International Transport Forum | CPB Corporate Partnership Board

Shifting the Focus

Smaller Electric Vehicles for Sustainable Cities

Corporate Partnership Board Report

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The International Transport Forum

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Executive summary

What we did

This report identifies emerging electric vehicle (EV) types and use cases that could form the backbone of a more sustainable, electric future for urban passenger and freight transport. It explores urban EV use cases: electric "car-like" light vehicles, including micro cars and micro EVs; two- and three-wheelers; shared electric mobility, including shared vehicle fleets, ridesourcing and micro-transit services; electric public transport buses; e-cargo bikes and electric light commercial vehicles.

The report compares the sustainability impacts of two scenarios that follow different electrification pathways. The *like-for-like* pathway assumes that vehicles with internal combustion engines (ICE) will be replaced with electricity-powered equivalents. In the *broader uptake* pathway, electric vehicle uptake involves a shift to emerging smaller vehicle types and shared use cases.

The report also explores the impacts of three additional scenarios, reflecting different degrees of policy ambition for EV uptake by 2030. It does so by calculating the electricity demand, charging infrastructure needs and local pollutant and greenhouse gas (GHG) emissions for low, medium, and high levels of electrification.

Finally, the report offers recommendations for supporting sustainable EV uptake in cities. The study builds on an expert workshop and qualitative and quantitative analysis. The latter relies on the ITF urban agent-based model developed for the Greater Dublin area, which is used to simulate vehicle use and charging patterns.

What we found

EV uptake policies often focus on the like-for-like replacement of larger vehicles. This means conventional vehicles are being replaced by electric ones without changing their use patterns, addressing their increasing size, or improving their low occupancy. This limits the EVs' role in making cities more sustainable, as they will not reduce the pressure on urban space, alleviate traffic congestion or improve road safety. A like-for-like approach also misses the opportunity to reduce the need for electricity and battery materials.

Sustainable and electric urban mobility will be small and shared. However, the low policy prioritisation of smaller EVs compared to larger ones is limiting their uptake. Barriers include low financial incentives, a lack of adapted infrastructure and regulatory challenges for emerging vehicles. Among others, some emerging vehicles face the challenge of not being approved in various markets.

Modelling results show that the *broader uptake* pathway delivers more sustainability benefits than the *like-for-like* pathway. Under this scenario, vehicles require one-third less street space, one-third less battery capacity (and battery materials) and one-third fewer charging points compared to the *like-for-like* pathway. Electricity use would be 15% lower. A *broader EV uptake* can also deliver safer streets when supported by segregated infrastructure and regulated street access, use and speeds. Private cars pose the biggest threat to pedestrians and micromobility users. The *broader uptake* pathway reduces these risks of conflict by almost 40% and 60%, respectively, compared to the *like-for-like* pathway.

Under the high electrification ambition scenario, the modelling results show that by 2030, CO_2 and local pollutants tailpipe emissions will be 65% lower for passenger transport and 10% lower for freight transport than in a *low ambition* scenario. The electricity required to power such an urban transport system is 1.5 Gigawatt-hours per day, with the highest demand occurring during the night. Almost half of this electricity demand would be required by private passenger cars (67% from home chargers, 17% from public on-street charging points and 16% from other off-street charging facilities). Home charging of private EVs could increase daily residential electricity consumption by 10% relative to today.

A well-developed network of public charging points is necessary for a successful transition to electric mobility. To ensure equitable access and coverage, it will require a high density of on-street public chargers in areas with high population density and sufficient public chargers in less dense areas. The deployment of public charging infrastructure must be aligned with the increasing uptake of EVs. The modelling results show that the city's average number of chargers per km^2 required increases from 0.7 in a *low ambition* scenario to 2.4 in a *high ambition* scenario. Conversely, as the share of smaller EVs increases, the number of public chargers needed per 1 000 EVs decreases from 12.2 in *low ambition* to 8.6 in *high ambition*.

What we recommend

Shift the focus of policies that promote electric vehicles to end the dependency on large, under-used vehicles

Authorities need to avoid providing incentives for replacing larger vehicles with similar electric models. Such a shift requires setting clear and realistic objectives for reducing the dependency on large vehicles and maximising the use of vehicle capacity. It also requires an understanding of how emerging small and "car-like" light types of electric vehicles can help meet these goals. For instance, authorities should support urban goods deliveries that use electric cargo bikes and electric light commercial vehicles with high load factors for low-carbon, multimodal city logistics.

Help make smaller electric vehicles an attractive choice for citizens

Authorities should help overcome cost barriers to make small and innovative electric vehicles an affordable option. Support schemes should be differentiated by vehicle size and weight to counter the ongoing increase in vehicle size. Standards for fuel economy or vehicle weight could also be used. Support could include targeted subsidies for the purchase of passenger EVs, particularly for citizens with lower incomes. It could also encompass loans and similar mechanisms to help finance the purchase or leasing of (small) passenger EVs. Authorities should support the creation of break-bulk centres (transhipment centres that allow loads to be shifted from larger vehicles to smaller ones) and parking spaces for electric cargo bikes to make urban logistics more sustainable. Support could be funded via road and parking charges for legacy vehicles and "feebates" that impose surcharges on the purchase of polluting vehicles to subsidise buyers of electric cars.

Ensure the transition to smaller electric vehicles goes in hand with adequate safety provisions

For their safe use and coexistence with other vehicles, the smaller vehicle types that are emerging require road-worthiness approval as well as updated safety regulations. The latter may include clarification on use requirements, for instance, vehicle-specific maximum speeds or the type of streets where they may circulate. Beyond such basics, they could also include stipulations for the design of larger vehicles which facilitate their sharing of public space with smaller EVs to reduce crash risks. Investing in adapted street infrastructure, such as separate lanes for micromobility, will also reduce conflicts.

Fast-track the electrification of shared mobility services in complement with public transport

Authorities should support and manage emerging electric shared mobility services. Public bodies can either lead by establishing these services or manage them to complement cities' public transport. Authorities can introduce measures, such as urban vehicle access regulations or facilitating charging or parking for shared EVs, to increase the uptake of shared electric services. Fostering shared electric fleets could also require strong partnerships with new mobility stakeholders, such as electricity providers embarking on shared fleet provision services. This will enable charging points deployed by companies to be integrated into a city's public charging infrastructure rather than being exclusive to a user base of specific operators.

Ensure the availability of enough charging points to make electric mobility attractive

Authorities must ensure off-street charging is widely available and complemented by a solid network of public on-street charging points. For off-street charging, building regulations can include minimum requirements for the deployment of charging points. Authorities can also provide tax incentives and subsidies for establishing a charging network. Funding can come from lowering subsidies for large EVs, revenues from taxes on larger, more-polluting vehicles and charges on the use of public space. Offering concessions for privately-operated charging networks that cover more and less profitable areas can ensure good coverage of public charging points. Authorities can also partner with companies already operating public charging, e.g., shared-mobility operators. The use of charging points could be optimised by limiting the allowed parking time per charger.

