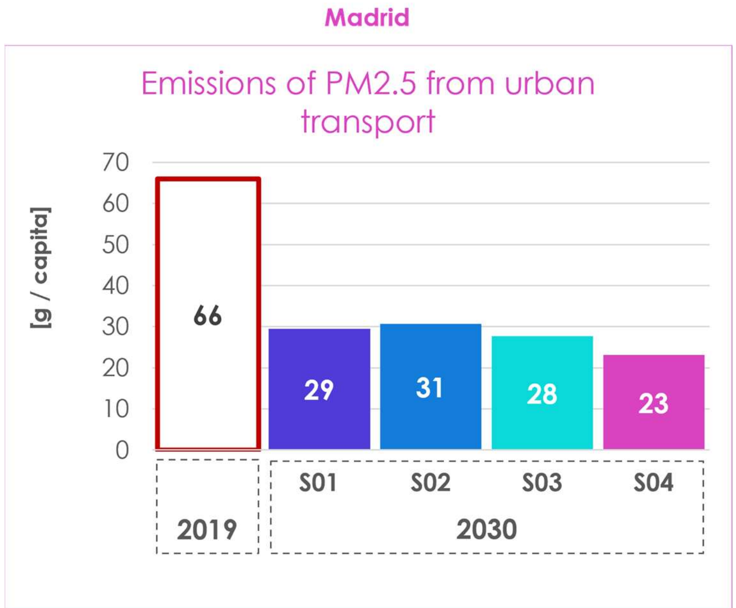

Figure 12: Emissions of PM2.5 in Madrid

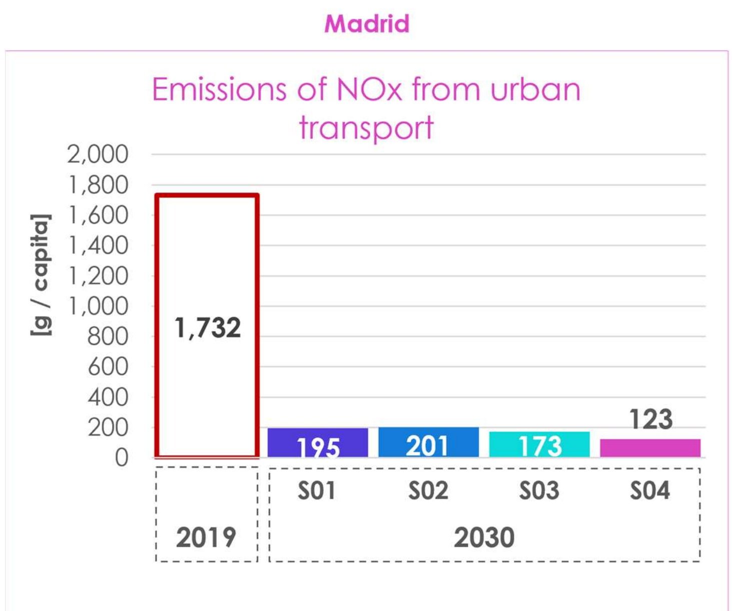

Figure 13: Emissions from NOx in Madrid

Similar results are observed for the other pollutants, except for NOx emissions, which drop by more than 80% in the first three scenarios, and more than 90% in the S04. This is explained by reductions in traffic demand and by the renewal of the vehicle fleet (accounting for about -19%) with more restrictive emission limits set for newest engines concerning NOx [21].

Detailed results on the emissions of PM2.5, NOx, VOC, and CO are available in Annex IV: Full results of the study.

4.4 Road safety

Despite considerable improvements in road safety achieved in the past decades, the number of transport-related deaths and injuries is now stagnating at high levels, especially within many urban areas [22]. In fact, according to the European Green Deal, road traffic deaths should eventually tend towards zero by 2050.

In S01 and S03, the implementation of policies aiming at improving safety for cycling and walking allows to achieve slight reductions in road traffic deaths with respect to 2019 (-4.1% in S01, -5.6% in S03). One of the main reasons for these relatively small reduction is that in Madrid, traffic calming (the most effective policy in terms of safety) was already in place at the base year, thus resulting in a lower reduction effect. S02 and S04 achieves marginally better results thanks to technological measures to improve transport safety (e.g., cooperative-ITS). It should also be noted that road traffic deaths shown in the chart below are in relation to the population size. However, the total amount of road traffic deaths also reflects the increase in the number of kilometers cycled. Therefore, to complement the analysis, the fatality rate (as ratio between road traffic deaths and kilometers cycled) is included in the Annex IV: Full results of the study.

To further explain the impact of the different scenarios on road traffic deaths, it is worth noting that there are two main components affecting the trend. On the one hand, the reduction of private cars and trucks drives down the number of road traffic deaths, when more people are moving to safer modes, such as buses and metros. Furthermore, the construction of dedicated infrastructure (cycling lanes or pedestrian areas) can improve the safety of pedestrians and cyclists. On the other hand, cyclists are the most vulnerable road users, with the highest fatality rate. Therefore, in the expected decrease of road traffic deaths, the fact that more people are using the bike as a transport mode contrasts with the fact that the infrastructure is generally safer, thus limiting the overall reduction.

Madrid

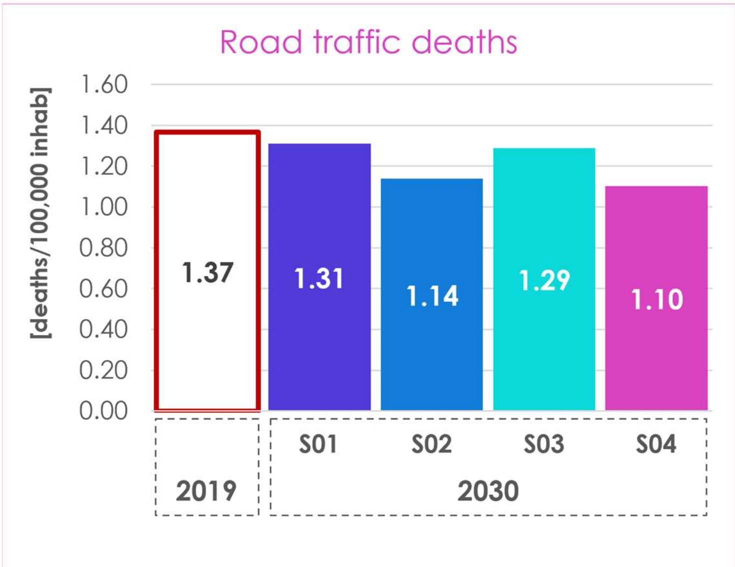

Figure 14: Road traffic deaths in road transport in Madrid

In Annex IV: Full results of the study, other indicators related to safety are reported, such as road traffic injuries, road traffic deaths per passenger-km, both for all modes and with a focus on cycling only.

4.5 Costs and Savings

On the basis of the output provided by the MOMOS model, an analysis of the impacts in monetary terms has also been performed. The objective is to estimate costs and benefits associated with the transition scenarios.

Most of the policy measures implemented in the scenarios imply specific costs for the city (for the implementation and management of the measures) but also generate revenues. The analysis has quantified those costs and revenues[5]. Furthermore, it also included the monetisation of externalities (GHG emissions, air pollutant emissions, noise, and road traffic injuries/deaths) and savings or losses for passengers and freight operators in terms of transport costs. The aim is to allow a comparison between the four transition scenarios, highlighting areas and aspects where scenarios perform better (e.g., environmental benefits) or worse (e.g., high costs).

The investments lead to reductions in air pollutants and GHG emissions, fewer road traffic deaths, and less noise[6], generating benefits while improving the quality of life

[5] As an example, as outlined in Madrid SUMP 2022, in the City Council has a planned investment of up to 2 million euros to promote, through subsidies, the renewal of the bus fleet until 2025, whereas 50 million euros are earmarked for completing the cycling network by 2030 and 500 million euros for the Improvement of the main pedestrian routes in the neighbourhoods.
[6] Noise is calculated by multiplying the transport activity (per mode) by the Handbook's unitary cost (per pkm/vkm).

inside the urban area. By monetising these reductions, it is possible to assess the external cost savings associated with the implementation of the scenarios.

The monetisation of externalities has been performed in $Euro_{2021}$ with reference to the unit costs published in the Handbook on external costs of transport [23] and the *Economic Appraisal Vademecum 2021-2027* [24]. The unitary values (applicable to Spain) are shown in Table 10 in Annex I: Study area and input data.

It is important to underline that all costs and revenues considered are only those associated with the implemented policies and are additional with respect to the business-as-usual (BAU) scenario (see 3.6). In the BAU scenario, no policy measures are simulated, and conservative exogenous trends are applied. 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.

All costs are cumulated over the analysis period (2019 – 2030). This allows us to comprehend all the investments and maintenance costs needed, as well as benefits in terms of the reduction in externalities over time. A yearly discount rate of 3% has been applied, as also recommended by the *Economic Appraisal Vademecum 2021-2027*.

With respect to the city, two components are presented: costs and revenues. Costs refer to the maintenance, management and implementation costs, such as the construction of new metro lines, cycle lanes, priority systems for buses, monitoring systems for traffic management, etc. On the other side, city users (residents, freight operators and people incoming from outside) pay for the services, leading to city revenues.

Looking at the city's costs and revenues, the amount of money invested by the city in S02 is the lowest across the four scenarios. Indeed, the policies in this scenario are mainly focused on vehicle fleet renewal, paid by the city users. That said, city costs are higher than city revenues in all simulated scenarios.