1. The rationale for broader electric vehicle uptake in urban areas

Electrifying passenger and freight transport activities could be one of the main ways for cities to meet wider environmental challenges. In the future, electric vehicles will be the norm rather than the exception in urban areas. In 2012, there were less than 100 000 electric cars worldwide, including battery and plug-in hybrid vehicles. Ten years later, the number has increased to more than 18 million, mostly in urban areas (IEA, 2023). Electric forms of two- and three-wheelers show even higher potential. In 2021, more than thirty million two- and three-wheeled vehicles were sold, most of them in cities and without taking micromobility into account. With emerging micromobility vehicles, this number could be well beyond one hundred million (IEA, 2023). Likewise, recent forecasts indicate that by 2030 more than 45% of buses in the European Union and the United Kingdom markets will be electric, compared to only around 22% in 2020 (EBRD, 2021). Push from policy makers, such as the European Parliament's ban on new fossil fuel-propelled cars starting in 2035, as well as a proposed revision by the European Commission on regulating CO_2 emission standards for heavy-duty vehicles, contribute to the expansion of electric mobility (European Commission, 2023). Democratising EVs could spearhead short-term transport action toward a sustainable mobility future, but only under the right conditions (Wappelhorst, 2021).

The central point of this report is that cities need to promote and prepare for the upcoming broader array of EVs as the basis for a more sustainable future – not just traditional private cars. The report is structured as follows:

- Section 1 explains the rationale for and benefits of promoting a broader EV uptake for various use cases for passenger and freight activities.
- Section 2 showcases the main elements of the ITF modelling framework for measuring the impacts of different EV uptake pathways. An annex at the end of the report provides additional insights.
- Sections 3 and 4 present the sustainability impacts of various EV uptake pathways differing on mode, vehicle split and electrification ambition.
- Section 5 gives policy insights on how to support broader and sustainable EV uptake for more sustainable urban mobility futures.

Plug-in hybrid electric vehicles (PHEVs) are not included in the analysis. This is because of the environmental challenges raised by these vehicles. The real-world use of PHEVs leads to two to four times higher GHG emissions than values from PHEV testing for approval processes under the New European Drive Cycle (Plötz et al., 2020). Because of this, authorities of various countries have targets for phasing out sales of PHEV as early as 2025 (Wappelhorst, 2021).

Broader electric vehicle uptake will make net-zero urban transport achievable

EVs must go in hand with policies that transform urban mobility systems into net-zero by design (OECD, 2022). Net-zero by-design systems aim to minimise as much as possible or eliminate their negative environmental, social, and economic impacts from the start. This includes looking at the wider impacts of vehicle use in terms of GHG and other aspects linked to well-being and urban liveability. Other such externalities can include local pollutants, access to opportunities, road safety and the use of street space – a scarce commodity in cities worldwide (ITF, 2022a, 2022b).

Net-zero by-design cities will only be achievable if urban transport systems steer away from ownership of and dependency on larger, energy-inefficient private vehicles, especially for passenger transport. Private passenger cars are one of the highest emitting modes – the GHG emission per passenger-kilometre of a private electric car are considerably higher than those of a relatively well-loaded electric bus and than forms of electric micromobility (ITF, 2020b; ITF, 2021a; ITF, 2023e). Private cars, electric or not, also take up more than 80% of the street space used by transport activities in cities (ITF, 2022b). These vehicles are also one of the main road safety hazards.

These issues will continue increasing alongside increasing vehicle sizes and weights (ITF, 2019c). In the Americas, in 2021, more than half of private passenger cars sold were sport utility vehicles (SUVs), compared to only around 20% in 2017. In Europe, while only 10% of vehicles sold in 2017 were SUVs, in 2021 this category amounted to almost 40% of sales (EV Volumes, 2022). In the European Union, while only 14% of sales were SUVs in 2011, this increased to almost 50% in 2022 (ACEA, 2023). Size increases result from car original equipment manufacturers (OEMs) pushing for sales of larger and more premium vehicles to increase profit margins. This profit margin is more than 5% for larger vehicles compared to less than 1% for smaller vehicles (Baggott, 2021).

Yet, current EV uptake policies seem to focus on like-for-like replacement of private cars while ignoring other vehicle types that support net-zero by design strategies. Like-for-like replacement focuses on replacing existing ICE vehicles with electric equivalents without considering mode shift or smaller vehicle sizes. In 2020, around 20 second-generation Nationally-Determined Contributions (NDCs) had specific electrification measures for electric passenger cars, while less than ten had actions for two- and three-wheelers. This is set against the backdrop of a shift in policy focus between first- and second-generation NDCs. This shift has meant that, recently, greater attention has been given to vehicle electrification and technology improvements than supporting the mode shift towards more sustainable alternatives (SLOCAT, 2022). More than 30% of non-GHG targets in second-generation NDCs concern the promotion of zero-emission vehicles, compared to around 10% for mode shift towards sustainable modes and less than 3% for measures that avoid the need of travelling. Freight transport is mostly overlooked, and only ten second-generation NDCs look at measures to electrify trucks. Little mention is given to the use of cargo bikes and other forms of electric micromobility for urban logistics (SLOCAT, 2022). Beyond NDCs, ambitious Climate Action Plans have been developed by city-level authorities in around fifty cities worldwide that combine vehicle electrification and mode shift policies (C40, 2023). Yet, these plans are not a generalised practice in urban areas around the world and even when they exist, they do not always aim at harnessing benefits brought about by EVs beyond GHG emissions, such as reducing vehicle sizes.

A *like-for-like* pathway for *full vehicle electrification* that maintains private larger vehicles dependency will not reap the same benefits for cities as one based on mode shift and a broader and more diverse vehicle uptake. As ITF modelling shows (see Section 3), with a *like-for-like pathway*, transport systems will require almost 16% more electricity demand, as well as 33% more public charging points, than a *broader uptake* scenario that features higher shares of smaller and shared modes, for both passenger and freight mobility, including public transport. *Like-for-Like* will also take up around double the street space. In other words, even if cities were to reach full vehicle electrification, doing so while maintaining higher dependency on larger vehicles will bring higher costs and comparatively less liveable cities.

Like-for-like urban EV uptake will also considerably increase the demand for rare battery materials. As Section 3 will show, a *like-for-like* pathway will require 1.5 as much battery capacity as a *broader uptake* one. Increased battery demand raises environmental sustainability and geopolitics challenges for meeting EV uptake goals (ITF, 2021a). On the contrary, reduced battery materials demand resulting from decreased vehicle sizes and mode shift can be key for a safer and more sustainable future (Riofrancos et al., 2023).

Achieving the benefits of net-zero will require a transport policy shift to refocus on broader EV uptake – steering away from larger private vehicle dependency and reducing vehicle sizes. Such a shift of perspective would also ask that electrification policies be part of a wider strategy that avoids the need for unnecessary travel and supports the use of more sustainable modes. For instance, by fostering denser living environments where people can find opportunities close by and where goods can be accessed locally.

In addition, vehicle electrification needs to rely on decarbonised electricity. An ambitious approach combining these elements could yield an urban future where transport activities in 2050 emit less than one-third of the GHG emissions than in 2019 (despite the expected activity growth in urban areas) and fewer road fatalities (ITF, 2023d). Beyond its clear benefits for urban areas, a broader electric vehicle uptake in cities will facilitate the business development of electric vehicles for both urban and non-urban markets, for example by serving as market test examples.

To allow for such a future, policy makers must adapt regulations for new vehicle types and address the safety concerns of a new vehicle ecosystem. A challenge for planning for these changes is uncertainty over the likely speed of EV uptake and how and to what degree a change in the fleet composition will occur.

Policy makers' challenges adapting and preparing for a new urban transport future will also relate to energy provision. Understanding the peak electricity demand and the daily demand profile for EV charging will become crucial for cities to plan and upgrade their grid and electricity generation capacity. A detailed analysis of the impact of EV charging behaviour on the electricity demand at different times of day and in different places in an urban area will be important to achieve high EV uptake ambitions. Such information will allow policy makers to facilitate the necessary infrastructure to support EV adoption. It will also allow them to promote measures that nurture more sustainable charging behaviour among EV users – i.e., when there is less demand for other activities or when electricity demand is greener.

Use cases for a more sustainable and broader urban electric vehicle uptake

This subsection highlights some of the use cases where EV uptake could transform how people and goods move in urban areas for the better. It will show how light electric mobility vehicles, both private and shared, are changing people's mobility preferences and experiences. Light electric mobility vehicles explored include emerging "smaller-than-car" EVs – both micro EVs and electric microcars- and electric two- and three-wheelers (ITF, 2023c). Other shared EV services also provide newer ways of moving in urban passenger transport systems. The section will also highlight how electric buses can be crucial to sustainable public transport networks. Finally, it will emphasise the role of electric deliveries – both by cargo bicycles and electric vans – in sustainable urban logistics systems.

The potential of use cases to address the mobility needs of users will depend on local characteristics. In areas with lower population densities, such as peri-urban ones, distances tend to be longer, affecting the capacity of certain vehicle types to meet trip range requirements. Even when vehicles, or a combination, can cover users' travel distances, new mobility options might not always meet users' perceived comfort and travel habits. This is because of potential higher waiting or travel times or perceived low reliability of systems. Changing these perceptions will require changes in cities' mobility systems towards contexts that support new habits (ITF, 2023c; OECD, 2022). Charging availability across a metropolitan area will also play a role. In some cities, the allocation of new mobility services and charging infrastructure has targeted less low-income sectors than higher-income ones (Roy & Law, 2022). In such situations, potential EV uptake could be limited for lower-income groups, raising equity challenges for authorities (Roy & Law, 2022).

"Car-like" light electric vehicles for seamless urban passenger travel

Electrification has facilitated "car-like" light EVs, including micro EVs and micro cars. This also includes four-wheeled vehicles with at least a 70 km range and a size less than one-third of an SUV. In Europe, micro vehicles can correspond to vehicle categories L6e and L7e. These refer to quadricycles with a maximum construction weight of 350kg for L6e and 400 kg for L7e vehicles. L7e freight vehicles have a maximum construction weight of 550kg (ITF, 2023c). In the case of L6e models, these vehicles can have maximum speeds of 45 km/h (ITF, 2023c). Microcars are passenger cars weighing more than 400 kg, but they can be similar in size and use characteristics to micro EVs than other, larger, M-class cars (ITF, 2023c). Most new "car-like" light models are electric, as electrification reduces vehicles' mechanical complexity and weight, enabling greater design freedom (ITF, 2023c).

Figure 1. Examples of "car-like" light vehicles in Paris

Micro EVs | Microcar

Citröen Ami | Renault Twizy | Smart EQ FourTwo

Source: Andrea Papu Carrone.

"Car-like" light EVs already cater to the mobility needs of people in car-dependent contexts, according to the model. For instance, a micro EV with a 70 km range could cover more than one day of travel in cities in the United States, where on average, people travel around 46 km each day (Hou et al., 2013; U.S. Department of Transportation, 2017) They are also less resource intensive than larger vehicles in terms of their manufacturing materials, the energy required for their production and for their use. Due to their characteristics, about 35% of existing private vehicle users could eventually replace their current vehicles with a "car-like" light alternative, mostly in urban and suburban areas (Grausam, 2022). Before such a mode shift becomes a reality, however, mobility environments in car-dependent contexts will need to cater for their use. As Section 5 shows, this includes regulating travel speeds in cities' streets to guarantee the safe use of "car-like" light vehicles alongside regular traffic. Mode alternatives for extra-urban travel will also facilitate a mode shift away from private cars, as their purchase behaviour in car-dependent contexts can also be influenced by the perceived need for longer-distance (infrequent) travel.

Asian and European cities lead the uptake of "car-like" light EVs. Micro EVs and cars are an increasingly popular alternative for a first vehicle purchase in Asian urban markets, where car ownership is more recent and where users do not have expectations regarding vehicle size. Instead, smaller vehicle sizes and higher affordability of these EVs have allowed for a trend of vehicle customisation, making them attractive to a younger consumer base (Zhang, 2021; Zou et al., 2022) (Figure 2). "Car-like" light EVs are also becoming an attractive option in denser European cities, where users can benefit from the appeal of easier parking and lower delays due to congestion (CEPSA, 2022). In European cities, electric micro vehicles can be used by people as young as 14. However, there is a risk that such private vehicles could become the norm for younger users instead of more sustainable, even smaller, vehicle alternatives or active travel (i.e., walking or cycling).

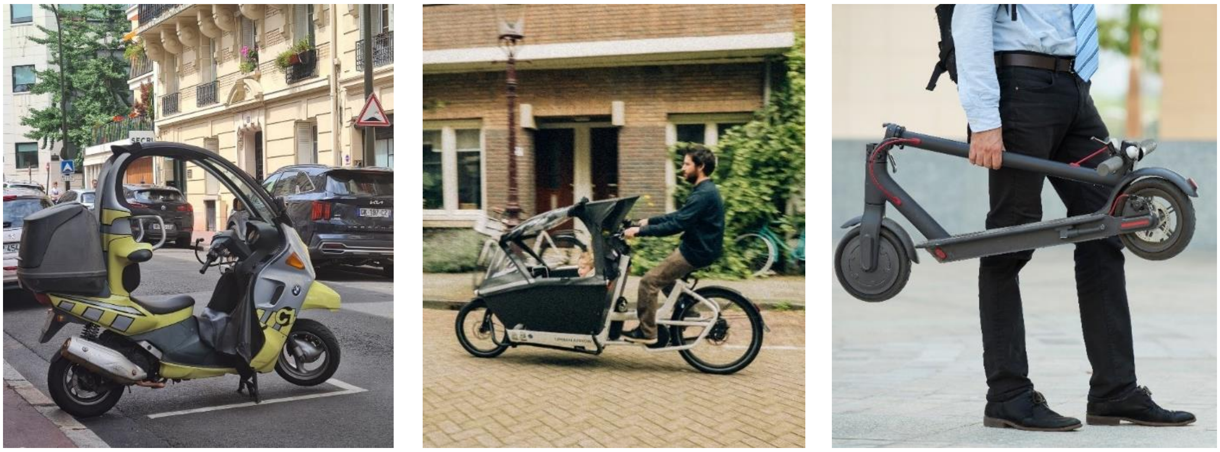
Figure 2. A customised WuLing Hongguang Mini EV, the leading micro electric vehicle in China

Source: Wheelsboy (2020).

Two- and three-wheeled private light electric vehicles for personal mobility

People are using their own electric two- and three-wheelers more and more for urban trips (Heineke et al., 2020). Two- and three-wheelers include forms of micromobility, such as bicycles and scooters, as well as forms of powered light mobility, such as motorcycles and tuk-tuks (Figure 3). A recent ITF report provides a more in-depth characterisation of two- and three-wheelers (ITF, 2023c). They also include cargo bikes for passenger transport – increasingly used in cities to transport personal belongings or even children. These vehicles can be used for commuting and leisure activities. Electric two- and three-wheelers can cover ranges between 12 and more than 200 km on one charge, depending on the model.