Table 5: Costs and revenues of the four scenarios in Madrid

Costs and revenues in Madrid	
[million euro]	**2019 2030 (cumulated)**

	S01	S02	S03	S04
City costs	1,688	1,046	1,830	2,141
City revenues	1,134	540	1,133	1,474
User costs	2,141	2,685	2,331	3,928
Freight operators' costs	1,505	1,877	1,679	1,970
TOTAL Net cost	**4,200**	**5,068**	**4,707**	**6,565**

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. Users pay slightly more in S02 (compared to S01 and S03) due to higher fleet renewal required from both residents and incoming city users. In fact, the introduction of the LEZ, for example, forces both the resident population and incoming citizens to change mode or change their vehicle to comply with access restrictions. The higher intensity of S04's policies also requires a higher economic effort from users.

Looking at costs borne by the freight operators, S01 is the least costly, while the higher cost is foreseen in S04, due to the more restrictive regulations of the LEZ resulting in a more ambitious and costly freight fleet renewal.

Overall, looking at total net costs (calculated as the difference between total revenues and costs) and without taking into account external costs (see below), S02 is the cheapest (4.2 billion euros) and the S04 is the most expensive (6.57 billion euros).

Due to the different unitary costs associated, the external costs savings have different orders of magnitude. Road traffic injuries/deaths account for the larger portion of the savings, followed by GHG emissions reduction. Whereas S01 and S03 are quite similar in total savings, S02 shows an overall slightly lower result. This is mainly due to a much lower reduction in road traffic crashes and is a direct consequence of lower reductions in the private car share and less emphasis on safe infrastructure for pedestrians and cyclists. Finally, in S04 the whole set of external costs savings is larger than the first three scenarios, as can be expected from the more ambitious target set in this scenario.

Table 6: External costs savings of the four scenarios in Madrid

External costs savings in Madrid				
[million euro]	**2019 2030 (cumulated)**			
	S01	**S02**	**S03**	**S04**

GHG	1,183	1,148	1,259	1,982
Air pollutants	359	351	365	388
Road traffic injury/deaths	3,122	2,695	3,131	5,433
Noise	306	234	310	672
TOTAL Savings	**4,970**	**4,427**	**5,065**	**8,474**

Table 7: Comparison between total net costs and total net savings in Madrid

Costs vs net savings in Madrid				
[million euro]	**2019 2030 (cumulated)**			
	S01	**S02**	**S03**	**S04**
TOTAL Net costs	**4,200**	**5,068**	**4,707**	**6,565**
TOTAL Savings	**4,970**	**4,427**	**5,065**	**8,474**

In three scenarios, the total savings from externalities reduction generated by the policies' implementation outweigh the total net costs of the scenarios. This is true for S01, S03 and S04.

Figure 15: Net costs per ton of CO2-equivalent reduced in Madrid

The cost of each scenario can also be presented as costs per ton of CO_2-equivalent reduced. S02 – that showed the lowest reduction in GHG emissions – also achieves the worst result in this regard. On the other hand, even if S04 has the largest costs associated, its very high abatement in CO_2 emissions results in the best ratio between costs and tons of CO_2 abated.

Finally, the time saving component requires a clarification. The aggregated nature of the model requires an approximation for the travel time indicators (Total travel time, Average travel time). Therefore, it is not appropriate to monetise travel time savings. In addition, some recent controversy emerged in scientific literature about the correct method to monetise small time savings (i.e., the most frequent typology of trips in urban contexts) [25]. Furthermore, in the transition scenarios, a part of the travel time savings is linked to a smaller number of trips due to cancelled activities commuting trips not carried out because of the "working from home" policy. It is still unclear how such travel time savings should be evaluated.

Moreover, the health benefits of higher levels of physical activity from increased walking and cycling are not quantified and monetised either, despite the scenarios S01, S03 and S04 showing a shift towards active travel which is likely to generate significant health benefits.

4.6 Policy effectiveness

The results of this study reflect the combined effects of different sets of policy measures implemented within the same scenario. As explained above, there is a strong correlation among policies, which can reduce or amplify each other's effect.

Nevertheless, each single policy could be "isolated" from the scenario, and its individual effectiveness in reducing CO_2 emissions could be estimated. Of course, the effects of each single policy should be taken carefully as they are strongly linked to the base year situation as well as to the 2030 intervention levels foreseen for each policy in the specific context of application.

In Madrid, the policies with the highest individual[7] impact on GHG emission reductions between 2030 and 2019 are:

- a low-emission zone (LEZ) for passenger traffic and for freight
- Cycling and network facilities
- Greening the public transport fleet
- Greening the logistics fleet
- a Limited Traffic Zone (LTZ) for passenger traffic

[7] Without taking into account synergies among policies

5 Conclusions

This study has assessed the transition towards a zero-emission urban mobility by 2030 in the city of Madrid. Similar analyses have been carried out for 4 other cities and metropolitan areas and are available in separate documents.

The simulation did not have the intention of presenting the most likely transition outcome but simulated potential transition scenarios in a context of large uncertainty (policies, trends, etc.) while demonstrating the efforts needed to reach (near) zero-emission urban transport by around 2030. The impact of the different scenarios on mobility patterns, the environment and road safety were also assessed.

The simulation results showed that reaching the zero-emission target by 2030 is very challenging in Madrid, considering the magnitude of the needed interventions and the very short timeframe in which these changes need to be implemented.

The simulation of the most ambitious scenario (S04) suggests that with a set of highly ambitious and targeted policies, a 93% reduction of greenhouse gas (GHG) emissions is attainable. However, getting there implies strong changes in the mobility behaviour of citizens, especially in terms of their modal choice, primarily by reducing car use in favour of alternative modes of transport. A very strong uptake of zero-emission vehicles in the fleet is also essential for a successful transition. High fleet renewal rates as well as the decarbonisation of last-mile delivery with cargo-bikes and increased efficiency of freight transport are equally required.

Although they do not get close to the zero-emission target, scenarios S01 and S02 have both shown that a strong emissions reduction (-61% and -60% reduction of GHG respectively) can be achieved by either focusing on the improvement of urban transport infrastructure, shared mobility, and traffic regulation (S01) or on the uptake of electric vehicles in the fleets (S02). These results suggest that different pathways could be followed towards the goal of decarbonisation, prioritising different sets of measures. By applying the same policies altogether (S03) a -65% reduction of GHG emissions is obtained. Compared to S04, the policies included in the first three scenarios are comparatively less ambitious (though they remain ambitious in their own right). While this might help implementation and acceptance of these measures, neither of the three achieves the reductions in GHG emissions from urban transport that are required. This is only achieved by the most ambitious scenario, S04.

As explained above, this study only aims to illustrate potential scenarios for the sustainable mobility transition of European cities and clarify what measures and what level of ambition is required to switch to zero-emission urban mobility in European cities. This can help a better design of policy parameters, targets, and scenarios that are aligned with the local vision and near or long-term mobility and overarching objectives.

The main results and outcomes of this study are also available in this user-friendly online dashboard.

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Annex I: Study area and input data

Table 8: Districts categorization in Madrid

Category	District name	Category	District name
Urban Core Area	Centro	Urban Core Area	Usera
Urban Core Area	Arganzuela	Urban Core Area	Puente de Vallecas
Urban Core Area	Retiro	Urban Core Area	Moratalaz
Urban Core Area	Salamanca	Urban Core Area	Ciudad Lineal
Urban Core Area	Chamartin	Urban Core Area	Hortaleza
Urban Core Area	Tetuan	Urban Core Area	Villaverde
Urban Core Area	Chamberi	Peripheral Area	Villa de Vallecas
Peripheral Area	Fuencarral - El Pardo	Peripheral Area	Vicalvaro
Peripheral Area	Moncloa - Aravaca	Urban Core Area	San Blas - Canillejas
Urban Core Area	Latina	Peripheral Area	Barajas
Urban Core Area	Carabanchel		

Table 9: List of the input indicators for Madrid

Group	Input data	Description	Categories	Values	Source
Urban context	**Area typology**	Type of the study area	City or Functional Urban Area	City	
	Population	Population of the city / FUA	//	3.29 m	Portale Stadistico
	Population structure	Age distribution of the city population	a) <18 b) 18-65 c) >65	a) 13% b) 67% c) 20%	Portale Stadistico
	Population growth	Expected trend of the population growth	//	+0.57%	Population Projections 2022-2072, Instituto Nacional de Estadistica (INE), 2022 and World Population Review
	Population distribution	Population distribution between city centre and outskirts	a) urban core area b) peripheral areas	a) 82% b) 18%	Portale Stadistico
Urban mobility	**Motorization rate**	Number of private cars every 1,000 inhabitants	//	575	EUROSTAT

Group	Input data	Description	Categories	Values	Source
	Modal split	Modal split with respect to the urban area only	a) walk b) bike c) motorbike d) car e) bus f) tram g) metro	a) 36.0% b) 0.7% c) 2.0% d) 26.0% e) 16.0% f) 0.6% g) 19.1%	TRT elaboration from data of Madrid SUMP 2021
	Congestion level	Qualitative description of road congestion in the city	1 = negligible 2 = only during rush hours 3 = significant	Only during rush hours *(TomTom Index: congestion level 23%)*	TRT elaboration from data of TomTom Index and TomTom Index 2019
	Incoming trips	Share of incoming trips in the urban area, with respect to the total amount of trips within the area	//	23%	TRT elaboration from data of Encuesta Movilidad 2018
	Modal split of the incoming trips	Modal Split of the incoming trips into the urban area	a) private car b) train c) bus	a) 61% b) 20% c) 20%	TRT elaboration from data of Encuesta Movilidad 2018
	Freight vehicles rate	Share of freight vehicles with respect to the total vehicles (freight and cars) travelling in the urban area	//	5.0%	TRT elaboration from data of Madrid SUMP 2021
Public transport	**Ticket price**	Average Ticket price per journey (€)	a) subscribers b) single users	a) 1.1 b) 1.5	Monthly pass for Zone A (2023) and One-way ticket, Metro ticket (Metro Zone A and ML1) (2023)
	Cost	Implementation and management costs for public transport operators (€/vkm)	a) bus b) tram c) metro	a) 3.9 b) 3.9 c) 3.9	CRTM Annual report 2020
	Network	Length of the network (km)	//	2,249	Consorcio Transportes Madrid
	Average speed	Average speed of the vehicles (km/h)	a) bus b) tram c) metro	a) 13 b) 25 c) 31	EMT Madrid, Metro Madrid
	Transport service offer	Annual vehicle-kilometre (million vkm)	a) bus b) tram c) metro	a) 96.4 b) 15.7 c) 164.8	EMT Madrid, Consorcio Transportes Madrid