Figure 3. Examples of electric two-wheelers



Moped: BMW C1

Electric cargo bike: Urban Arrow, with kids in Amsterdam

Person travelling with an electric scooter

Source: Left to right: Andrea Papu Carrone; Tomas Alexander; Dragon Images/Shutterstock.

Two- and three-wheeled EVs are used for commuting purposes. E-scooters are also used for leisure trips and activities, potentially leading to induced demand by this mode (Christoforou et al., 2021). Still, in some cities, most of their usage tends to have a non-entertainment purpose (Cherry, 2022). The main motivations for using these vehicle types are time-saving, especially in highly congested areas, cost-saving and enjoyment (Christoforou et al., 2021).

Two- and three-wheeled EVs not only replace private, public and active mobility forms but also complement public transport use. In Paris, 16% of e-scooter users replaced private motorised trips with this mode. Yet, also in European contexts, observed mode shifts towards two- and three-wheeled EVs take place, among others, from public transport, walking and cycling, especially for e-scooters (Christoforou et al., 2021). Owning an electric two- or three-wheeled vehicle also supports shift away from private cars, as experiences in Paris show (Christoforou et al., 2021).

User characteristics influence electric two- and three-wheelers use. Women tend to use micromobility considerably less than men in most cities, especially at night. When they do, they tend to use dedicated infrastructure and travel at lower speeds. Gender differences are more prevalent in some cities than in others. While studies in Greek, Spanish and Swedish cities have shown gender disparities in e-scooter use, these are much less present in Seoul, Korea (Cubells et al., 2023). Age also affects vehicle use, but differently depending on the vehicle type. Most e-scooter users tend to be young (18-35 years old), with the fastest users being the youngest (Pazzini et al., 2022). Although, younger e-cyclists are also the slowest (Cubells et al., 2023).

The highest uptake of electric two- and three-wheeled vehicles occurs in emerging economies. In 2021, China captured around 95% of the 10 million sales of heavier electric two- and three-wheelers, such as mopeds and throttled e-bikes. This number does not consider micromobility sales – only e-bicycle sales amounted to 41 million in the country (Statista, 2023). In the same year, there were also high sales of heavier electric two- and three-wheelers in other markets where ICE two- and three-wheeler use is common, such as Viet Nam (230 000 sales) and India (300 000 sales) (Murugan & Marisamynathan, 2022; IEA, 2022a). High uptake also exists in European cities.

Electric vehicles for shared passenger vehicle services

Shared mobility services respond to people's mobility needs. Shared mobility comprises forms of ride services, such as:

- ridesourcing, which are "services that provide a single [or multiple] pre-arranged or on-demand ride in a vehicle operated by an employee or contractor of the ridesourcing platform"
- ridepooling, a service providing "an open seat for a single trip in a privately-owned vehicle operated by another user of the platform"
- microtransit, "a type of on-demand multi-passenger ride-sourcing service typically transporting passengers in small buses or vans along flexible routes or at flexible times". (ITF, 2023a)

It also includes fleet-sharing services, such as:

- shared micromobility vehicles
- moped sharing
- carsharing, of various vehicle types and sizes.

Fleet-sharing services can either be supported by docked points or fixed stations, often serving as vehicle charging infrastructure, or dockless and free-floating.

A study of the most congested cities in Germany, the United Kingdom and the United States shared that micromobility services covering distances of 5 km could replace at least half of motorised car trips (INRIX, 2019). Although shared mobility services suffered during the Covid-19 pandemic, recovery is underway. While in some cities, the role of shared micromobility services is being debated, many other services are expected to keep increasing their shares in the coming years (Andersson et al., 2020; Heineke et al., 2021).

EV-sharing services could deliver more sustainable EV uptake. Exposing users to EVs through these schemes could increase their purchase intention (Shaheen et al., 2020). These services can also be responsible for partial or total mode shift away from private vehicles and towards a scheme that increases the intensity of vehicle use. In five US cities, car-sharing services reduced private vehicle kilometres travelled by 6 to 16% by the few users of the platform (Martin & Shaheen, 2016). Levels of shared fleet use will vary according to the density of locations. Previous studies have shown a lower predisposition to use shared micromobility fleet services in lower-density areas than in higher-density urban centres (Blazanin, 2021). This could be due to higher trip distances, as well as to a lower density of micromobility stations and higher latency in vehicle access. Yet, station-based versions of these services can still increase access to essential opportunities in lower-density urban areas. To this end, station location needs to be optimised by considering local characteristics, such as the location of places of interest like shopping centres or education institutions (Askarzadeh & Bridgelall, 2021). Car and other long-ranged vehicle-sharing services can be particularly suited to respond to the needs of less dense areas, especially those with potentially higher car dependency.

The use of electric passenger shared micromobility services can complement public transport. Surveys in Paris show that around 9% of e-scooter trips complemented public transport – similar to some US cities like Denver or Norfolk (Wang et al., 2022). Micromobility can also substitute public transport trips, especially when public perception of public transport quality is low, or in denser areas where trips are shorter (Christoforou et al., 2021). Conversely, in more sprawling cities, rates of public transport substitution by micromobility tend to be lower because of longer average public transport trip lengths. Substitution is not necessarily negative: especially for denser areas and for shorter distances, it can signify a complementarity between the use of public transport for longer trips and micromobility for shorter ones, alongside potential improvements in user experience. Users also make the most out of the multimodality offered by shared micromobility. For example, a trip by shared e-scooter can be complemented by a return trip by public transport (Wang et al., 2022). Finally, the sector within the urban area where trips originate or finish also plays a role. In Warsaw, electric bicycles are used more for connecting to the public transport network in the city's peripheries than in the city centre itself (Nawaro, 2021).

Emerging forms of ridesourcing and microtransit could complement existing public transport networks. Previous simulations from the ITF show that a combination of public transport with forms of ridesourcing and microtransit, could respond to almost all mobility needs of dwellers of cities like Lyon, Lisbon, Dublin and Helsinki (ITF, 2018; ITF, 2020e). In practice, ridesourcing and microtransit can connect users with existing public transport services or act as substitutes for low-frequency routes, as well as in cases where no routes exist. They can provide more flexible routing with smaller vehicles, potentially increasing vehicle capacity use. In the Paris area, for instance, authorities have developed a microtransit service to complement public transport in areas where it is not viable to keep regular bus services (Île-de-France Mobilités, n.d.). In Caracas, Venezuela, following the deterioration of public transport services in the city, a start-up has developed an on-demand microtransit service to grant shared mobility access throughout the metropolitan area. At the time of writing, the start-up operates on-demand services around more than 20 lines, which often provide parallel services to, or replace, existing and former public transport routes (LaWaWa, 2023).

Increased uptake of electric shared mobility services could positively impact cities’ sustainability by increasing the intensity of vehicle use and fostering a mode shift away from private alternatives. Yet, the sustainability of shared mobility systems could be limited by the energy and eventual emissions required for these services’ operations. Operations include reallocating dockless vehicles across an urban area to meet demand and movements linked to their collection, recharging and repositioning (ITF, 2020b).