Group	Input data	Description	Categories	Values	Source
	Public transport reserved lanes	Length of the public transport reserved lanes (km)	//	197	Intelligent Transport
Transport infrastructure	**Bike lanes**	Length of the bike lanes in the urban area (km)	//	239	Data provided by CCC via cities or Openstreetmap data
	Electric charging stations	Number of electric charging stations	//	2,844	Eco-Movement
	Park & Ride capacity	Number of parking lots	//	6,876	Park&Ride Madrid
Parking	**Paid parking**	Number of paid parking lots in the urban area	//	150,554	Madrid SUMP 2021
	Parking price	Average hourly parking price (€)	//	1.4	Servicio de Estacionamiento Regulado Madrid
Car sharing	**Vehicle fleet**	Number of car sharing vehicles	//	2,766	Data provided by CCC via cities and Fluctuo
	Tariff	Average tariff (€)	a) fixed b) hourly	a) 0.0 b) 10.0	Car sharing Madrid
Bike sharing	**Vehicle fleet**	Number of shared bicycles	//	4,050	Data provided by CCC via cities and Fluctuo
	Tariff	Fixed and hourly average tariff (€)	a) fixed b) hourly	a) 20.0 b) 1.55	BiciMad
	Area coverage	% of the study area covered by the service at base year	//	80%	BiciMad
Moped sharing	**Vehicle fleet**	Number of shared mopeds	//	5,000	Official Tourism Website
	Tariff	Fixed and hourly average tariff (€)	a) fixed b) hourly	a) 0.0 b) 15.0	Official Tourism Website
	Area coverage	% of the study area covered by the service at base year	//	80%	Official Tourism Website
Micromobility	**Vehicle fleet**	Number of shared micromobility devices	//	6,270	Data provided by CCC via cities and Fluctuo
	Tariff	Fixed and hourly average tariff (€)	a) fixed b) hourly	a) 0.0 b) 9.0	Fluctuo
Traffic control and management	**Limited Traffic Zone (LTZ) - Passenger**	Quantification of the share of urban area under LTZ for passengers (%)	a) urban core area b) peripheral areas	a) 0% b) 0%	Urban Access Regulations

Group	Input data	Description	Categories	Values	Source
	Limited Traffic Zone (LTZ) - Freight	Quantification of the share of urban area under LTZ for freights (%)	a) urban core area b) peripheral areas	a) 22% b) 0%	Urban Access Regulations
	LTZ time	Time of the day when LTZ is active for freight vehicles	0 = Never 1 = Peak 2 = Off peak 3 = All day	All day	Urban Access Regulations
	LTZ modes - Freight	Type of vehicles banned from LTZ access	0 = None 1 = HDV 2 = LDV 3 = HDV & LDV	HDV & LDV	Urban Access Regulations
	Low Emission Zone (LEZ) - Passenger	Quantification of the share of urban area under LEZ for passengers (%)	a) urban core area b) peripheral areas	a) 22% b) 0%	Urban Access Regulations
	Low Emission Zone (LEZ) - Freight	Quantification of the share of urban area under LEZ for freigths (%)	a) urban core area b) peripheral areas	a) 0% b) 0%	Urban Access Regulations
	Pedestrian areas	Quantification of the share of urban area with pedestrian areas (%)	a) urban core area b) peripheral areas	a) 1% b) 0.5%	Madrid Web Portal
	Traffic calming area	Share of the urban area under 30 km/h speed limit (%)	a) urban core area b) peripheral areas	a) 85% b) 20%	Madrid SUMP 2021
Vehicle fleet composition	**Private cars**	Vehicle fleet composition by fuel type	a) gasoline b) diesel c) CNG d) LPG e) PHEV f) BEV	a) 40.6% b) 58.7% c) 0.1% d) 0.0% e) 0.3% f) 0.3%	Madrid 360°
	LDV	Vehicle fleet composition by fuel type	a) gasoline b) diesel c) BEV/PHEV	a) 4.7% b) 94.8% c) 0.5%	ACEA National Data 2021

Group	Input data	Description	Categories	Values	Source
	HDV	Vehicle fleet composition by fuel type	a) diesel b) CNG c) BEV	a) 99.7% b) 0.3% c) 0.0%	ACEA National Data 2021
	Motorbikes/ Scooters	Vehicle fleet composition by fuel type	a) gasoline b) BEV	a) 99.4% b) 0.6%	ACEA National Data 2021
	Public Buses	Composition of the fleet, with respect to the fuel type	a) diesel b) CNG c) PHEV d) BEV	a) 0.7% b) 90.7% c) 0.0% d) 8.6%	EMT Madrid Informe Gestion y Estado Informacion No Financiera 2021

Table 10: Details of unitary cost factors for externalities (Spain values)

Element	Cost	Measure unit
Environment		
CO2	83 at 2019, 259 at 2030	€/ton
PM (cities with > 500,000 inhab.)	116,029	€/ton
CO	10	€/ton
NOx	8,806	€/ton
VOC	725	€/ton
Safety		
Road traffic deaths	3,128,512	€/person
Road traffic injuries	474,690	€/person
Noise		
Motorbike	0.116	€/pkm
Car	0.010	€/pkm
Bus	0.156	€/vkm
Tram	0.107	€/vkm
Metro	0.000	€/vkm
HDV	0.012	€/tkm
LDV	0.058	€/tkm

Annex II: Policy measures rationale

Table 11: Rationale of policy measures

Policy	Rationale
Vehicle fleet and charging infrastructure	
EV uptake	The policy assumes an increased uptake of electric vehicles in the private car vehicle fleet, on top of the exogenous trend (accounted for in the Technological Innovation Trend) as a consequence of technology development, restrictions on conventional fuels and municipal or national subsidies.
EV charging infrastructure	An increased rollout of electric vehicle charging infrastructure results in more and better availability of charging points, that, in turn, increase the uptake of electric vehicles.
Green public transport fleet	The policy assumes an increased deployment of electric vehicles in the local bus fleet, on top of the exogenous trend.
Green logistics fleet	The policy assumes an increased uptake of electric vehicles in the light duty vehicle fleet used for logistics, on top of the exogenous trend driven by technology development.
Cooperative ITS	The diffusion of Cooperative Intelligent Transport Systems is expected to improve safety and efficiency in road transport, in terms of urban travel time, energy consumption, air pollutant emissions, etc. Thanks to this technology, the vehicles will be able to avoid collisions and use the engine in a more efficient way, resulting in less fuel consumption.
Innovative and shared mobility services	
Bike sharing	The policy assumes an enhancement of the bike sharing scheme already in place at the base year, both in terms of increased fleet size and of larger area covered by the service.
Car sharing	The policy assumes an enhancement of the car sharing scheme already in place at the base year, both in terms of increased fleet size and of larger area covered by the service.
Moped sharing	The policy assumes an enhancement of the moped sharing scheme already in place at the base year, both in terms of increased fleet size and of larger area covered by the service.
E-scooter sharing	The policy assumes the diffusion of e-scooters, also in the form of shared devices, both in terms of increased fleet size and of larger area covered by the service.
MaaS	The policy assumes that a MaaS (Mobility as a Service) platform is implemented in the city, allowing to integrate various forms of

Policy	Rationale
	mobility services into a single and comprehensive service. MaaS offers end-users the added value of accessing mobility through a single application and a single payment channel. Furthermore, it is assumed that an integrated ticketing systems is in place, resulting in seamless travels and no requirement to buy tickets whilst switching either transport modes or services. It is assumed that the integration includes public transport, shared mobility services, and micromobility. The MaaS activation reduces both users' costs for transport services and travel time.
DRT	Demand-responsive transport is simulated as a new PT service, partially replacing the existing bus routes, but mostly adding a new service in areas where standard public transport cannot be very effective (e.g., low density areas, peripheries, etc.) Hence, with a small number of vehicles, it is possible to provide the Public Transport service in a wide area.
Transport infrastructure	
Cycling network extension	The policy is aimed at making cycling trips easier and safer. The implementation of the measure foresees that, when these facilities are provided, the bicycle modal share grows at the expense of competing modes
Bus network extension	The policy increases the reliability and attractiveness of the bus by increasing the service frequency over the entire network. The application of this measure incentivizes citizens to use public transport more at the expense of competing modes.
Tram network extension	The policy increases the reliability and attractiveness of the tram by increasing the service frequency over the entire network. The application of this measure incentivizes citizens to use public transport more at the expense of competing modes.
Metro network extension	The policy consists of making the metro transport services more accessible, mostly through an extension of the service and the construction of new lines/stations. Due to the complexity of such infrastructure measures and the short time frame, this is only applied to cities that have already planned and approved such extensions or constructions.
Park & Ride	The concept of Park & Ride assumes that parking spaces for commuters are provided at major public transport stops at the border of the city area. This means that a larger share of trips incoming from external zones by car will interchange to public transport.

Policy	Rationale
Transport avoidance	
Working from home	The policy assumes an increasing adoption of working from home/teleworking, resulting in a reduction of travel to work trips per person. Also, rebound effects are modelled, taking into account an increase in trips for personal purposes when the commuting trip is avoided.
Car-free days	On car-free days, people are encouraged to travel by modes other than cars and car use is temporarily prohibited. Therefore, when the policy is applied, trips are shifted to other modes of transport, while taking into account that a share of trips is avoided or redistributed on other days.
Pricing schemes	
Congestion and pollution charging	It is assumed that a congestion charging scheme is implemented in a limited area of the city, applied to both cars and freight vehicles. The charge is in place during the day for all vehicles. Due its complexity, especially in terms of citizens' acceptance, this measure will only be applied to cities that already have such a scheme in place, i.e. not the city of Madrid.
Parking pricing	The policy assumes an increase the price for parking in the urban area, with dedicated discounts to hybrid electric and electric vehicles. Also, the policy aims to reduce the overall number of parking spaces while increasing the share of paid parking (vs free parking).
Public transport fare reduction	The policy is designed to reduce the cost of public transport in a targeted way by providing a discounted tariff for young citizens (<18 years old) and for the elderly (> 65 years old) to incentivize travel by public transport.
Traffic management and control	
Prioritizing PT	The policy requires regulations but also appropriate infrastructures such as reserved lanes and automated traffic lights to give way to buses and trams when they approach crossroads. The result is an improvement of public transport speed, making PT more attractive.
Limited traffic zones (LTZ)	The policy aims at reducing the space available for using cars and for parking cars in order to increase the liveability of the urban space. The assumption is that the restrictions applied make it less convenient to use a car for some trips and so there is a reduction in the share of cars in traffic. The policy can be applied to cars, freight vehicles or both.

Policy	Rationale
Low emission zones (LEZ)	The policy aims at implementing low-emission zones, where access for certain some polluting vehicles is restricted. The policy allows for defining the restriction by vehicle type for cars and freight vehicles, resulting in a reduction of car and trucks transport demand (depending on the composition of the vehicle fleet) as well as an accelerated scrappage rate of vehicles not complying with the LEZ. If stepped up, it can be turned into in a zero-emission zone ZEZ) where only non-pollutant vehicles are allowed.
Traffic calming	The policy assumption is the implementation of traffic-calming measures in the city, making the use of cars less convenient and more time-demanding. A reduction in injury/fatality rates is also foreseen. Traffic-calming consists of regulations (e.g., zones with maximum allowable speed of 30 km/h) but also in various physical interventions (e.g., to restrict carriageways).
Pedestrian areas	The policy is aimed at making pedestrian trips easier and safer. The implementation of the measure assumes that when pedestrian areas are provided pedestrian trips grow at the expenses of competing modes. Furthermore, injury/fatality rates are also reduced.
Urban logistics	
Urban delivery centers	The policy is modelled assuming that urban freight consolidation centres are created at the border and within the urban area in appropriate locations to serve as hubs for the final distribution. A share of the shipments arriving from outside the city pass through the delivery centres, where loads are consolidated and distributed in a more efficient way, increasing the load factor of vehicles, shortening consignment routes and using cleaner vehicles. This results in fewer freight vehicle-km in the urban area.
Delivery and servicing plan	The policy represents the implementation of detailed plans to consolidate and reduce delivery and servicing vehicles accessing a site or building. The expected impact is a reduction of the number of goods vehicles entering the urban area as a result of more efficiency.
Cargo bikes	The policy simulates the diffusion of delivery services with cargo bikes within the urban area. It is therefore assumed that part of the freight demand delivered with LDVs can be shifted to cargo bikes.

Annex III: Intervention levels in the scenarios

Table 12: Madrid's list of scenarios' intervention levels

Policy		Scenarios 1,2,3	Scenario 4
Vehicle fleet and charging infrastructure			
EV uptake	*Target*	**Additional increase electric cars penetration compared to 2019 including Baseline trend**	"
	% BEV/PHEV cars	3% → 24%	
EV charging infrastructure	*Target*	**1 charging point / 8 EV** **50% fast charging**	**1 charging point / 5 EV**
	No. charging points	2,844 → 21,528	
Green public transport fleet	*Target*	**100% of green public transport fleet by 2030**	"
	% BEV/PHEV buses	9% → 100%	
Green logistics fleet	*Target*	**Additional increase electric LDV penetration compared to 2019 including Baseline trend**	"
	% BEV/PHEV LDV	0.5% → 24.3%	
Cooperative ITS	*Target*	**Increase safety and efficiency in road transport**	"
Innovative and shared mobility services			
Bike sharing	*Target*	**6 bikes / 1,000 inhab. or +20% from base year**	"
	No. bikes	4,050 → 19,720	
Car sharing	*Target*	**2 cars / 1,000 inhab. or +20% from base year**	"
	No. cars	2,766 → 6,753	
Moped sharing	*Target*	**1 moped / 1,000 inhab. or +20% from base year**	"
	No. mopeds	5,000 → 6,000	
E-sooter sharing	*Target*	**4 devices / 1,000 inhab. or +20% from base year**	"
	No. devices	6,270 → 13,147	

Policy		Scenarios 1,2,3	Scenario 4
MaaS	*Target*	Increase integration between services (TPL, sharing, etc.) and improve efficiency	“
DRT	*Target*	Implement DRT covering: 10% core urban area, 50% peripheral areas	“
Transport infrastructure			
Cycling network extension	*Target*	0.2 km of bike lanes / 1,000 inhab.	Additional +30% increase
	Km lanes	239 → 657	
Bus network expansion	*Target*	90% of network with 4’ average frequency	“
Tram network expansion	*Target*	80% of network with 5’ average frequency	“
Park & Ride	*Target*	5 P&R spaces / 1,000 inhab. or +10% from base year	“
	No. P&R spaces	6,876 → 16,433	
Transport avoidance			
Working from home	*Target*	Reduce by 20% transport demand for working trips	“
Car-free days	*Target*	Establish 1 car-free day per month	Establish 1 car-free day per week
Pricing schemes			
Parking pricing	*Target*	Increase parking fee by 30% Reduce parking spaces to 2 / 10 inhab.	Triple parking fee
Public transport fare reduction	*Target*	Reduce by 20% fare for young people (<18) and the elderly (>65)	Reduce by 50% fare for young and elderly
Traffic management and control			
Prioritizing PT	*Target*	Reserved lanes on 15% of network Prioritizing systems on 30% of network	Reserved lanes on 25% of network Prioritizing systems on
	Km reserved lanes	197 → 337	

Policy		Scenarios 1,2,3	Scenario 4
			40% of network
Limited traffic zones (LTZ)	*Target*	**Passenger and freight LTZ covering:** **20% core urban area, 5% peripheral areas**	**40% core urban area, 10% peripheral areas**
	% core urban	0% → 20%	
Low emission zones (LEZ)	*Target*	**LEZ covering 100% study area** **Passenger: banned up to EURO 5 (gasoline) and EURO 6 (diesel)** **Freight: banned up to EURO 6 (LDV & HDV)**	**Zero-emission zone covering 100% study area**
	% core urban (pax)	22% → 100%	
Traffic calming	*Target*	**30 km/h speed limit on:** **85% core urban area, 30% peripheral areas**	"
	% core urban	80% → 85%	
Pedestrian areas	*Target*	**Pedestrian areas covering:** **5% core urban area, 1% peripheral areas**	"
	% core urban	1% → 5%	
Urban logistics			
Urban delivery centers	*Target*	**25% increase of retail freights managed by delivery centers**	"
Delivery and servicing plan	*Target*	**Reduce by 10% (LDV) and by 5% (HDV) retail freight**	"
Cargo bikes	*Target*	**Share of carried freight:** **5% (B2C), 0.5% (Retail)**	"

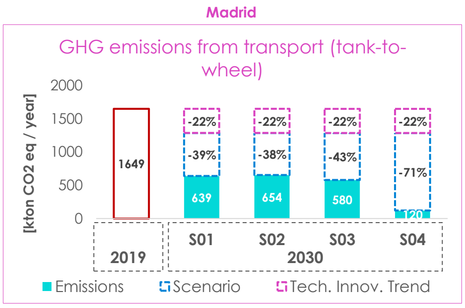
Annex IV: Full results of the study

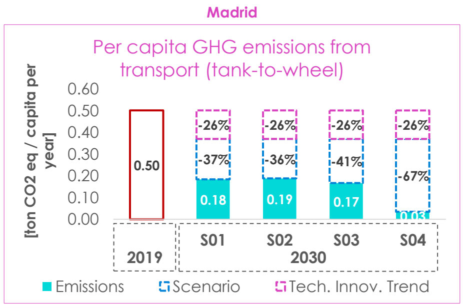
Madrid

Greenhouse Gases Emissions from transport

GHG emissions (tank-to-wheel)
[kton CO2 eq / year]

Scenario	2030
Base year	1,649
S01	639
S02	654
S03	580
S04	120
S01 - Diff base year	-61.3%
S02 - Diff base year	-60.3%
S03 - Diff base year	-64.8%
S04 - Diff base year	-92.7%





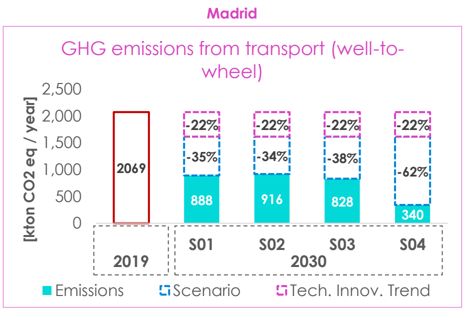
Per capita GHG emissions (tank-to-wheel)