EVs for more sustainable public transport

EVs are a leading vehicle technology for improving the sustainability of public transport buses. National and local authorities worldwide are adopting EV buses to meet various policy objectives. From reducing GHG and local pollutant emissions to vehicle noise EV buses are increasingly able to meet these objectives when compared to other vehicle technologies, such as Euro VI diesel or gas buses, hybrid, and hydrogen fuel cell vehicles. For instance, EV buses' total cost of ownership is comparable to diesel alternatives, even if the initial investment requirements might be larger. The attractiveness of EV buses for transitioning local bus fleets grows stronger due to the lower technology risks of this vehicle type, brought about by high public policy interest (EBRD, 2021). Increased ranges of at least 200 km, depending on the model, terrain characteristics and weather conditions, also contribute to higher attractiveness. For example, ranges would be lower in colder climates because of increased electricity consumption caused by interior vehicle heating and the temperature impacts on battery life (Papa et al., 2022).

Bus fleets in cities across the world are increasingly electric. Chinese cities lead, with more than 75% of their bus fleets expected to be electric by 2025 (Yiyang & Fremery, 2022). Local and national authorities worldwide have proposed ambitious objectives for electrifying urban buses. By 2028, around 40% of urban bus fleets in European markets are expected to be electric, as opposed to less than 5% in 2018 (UITP, 2021). Levels of electrification vary across countries. In Denmark and the Netherlands, local authorities aim to have fully zero-emission buses by 2030 (including both EVs and vehicles powered by fuel cells) (Wappelhorst & Rodríguez, 2021) (Figure 4). Other authorities aim at having fully zero-emission fleets by 2030 (New Zealand) and 2050 (Cape Verde and Costa Rica) (Wappelhorst & Rodríguez, 2021). Bogota, Colombia, has, at the time of writing of this report, the world's largest EV bus fleet outside of China, with almost 1 500 vehicles, representing more than 10% of its fleet (TRANSMILENIO, 2022).

The uptake of EV buses will vary according to travel requirements and local characteristics. EV buses can easily meet the operational needs of bus services in denser and more compact urban contexts, such as in many European cities. Yet, vehicle ranges cannot cover all distances in larger cities. In Bogota, fleet electrification has mostly occurred in feeder routes. On these routes, around 40% of the fleet is now battery-electric. Compared to this, there are not fully EVs operating in the trunk lanes of the city. This is because of buses' range limitation (TRANSMILENIO, 2022). The initial adoption of e-buses showed that their daily ranges averaged around 235 km per day, compared to around 440 km for diesel vehicles (SCLAR et al., 2019). As this report will discuss in Section 5, overcoming range issues will require balancing infrastructure investment costs with operational needs.

Figure 4. Electric buses in Copenhagen

Source: Andrea Papu Carrone.

Electric vehicles for urban deliveries and logistics

Freight carriers are increasingly electrifying their vehicle fleet, motivated by consumers' environmental expectations, increasing competition in the sector, technological evolutions, and heightened energy prices. Cities' sustainability objectives and policies, such as urban vehicle access regulations and electrification incentives, also contribute to the accelerated adoption of EVs for urban logistics, both for electric cargo bikes (e-cargo bikes) (Figure 5) and for electric light commercial vehicles (LCVs) (ITF, 2022b). Electrification can also lead to lower operational costs for carriers, depending on the context and goods delivered (ITF, 2019a).

Figure 5. Emerging small electric vehicles for freight transport in Paris

Electric two-wheeler | Electric three-wheeler | Four-wheeler electric assisted cycle (eQuad by Fernhay)

Source: Left to right: Andrea Papu Carrone; Joshua A. Paternina Blanco; Andrea Papu Carrone.

Electric cargo bicycles are changing urban logistics. Electric cargo bikes refer to two- and three-wheeled vehicles with a compartment allowing for transporting goods, which can carry up to 500 kg, depending on the vehicle type (Nürnberg, 2019). There has been a tremendous increase in cargo bike use. In Europe, annual sales by 2022 were estimated to reach up to half a million units, twice as many as in 2019, and could reach 2 million by 2030 (Cyclelogistics, 2022). The average size of a commercial carrier cargo bike fleet has increased fourfold since 2019. Of the cargo bikes sold, 98% are electric. And more than 80% of them are used for goods delivery (Cyclelogistics, 2022). Outside of Europe, big adopters include China, who will represent more than 50% of the market by 2031, and Australia and New Zealand, who are set to have the highest adoption in South Asia and the Pacific (Velco, 2022).

More traditional freight vehicles are also in the process of electrifying, albeit at a slower rate. By 2021 there were half a million electric LCVs (eLCVs) worldwide, most of them in China and Europe. One-third of eLCVs were sold only in 2021, reflecting recent accelerated electrification. Despite this, in Europe, the share of eLCVs from all such vehicles is only about 0.6% (IEA, 2022a). Such a low electrification rate highlights the many challenges for fleet electrification, such as limited model availability, often lacking incentives for operators and low use of regulations requiring fleet change (Val, 2022).

Electrifying larger LCVs will be essential for more sustainable urban logistics. LCVs are the most polluting urban freight delivery vehicles for GHG and local pollutant emissions, such as NOx (Boudet, 2021). Yet, they are also the preferred vehicle type for urban logistics in many European cities. In the Netherlands, for example, in 2017, between 15 000 to 25 000 LCVs were involved in e-commerce home delivery, and in the centre of Amsterdam, around 80% of all freight vehicles were LCVs (Visser et al., 2018). This is because, in optimised operations, these vehicles can carry higher payloads, which are essential for consolidating loads in a limited number of LCVs, thereby reducing vehicle numbers and bringing about efficiency and environmental gains. In addition, they can provide the technical in-vehicle requirements for correct storage and transport for certain commodity types, such as those requiring certain temperatures.

Electrification also enables new vehicle types for last-mile deliveries. Freight EV uptake facilitates a reduction in vehicle sizes. Emerging EV types include smaller forms of traditional vehicles and high-capacity two-, three- and four-wheelers. Vehicles can also include forms of electrically assisted pushcarts and electric trailers. These vehicles are well-suited to fit the needs of last-mile deliveries and micro-logistics, especially in dense urban areas. Some of them are also designed to fit the needs of a specific industry, such as food deliveries (Walford, 2021). Vehicles are increasingly designed, developed, and produced by local firms to fit local needs. In Uruguay, for instance, national and international public funds supported the development of new last-mile electric freight vehicles by local enterprises, supporting local supply chains and workforce (MOVÉS, 2021).

The electrification of urban logistics raises challenges for freight carriers. These include changes in the operational activities of freight carriers. Fleet electrification requires adapting delivery routes and hub-related operations to vehicle ranges and charging requirements. For like-for-like technology changes, carriers must adapt delivery routes and practices to EVs' charging and operational needs. Routes will need to include urban logistic hubs where charging is possible – around 80% of electric truck charging is expected to come from depot charging stations (Marcucci et al., 2020). Shifting towards using e-cargo bikes and other alternative vehicles could also require integrating consolidation and transhipment centres into their operations to cross dock loads from larger vehicles (Logistics City Chair, 2022). In both cases, staff training would also be required (Val, 2022). Depending on the context and goods carried, shifting towards e-cargo deliveries could increase the number of trips required for the same number of deliveries. This is not likely to happen for carriers with low load factors, but it could be the case for carriers transitioning from already optimised routes with high load factors to cargo bikes. Yet, when using e-cargo bikes and other smaller vehicle types, delivery times could be decreased due to less time being lost in congestion (ITF, 2022b).

2. How to measure the impacts of broader electric vehicle uptake?

This section describes the modelling approach developed by the ITF to assess the impacts of EV uptake on cities. It defines the wide array of vehicles and modes for passenger and freight transport included within the model. It shows how the use cases presented in the previous chapter are integrated into the big picture of mobility. The section also illustrates the detailed travel activity data for passenger and freight transport, supporting the quantitative analysis presented in the next two sections.

Modelling framework for measuring the impacts of electric vehicle uptake

The modelling for this study is based on and further develops the ITF Urban Agent-based model (ITF, 2018; Martinez & Viegas, 2017). It is a detailed transport simulation and optimisation model representing a typical day's passenger and freight travel activity. This work upgrades the ITF Urban Agent-based model to include a wide array of passenger and freight vehicle types with different vehicle sizes and powertrains (ICE and EV) (Table 2) used for various transport modes. New additions also allow tracking the state of charge (SOC) of each EV during the entire simulation period – a typical day. In addition, the updated model assigns electric modes and vehicle types to different charging facilities, depending on their needs and charging behaviour, as well as the charger's rated power and locations. These additions allow the modelling of the charging activity of each vehicle and the calculation of charging infrastructure and electricity demand to supply the EV fleet throughout the modelled day and for every five minutes.

The modelling work outlines the consequences of EV uptake in a mid-sized European city based on the Greater Dublin Area (Ireland) – the metropolitan area of Dublin. The modelled area accounts for more than 970 km^2 divided into 344 zones of varying size between 0.1 and 18 km^2. As this section will show, inputs to the modelling framework include observed datasets from the Greater Dublin Area and ITF-generated data reflecting a possible characterisation of the shared and free-floating transport supply, detailed parking availability and vehicle electrification rates. Because the modelling results do not exclusively depend on observed data, this report's results should not be used to assess measures in the specific case of Dublin.

This agent-based modelling framework constitutes the state-of-the-art modelling of EV uptake. First, it relies on a bottom-up approach that simulates transport and charging decisions at an agent (person or freight unit) level and draws well-grounded impacts at a system level. Second, its broad scope allows us to analyse comprehensively the impact of electrifying all transport within the city (freight carriers, private passengers, and public passenger transport). Finally, its fine temporal and spatial level of analysis allows for testing the impacts of a wide variety of policy measures.

The modelling framework (Figure 6) comprises four key components: a lexicographic travel demand framework, an EV charging component, a transport operation and management module and an infrastructure optimisation framework.

The two main inputs of the ITF Urban Agent-based model

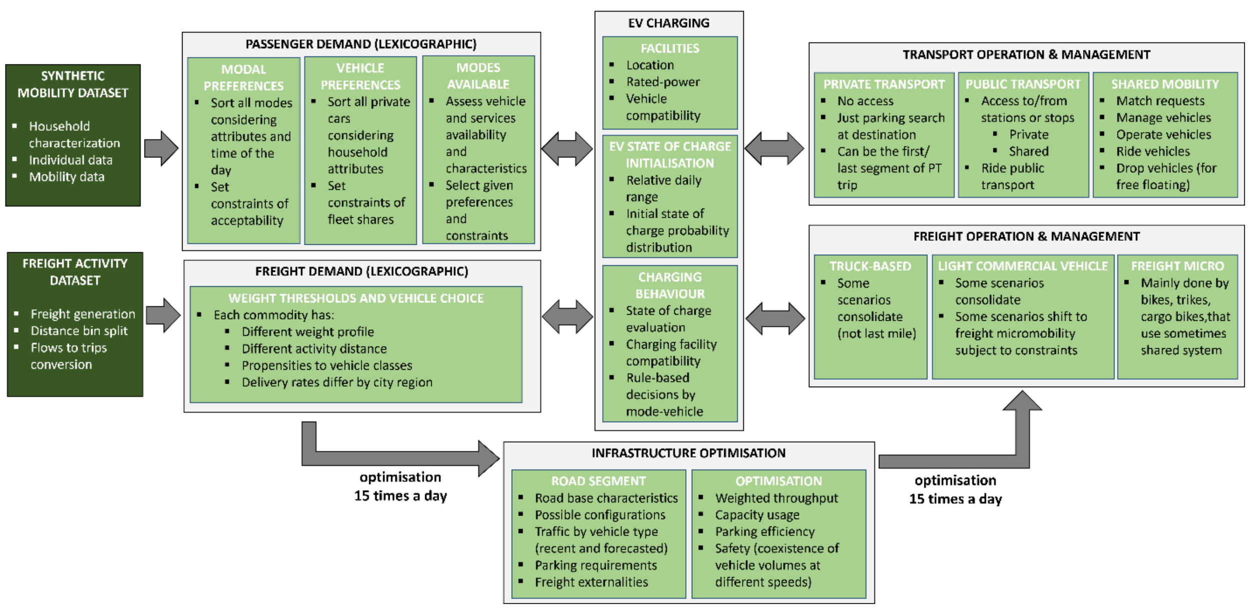
The synthetic mobility dataset for passenger travel

It provides information on all households, their daily travel activity and mode preferences within the Greater Dublin Area. Further details regarding the generation of the synthetic mobility dataset can be found in the ITF's report on shared mobility simulations for Dublin (ITF, 2018).

The freight activity dataset

It characterises the daily travel activity of each freight vehicle type classified by commodity (ten commodities) and travel distance (six distance bins). Further details regarding the generation of the freight activity dataset can be found in ITF's urban freight transport model EU Horizon 2020 publication (ITF, 2020d).

Figure 6. Updated modelling framework to account for electric vehicle uptake



Key components of the modelling framework applied in this study

The lexicographic travel demand framework

This component analyses the mode and vehicle choice of new alternatives not observed within the input dataset. To this end, it sets a pre-established order of mode and vehicle preferences for each person depending on transport availability, its expected attributes, and operational criteria, such as expected travel time and speed specification for each vehicle type.

This work adds new mode alternatives to the modelling framework for passenger transport. New alternatives include shared mobility, encompassing forms of ridesourcing and microtransit; and multiple free-floating shared vehicle fleets, including shared cars, shared micro EVs, shared mopeds, shared bicycles, and shared e-kick scooters. These modes are incorporated either as a principal travel mode or as secondary modes facilitating, for instance, first- and last-kilometre connectivity with public transport. This work is based on a plausible characterisation of shared and free-floating transport supply generated synthetically in previous ITF work (ITF, 2018; ITF 2022a). The modal preferences model is conceived as a sorting utility-based algorithm derived from the ITF Transport Outlook 2021 Global Urban Model (ITF, 2021b). Constraints are set to trigger potential mode shifts (i.e., the conditions under which one mode can be replaced by another). The specific modal availability of shared modes and vehicles depends on the time of day, trip purpose and location.