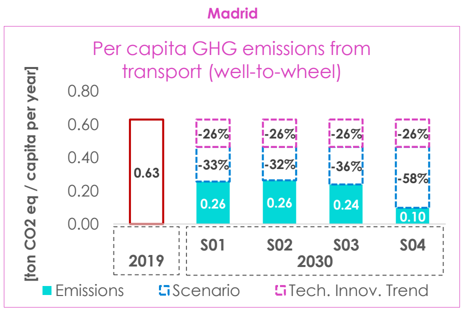
[ton CO2 eq / capita per year]

Scenario	2030
Base year	0.50
S01	0.18
S02	0.19
S03	0.17
S04	0.03
S01 - Diff base year	-63.3%
S02 - Diff base year	-62.5%
S03 - Diff base year	-66.7%
S04 - Diff base year	-93.1%

GHG emissions (well-to-wheel)
[kton CO2 eq / year]

Scenario	2030
Base year	2,069
S01	888
S02	916
S03	828
S04	340
S01 - Diff base year	-57.1%
S02 - Diff base year	-55.7%
S03 - Diff base year	-60.0%
S04 - Diff base year	-83.6%

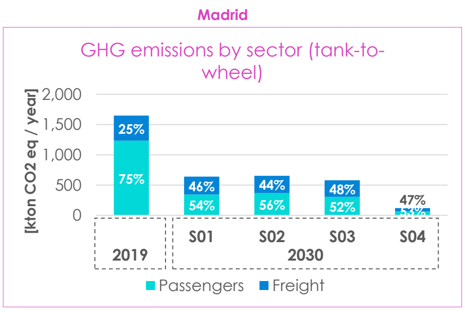


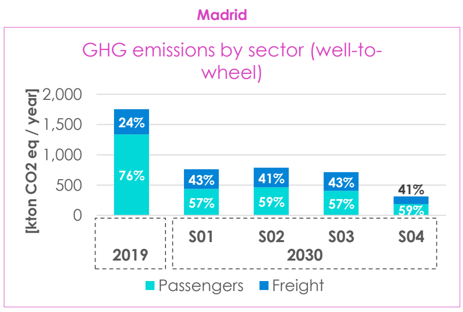


Per capita GHG emissions (well-to-wheel)

[ton CO2 eq / capita per year]

Scenario	2030
Base year	0.63
S01	0.26
S02	0.26
S03	0.24
S04	0.10
S01 - Diff base year	-59.4%
S02 - Diff base year	-58.1%
S03 - Diff base year	-62.1%
S04 - Diff base year	-84.4%





GHG emissions by sector (tank-to-wheel)

[kton CO2 eq / year]	2019	2030			
		S01	S02	S03	S04
Passengers	1,233	345	367	304	64
Freight	416	294	287	276	56
Passengers (%)	75%	54%	56%	52%	53%
Freight (%)	25%	46%	44%	48%	47%

GHG emissions by sector (well-to-wheel)

[kton CO2 eq / year]	2019	2030			
		S01	S02	S03	S04
Passengers	1,337	437	464	404	185
Freight	416	325	324	311	127
Passengers (%)	76%	57%	59%	57%	59%
Freight (%)	24%	43%	41%	43%	41%

Transport behaviour

Aggregated internal modal split based on pkm

[%]	2019	2030			
		S01	S02	S03	S04
Public Transport	51.4%	52.5%	55.1%	52.2%	57.1%
Private motorized	36.0%	24.2%	31.1%	24.6%	17.6%
Shared mobility*	0.2%	7.9%	0.3%	7.8%	7.8%
Bike	0.5%	3.3%	1.2%	3.3%	4.6%
Pedestrian	11.8%	12.2%	12.3%	12.1%	13.0%

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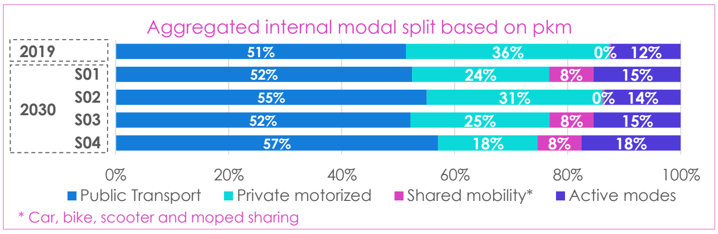

Aggregated internal modal split based on trips

[%]	2019	2030			
		S01	S02	S03	S04
Public Transport	35.1%	34.8%	37.2%	34.6%	37.1%
Private motorized	28.1%	18.3%	24.1%	18.6%	13.0%
Shared mobility*	0.2%	6.9%	0.3%	6.9%	6.8%
Bike	0.6%	4.0%	1.4%	4.0%	5.3%
Pedestrian	36.0%	35.9%	37.1%	35.9%	37.8%

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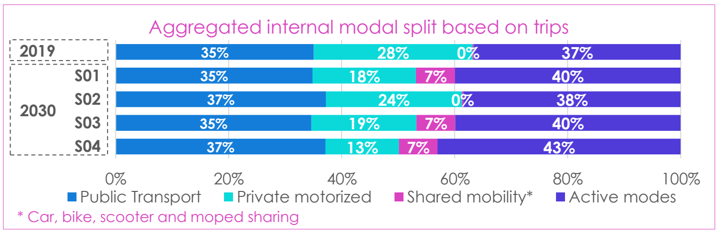

Car ownership level

[cars/1000 inhab]

Scenario	2030
Base year	575
S01	516
S02	543
S03	517
S04	422
S01 - Diff base year	-10.2%
S02 - Diff base year	-5.6%
S03 - Diff base year	-10.1%
S04 - Diff base year	-26.7%

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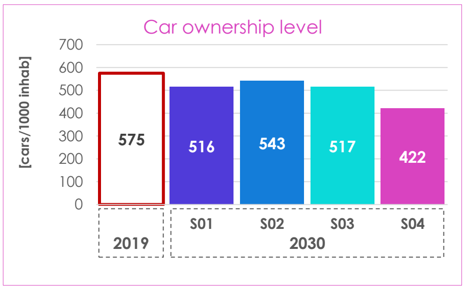

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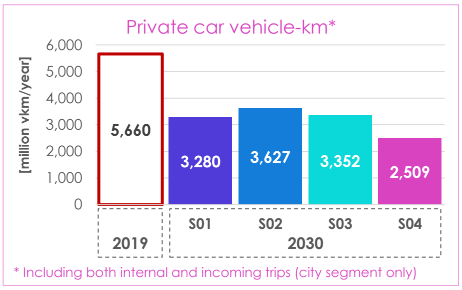

Private car vehicle-km*

[million vkm/year]

Scenario	2030
Base year	5,660
S01	3,280
S02	3,627
S03	3,352
S04	2,509
S01 - Diff base year	-42.1%
S02 - Diff base year	-35.9%
S03 - Diff base year	-40.8%
S04 - Diff base year	-55.7%

Transport activity - Passenger

Total Passenger-km*
[million pkm/year]

Scenario	2030
Base year	21,585
S01	20,638
S02	21,106
S03	20,665
S04	20,441
S01 - Diff base year	-4.4%
S02 - Diff base year	-2.2%
S03 - Diff base year	-4.3%
S04 - Diff base year	-5.3%

Total travel time*
[million h / year]

Scenario	2030
Base year	1,325
S01	1,259
S02	1,308
S03	1,269
S04	1,289
S01 - Diff base year	-5.0%
S02 - Diff base year	-1.3%
S03 - Diff base year	-4.2%
S04 - Diff base year	-2.7%

Average travel time
[min / trip]

Scenario	2030
Base year	31.7
S01	31.2
S02	32.2
S03	31.3
S04	31.9
S01 - Diff base year	-1.8%
S02 - Diff base year	1.6%
S03 - Diff base year	-1.2%
S04 - Diff base year	0.7%

Total trips*
[million trips / year]

Scenario	2030
Base year	2,505
S01	2,424
S02	2,435
S03	2,429
S04	2,421
S01 - Diff base year	-3.2%
S02 - Diff base year	-2.8%
S03 - Diff base year	-3.0%
S04 - Diff base year	-3.3%

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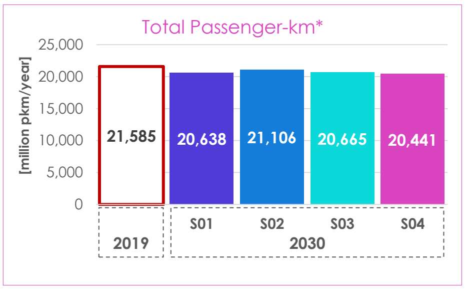

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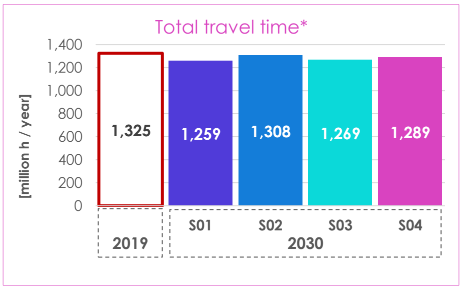

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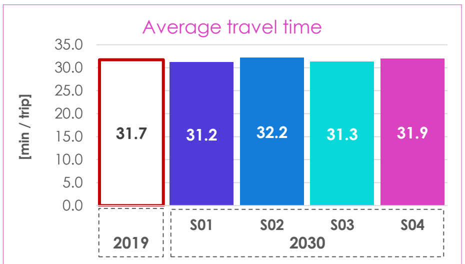