Vehicle choice for private cars results from households' characteristics and vehicle features. Features include vehicle sizes, such as micro, small, medium, and large, and powertrains (ICE, EV). Individuals' propensity to choose an alternative will vary according to household income, home parking availability and persons within the household. Private car owners are segmented into 14 profiles, and the propensity of each profile to choose a vehicle size and powertrain is based on the stated preference survey developed by Fjendbo Jensen et al. (2021), as described in Figure 22 in the Annex. Households with home parking availability have a higher propensity to own an EV, and households with more members tend to own larger cars. The choice of size and powertrain is constrained to the total fleet size and powertrain shares. Each shared or free-floating four-wheeled mode is associated with a unique vehicle size. At the same time, powertrain choice (ICE, EV) is randomly distributed and constrained to total fleet shares.

The model also assigns vehicle choice to freight transport needs. The vehicle type selection component determines the propensity of a given commodity transported at a given distance to shift to a smaller urban freight vehicle, such as bicycles and tricycles or cargo bikes. The modelling of the propensity to shift to smaller urban freight vehicles is further developed within (ITF, 2022b). The choice of powertrain (ICE, EV) for LCVs and trucks is randomly distributed and constrained to total fleet shares of each vehicle type.

The electric vehicle charging component

EV charging facilities within the modelling framework are classified into freight depots, shared modes and vehicle depots, public transport depots and private passenger facilities. Charging facilities for private passenger vehicles include home (off-street) charging, destination charging (workplaces, off-street parking lots, shopping malls) and public on-street charging, which can either be with a slow or fast charger. A detailed characterisation of the charging facilities and modelling assumptions regarding the vehicles charging at each facility and the power rate at which they are charged is provided in Table 1. This modelling framework does not include battery swapping as a charging alternative, despite its growing use for micromobility and micro cars.

The charging behaviour is vehicle specific. Freight vehicles are assumed to charge at their depots when they finish their daily tour (sequence of trips). Based on a rule-based modelling assumption, shared and public transport vehicles charge at their respective depots, beginning after 21h, when passenger travel activity in the network decreases. The exact time these vehicles start to charge depends on their activity and the availability of chargers in their corresponding depot. When no chargers are available within a depot, the vehicle wishing to charge queues until a charger becomes available.

In order of priority, private four-wheeled EVs charge when they arrive home if home charging is available, at their destination (if possible), or at on-street public charging facilities. In the modelled area, on average, 57% of households owning a four-wheeled vehicle have access to off-street home parking (50% in the urban centre and 60% in the peri-urban area). All households that own a four-wheeled EV and have access to off-street home parking are assumed to have a home charger. It is assumed that 18% of the private four-wheeled trips to workplaces have access to charging facilities at their destination and that all existing off-street parking lots (garages or shopping malls) have charging facilities too. Charging events at workplaces or off-street parking lots are bundled as destination charging. A detailed decision tree diagram of the rule-based modelling of private four-wheeled EV charging behaviour is included in Figure 23 in the Annex. Private micromobility is always charged at home.

Vehicles only charge if their SOC is not enough to complete one full day of their daily travel activity or if their SOC is lower than 20%. At any time, if a vehicle SOC becomes lower than 20%, it can charge at public charging facilities (except for trucks and buses), with a higher probability of choosing a fast charger. All vehicles charge until full-charge or until their following activity begins (if this happens before the time required to full-charge).

The SOC initialisation for each vehicle is a key component, given that the model simulates operations over a 24-hour period rather than simulating over multiple days. The definition of the initial SOC level of the individual EVs is highly influential to the results. Therefore, we rely on the steady-state SOC distribution proposed by Hipolito et al. (2022) and calibrated to empirical data collected from 10,000 EVs in Denmark. The authors define the probability of a certain SOC for an EV as a function of the relative daily range, i.e., the ratio of the daily travel activity and the maximum vehicle range. Figure 24 in the Annex shows the simulated distributions for the initial SOC levels of EVs included in the modelling.

Table 1. Characterisation of charging facilities for ITF's modelling framework

Charging facility	Location	Type of charging	Power rate (in kW)	Vehicle type
Home	Off-street	Slow	3.6	Private cars, private motorcycles
Home	Off-street	Other	0.2	E-scooter, e-bike, e-cargo bike
Destination (workplace, parking lots, shopping malls, for instance)	Off-street	Slow	11	Private cars, private motorcycles
Public	On-street	Slow	11	Private cars, private motorcycles, LCV
Public	On-street	Fast	50	Private cars, taxis, ridesourcing, carsharing, LCV
Freight depot	Off-street	Slow	11	LCV
Freight depot	Off-street	Fast	100	Medium truck, heavy truck
Freight depot	Off-street	Other	0.2	Freight e-bike, freight e-trike, freight e-cargo bike
Shared modes and vehicles depot	Off-street	Slow	11	Taxis, ridesourcing, microtransit, shared cars
Shared modes and vehicles depot	Off-street	Other	0.2	Shared e-scooter, shared e-bike, shared e-cargo bike, shared e-motorcycle
Public transport depot	Off-street	Fast	100	PT bus

The transport operation and management framework

The model includes a transport operation and management framework to determine modal attributes. Attributes vary according to factors such as operational needs, the expected travel time given the street capacity and the speed specifications for each vehicle type. All shared mobility users and vehicles operating in the area send and receive information to a centralised dispatch algorithm that optimises vehicle usage and plans for subsequent periods. More details about the simulation architecture of the passenger shared modes and the services optimisation approach can be found in (ITF, 2018). More details about the operation of free-floating shared vehicles can be found in (ITF, 2022a), and details regarding the operation of freight transport vehicles can be found in (ITF, 2022b).

The street infrastructure and optimisation component

A final component optimises the use of street infrastructure by various vehicle types. To this end, an optimisation algorithm runs on street segments, both static, such as parking, and dynamic, depending on vehicle space and speed needs. This algorithm enables changes in the street capacity reserved for each vehicle type (moving or standing) and in an optimal free flow speed, given the combination of expected flows. The optimisation of street infrastructure is calculated 15 times in the day, at the moments when higher fluctuations in travel demand occur. In these instances, the street design profile is selected among 19 predefined street profiles (with restrictions of street change compatibility, i.e., not allowing the conversion of a highway to a pedestrian road), and the permitted speed and space is attributed to each mode. More details regarding the implementation of this component can be found in (ITF, 2022a).

Integrating more sustainable use cases within the big picture of mobility

The ITF Urban Agent-based modelling framework includes various modes and vehicles aiming to represent all travel activity within an urban area. This work adds the representation of electric vehicles within the framework. These are included in Table 2, along with their key characteristics, such as range, efficiency, and battery effective capacity. The battery effective capacity of four-wheeled vehicles is defined as 85% of the total battery capacity, whereas it equals the total battery capacity for smaller vehicles. Table 3 shows the correspondence between the modes included in the model and the different vehicle types. Each use case discussed in the report's first section encompasses some of the passenger and freight transport modes and vehicles included in the following tables.