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*Including both internal and incoming trips (city segment only)

Transport activity - Freight

Total vkm (HDV, LDV, Cargo-bike)
[million vkm/year]

Scenario	2030
Base year	880
S01	1,972
S02	1,876
S03	1,957
S04	2,524
S01 - Diff base year	124.0%
S02 - Diff base year	113.1%
S03 - Diff base year	122.2%
S04 - Diff base year	186.7%

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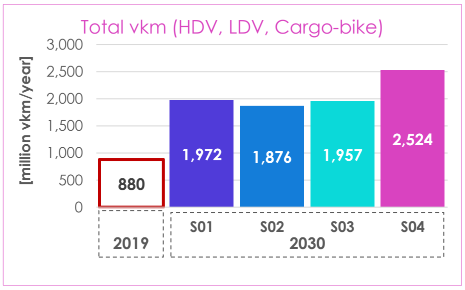

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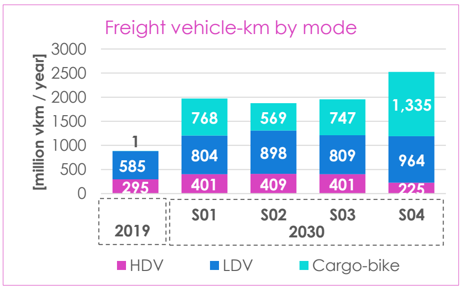


Vkm by mode

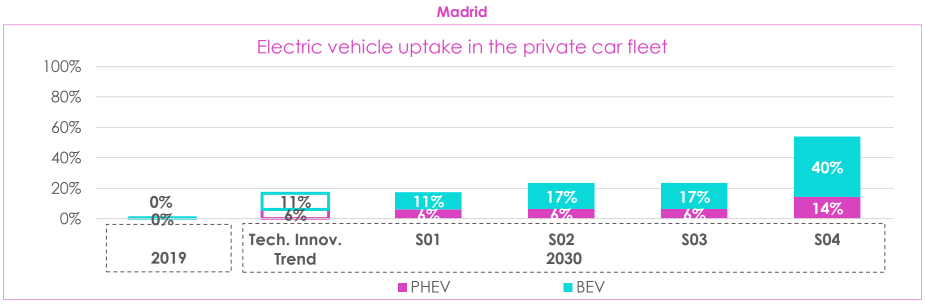
[million vkm / year]	2019	2030			
		S01	S02	S03	S04
HDV	295	401	409	401	225
LDV	585	804	898	809	964
Cargo-bike	1	768	569	747	1,335

Electric vehicles uptake

EV uptake of private cars

[%]

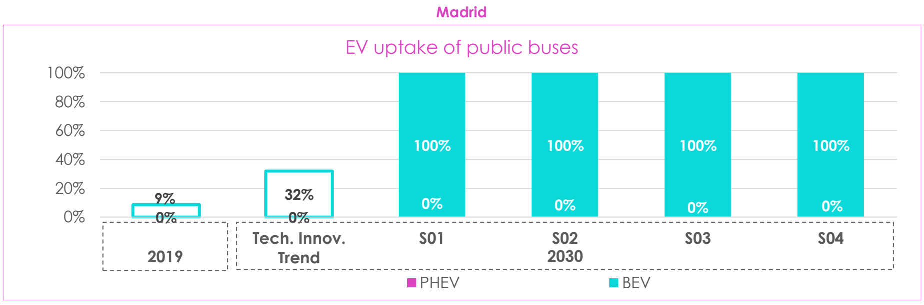
Scenario		2030
Base year	PHEV	0%
Base year	BEV	0%
S01	PHEV	6%
S01	BEV	11%
S02	PHEV	6%
S02	BEV	17%
S03	PHEV	6%
S03	BEV	17%
S04	PHEV	14%
S04	BEV	40%



EV uptake of public buses

[%]

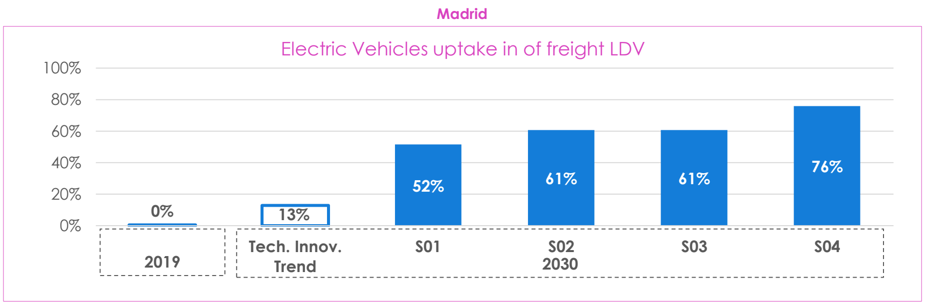
Scenario		2030
Base year	PHEV	0.0%
Base year	BEV	8.6%
S01	PHEV	0.0%
S01	BEV	100.0%
S02	PHEV	0.0%
S02	BEV	100.0%
S03	PHEV	0.0%
S03	BEV	100.0%
S04	PHEV	0.0%
S04	BEV	100.0%



EV uptake of freight vehicles (LDV)

[%]

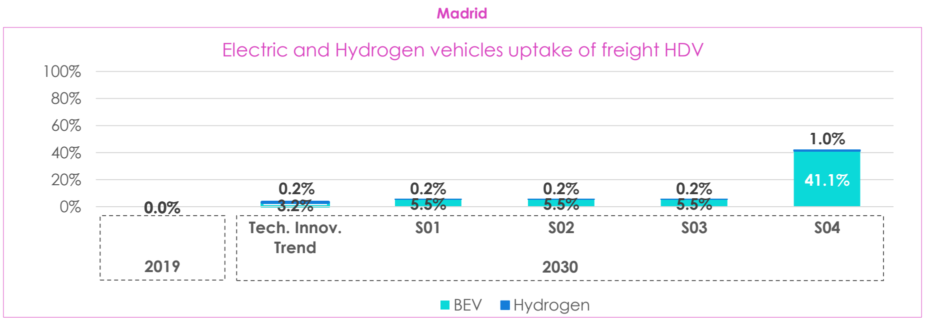
Scenario		2030
Base year	BEV	0.5%
S01	BEV	52%
S02	BEV	61%
S03	BEV	61%
S04	BEV	76%



EV uptake of freight vehicles (HDV)

[%]

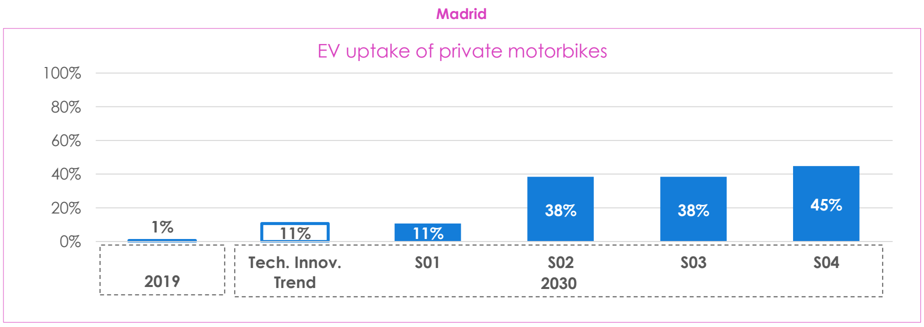
Scenario		2030
Base year	BEV	0.0%
Base year	Hydrogen	0.0%
S01	BEV	5.5%
S01	Hydrogen	0.2%
S02	BEV	5.5%
S02	Hydrogen	0.2%
S03	BEV	5.5%
S03	Hydrogen	0.2%
S04	BEV	41.1%
S04	Hydrogen	1.0%



EV uptake of private motorbikes

[%]

Scenario		2030
Base year	BEV	0.6%
S01	BEV	11%
S02	BEV	38%
S03	BEV	38%
S04	BEV	45%



Air pollutant emissions from transport

Emissions of PM2.5 from urban transport
[g / capita]

Scenario	2030
Base year	66
S01	29
S02	31
S03	28
S04	23
S01 - Diff base year	-55.3%
S02 - Diff base year	-53.5%
S03 - Diff base year	-58.0%
S04 - Diff base year	-64.9%

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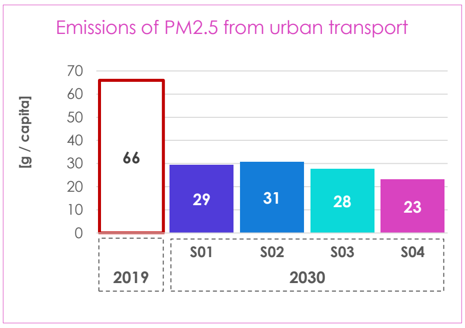

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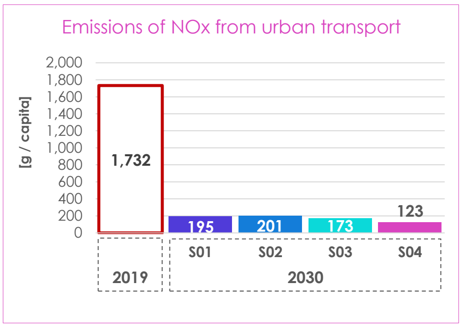

Emissions of NOx from urban transport
[g / capita]

Scenario	2030
Base year	1,732
S01	195
S02	201
S03	173
S04	123
S01 - Diff base year	-88.8%
S02 - Diff base year	-88.4%
S03 - Diff base year	-90.0%
S04 - Diff base year	-92.9%

Emissions of CO from urban transport
[g / capita]

Scenario	2030
Base year	2,452
S01	1,124
S02	1,182
S03	875
S04	523
S01 - Diff base year	-54.2%
S02 - Diff base year	-51.8%
S03 - Diff base year	-64.3%
S04 - Diff base year	-78.7%

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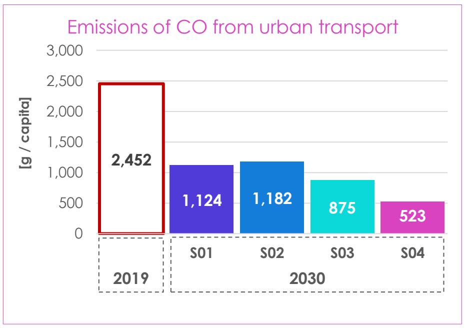

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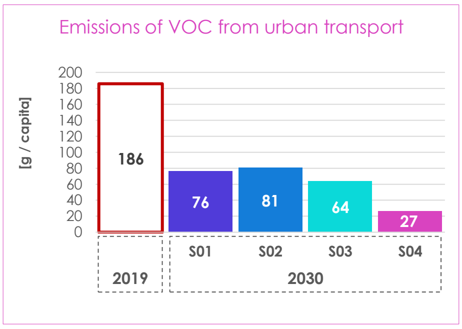


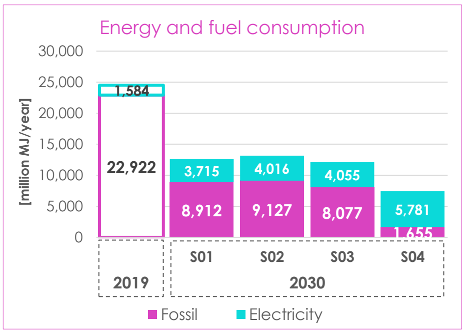
Emissions of VOC from urban transport
[g / capita]

Scenario	2030
Base year	186
S01	76
S02	81
S03	64
S04	27
S01 - Diff base year	-58.8%
S02 - Diff base year	-56.4%
S03 - Diff base year	-65.5%
S04 - Diff base year	-85.6%

Energy and fuel consumption
[million MJ/year]

Scenario	2030
Base year	24,506
S01	12,628
S02	13,142
S03	12,132
S04	7,437
S01 - Diff base year	-48.5%
S02 - Diff base year	-46.4%
S03 - Diff base year	-50.5%
S04 - Diff base year	-69.7%

Madrid



Road Safety

Road traffic deaths
[deaths/100,000 inhab]

Scenario	2030
Base year	1.37
S01	1.31
S02	1.14
S03	1.29
S04	1.10
S01 - Diff base year	-4.1%
S02 - Diff base year	-16.7%
S03 - Diff base year	-5.6%
S04 - Diff base year	-19.3%

Road traffic injuries
[persons/100,000 inhab]

Scenario	2030
Base year	85.1
S01	45.8
S02	51.1
S03	45.7
S04	35.8
S01 - Diff base year	-46.3%
S02 - Diff base year	-40.0%
S03 - Diff base year	-46.4%
S04 - Diff base year	-57.9%

Road traffic deaths/pkm: All Modes
[deaths/100 mio pkm]

Scenario	2030
Base year	0.3
S01	0.3
S02	0.3
S03	0.3
S04	0.3
S01 - Diff base year	4.4%
S02 - Diff base year	-11.6%
S03 - Diff base year	2.8%
S04 - Diff base year	-10.9%

Road traffic deaths/pkm: Cycling
[deaths/100 mio pkm]

Scenario	2030
Base year	2.6
S01	1.2
S02	2.3
S03	1.2
S04	0.4
S01 - Diff base year	-52.0%
S02 - Diff base year	-10.5%
S03 - Diff base year	-52.6%
S04 - Diff base year	-82.4%

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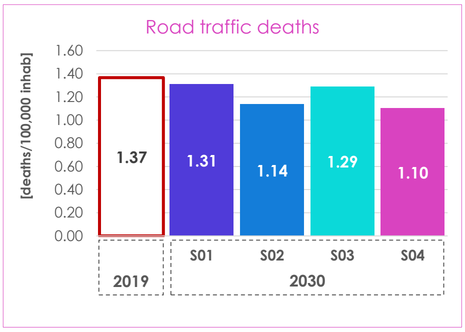

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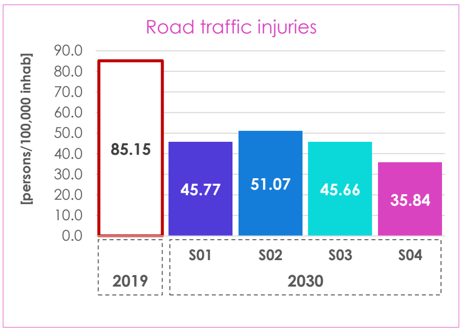

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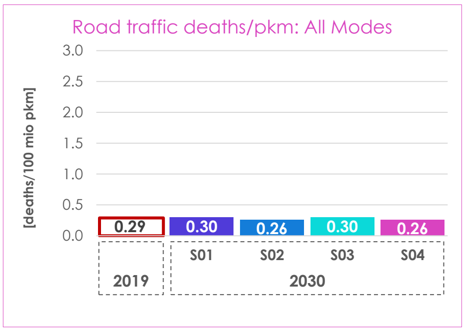

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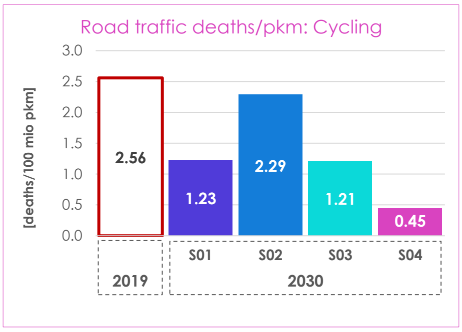


Economic analysis - City

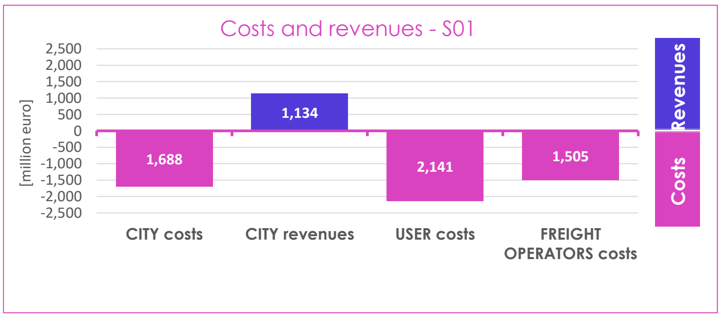
All costs are cumulated (2019 - 2030), discounted (3%), and compared to Business-As-Usual scenario

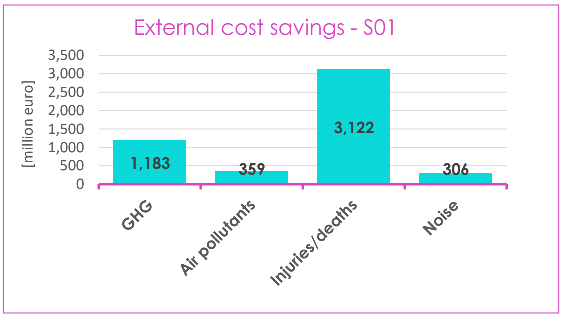
Costs and revenues
[million euro]

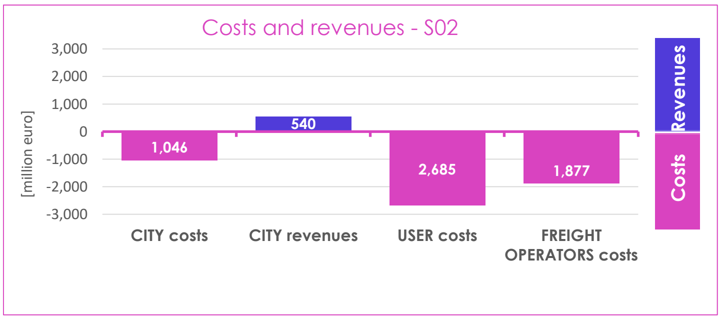
	2019-2030			
	S01	S02	S03	S04
CITY costs	1,688	1,046	1,830	2,141
CITY revenues	1,134	540	1,133	1,474
USER costs	2,141	2,685	2,331	3,928
FREIGHT OPERATORS costs	1,505	1,877	1,679	1,970
NET costs	4,200	5,068	4,707	6,565

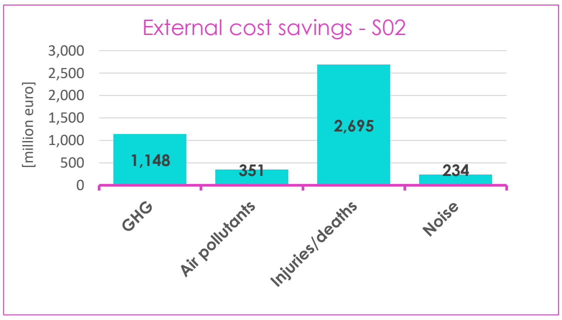
External cost savings
[million euro]

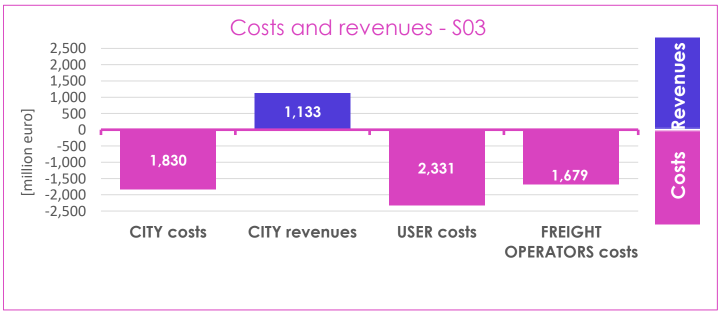
	2019-2030			
	S01	S02	S03	S04
GHG	1,183	1,148	1,259	1,982
Air pollutants	359	351	365	388
Injuries/deaths	3,122	2,695	3,131	5,433
Noise	306	234	310	672
TOTAL savings	4,970	4,427	5,065	8,474

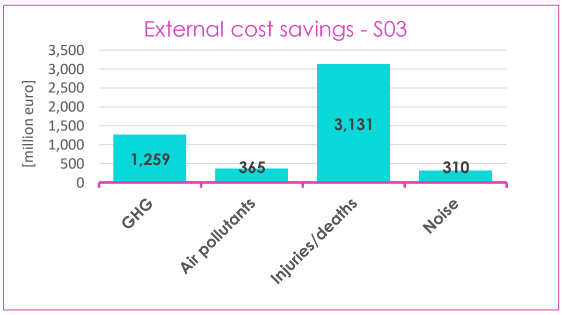


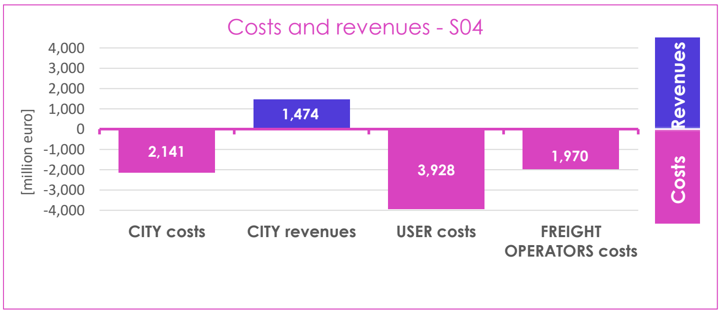


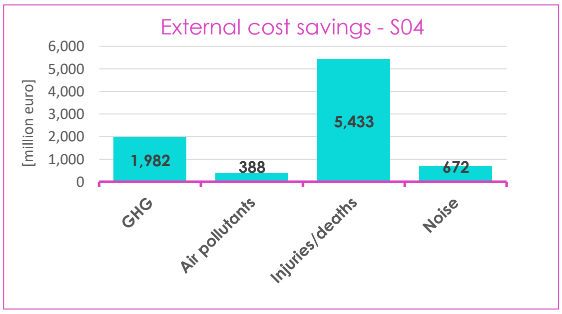












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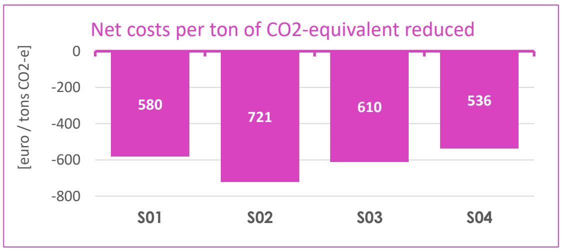


Net costs per ton of CO2-equivalent reduced
[euro / tons CO2-e]

	2019-2030			
	S01	S02	S03	S04
TOTAL	580	721	610	536

TRT CleanCities

Economic analysis - Per capita

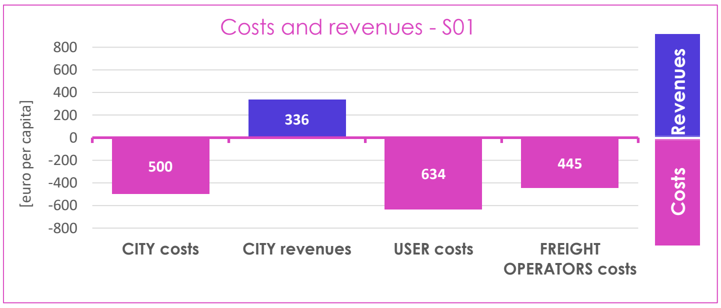
All costs are cumulated (2019 - 2030), discounted (3%), and compared to Business-As-Usual scenario

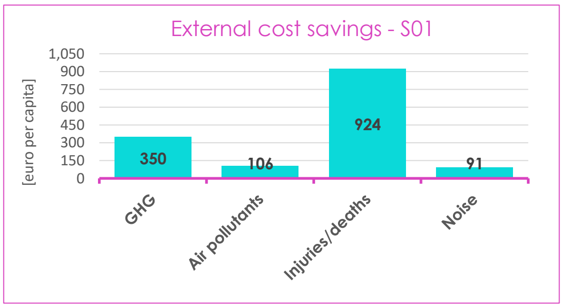
Costs and revenues
[euro per capita]

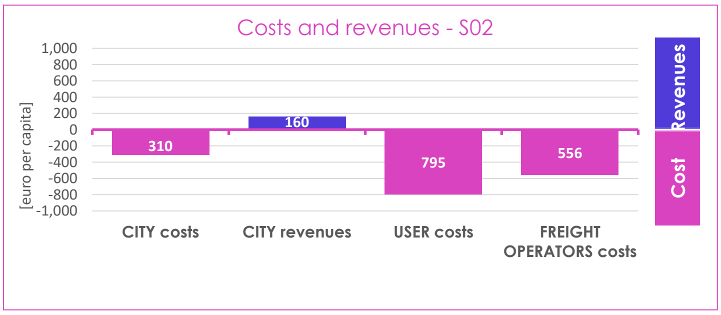
	2019-2030			
	S01	**S02**	**S03**	**S04**
CITY costs	500	310	542	634
CITY revenues	336	160	335	436
USER costs	634	795	690	1,163
FREIGHT OPERATORS costs	445	556	497	583
NET costs	**1,243**	**1,500**	**1,393**	**1,943**

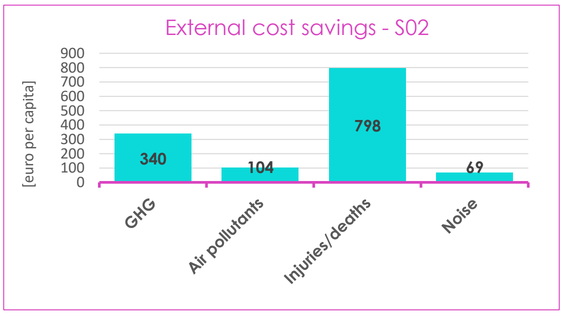
External cost savings
[euro per capita]

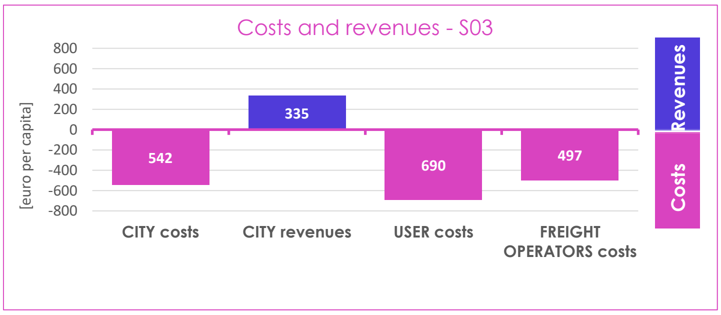
	2019-2030			
	S01	**S02**	**S03**	**S04**
GHG	350	340	373	587
Air pollutants	106	104	108	115
Injuries/deaths	924	798	927	1,608
Noise	91	69	92	199
TOTAL savings	**1,471**	**1,310**	**1,499**	**2,508**

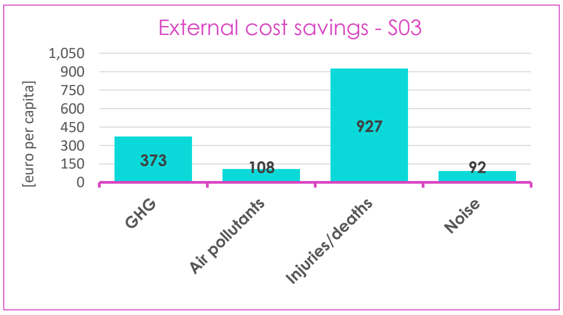


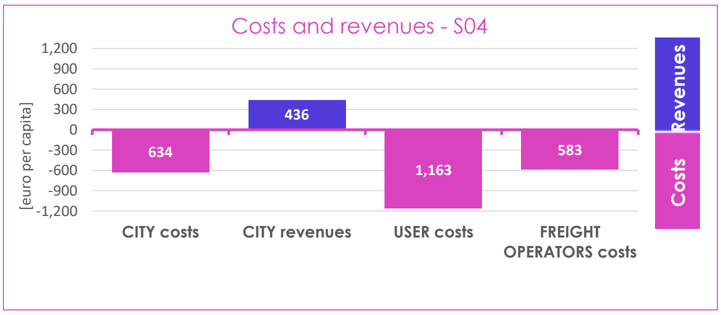


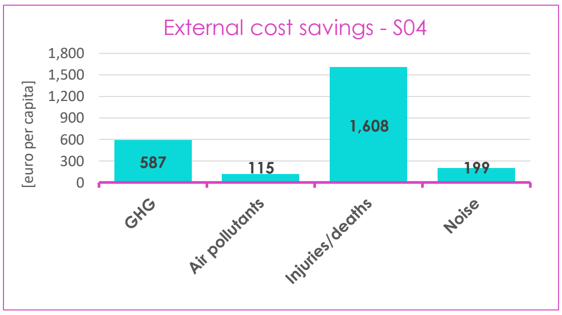












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