Table 2. Characterisation of electric vehicles for ITF's modelling framework

Vehicle Type	Efficiency (kWh/100km)	Battery Effective Capacity (kWh)	Range (km)
E-scooter	1.3	0.7	54
E-bicycle	0.9	0.7	80
Cargo e-bicycle/e-tricycle	1.6	0.8	50
E-motorcycle	2.2	2.6	120
Micro-EV	7.4	5.4	73
Small e-car	12.3	33.3	271
Medium e-car	15.8	43.2	274
Large e-car	19.4	70.2	362
E-van	34.5	80.1	232
Medium e-truck	114.7	238.5	208
Heavy e-truck	144.4	486	336
E-bus	112.2	396.9	354
Small e-bus	23.7	67.5	285

Table 3. Characterisation of modes and vehicles for ITF's modelling framework

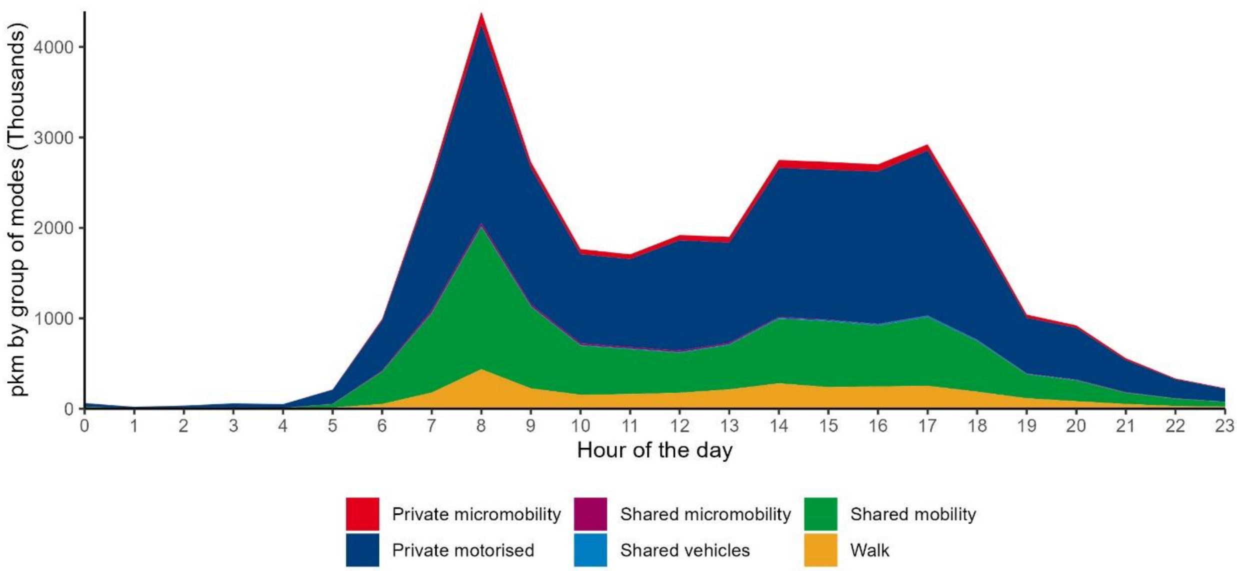
Type	Mode group	Mode	Vehicle Types
Passenger	Walk	Walk	
	Private micromobility	E-scooters	E-scooter
		Bicycle	Bicycle/e-bicycle
	Private motorised	Motorcycle	Motorcycle/e-motorcycle
		Car (driver)	Micro EV
			Small car/small e-car
			Medium car/medium e-car
			Large car/large eCar
		Car (passenger)	Micro EV
			Small car/small e-car
			Medium car/medium e-car
			Large car/large e-car
	Public transport	Bus	Bus/e-bus
		Rail	
		Light rail transit	
	Shared micromobility	E-scooters sharing	E-scooter
		Bicycle sharing	Bicycle/e-bicycle
	Shared mobility	Taxi	Medium car/medium e-car
		Ridesourcing	Medium car/medium e-car
		Microtransit	Small bus/small e-bus
		Feeder (microtransit)	Small Bus/small e-bus
	Shared vehicles	Shared motorbike	Motorcycle/e-motorcycle
		Carsharing	Medium car/ medium e-car
		Micro carsharing	Micro EV
Freight	Freight micromobility	Delivery bicycle	Bicycle/e-bicycle
		Cargo bicycle/tricycle	Cargo bicycle/tricycle/cargo e-bicycle/e-tricycle
	LCV	Delivery motorcycle	Motorcycle/e-motorcycle
		Van	Van/e-van
	Truck-based	Medium freight truck	Medium truck/medium e-truck
		Heavy freight truck	Heavy Truck/heavy e-truck

Modelling the daily activity of both passenger and freight transport

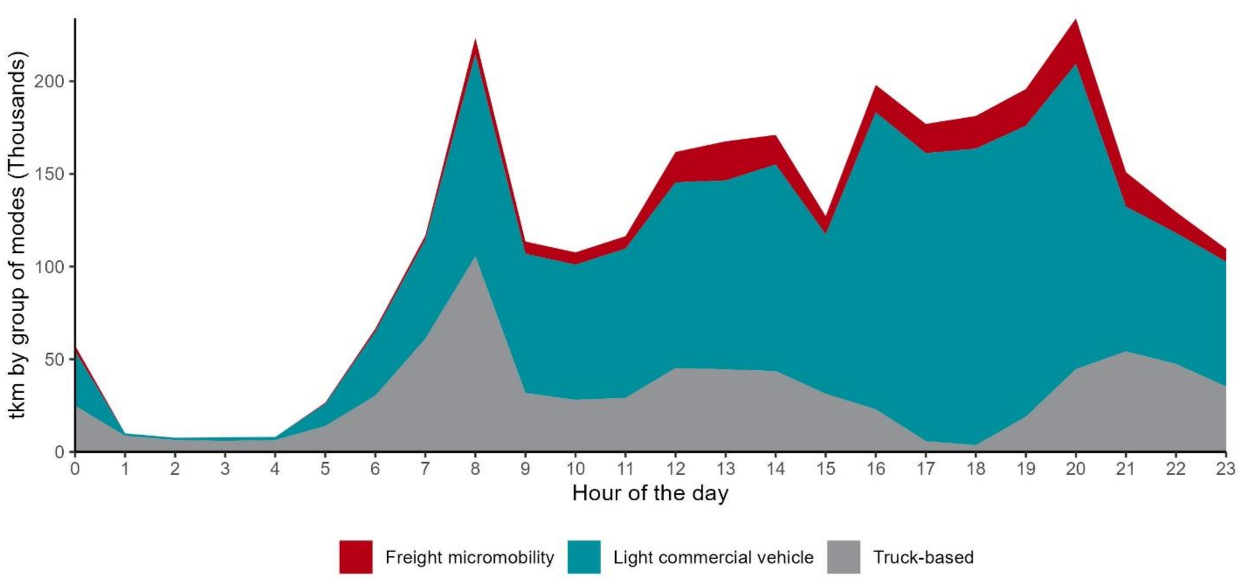
Electricity demand patterns and charging infrastructure requirements are strongly correlated to the temporal dynamics of local travel activity. Travel activity data for passenger and freight stems from the synthetic mobility dataset (ITF, 2018) and the freight activity dataset (ITF, 2020d), respectively. For instance, the travel activity by mode presented in Figure 7, for both passenger and freight activities, provides a foundation for the electricity demand patterns presented in Section 4.

Figure 7. Travel activity by mode

Passenger-kilometres (pkm)



Tonne-kilometres (tkm)



Note: Public transport is not represented in the figure because it is not included in the agent-based simulator.

3. How could electric vehicle uptake maximise the sustainability of cities?

Achieving net-zero systems will only be possible with a broader and more sustainable EV uptake. This section provides evidence to support this by comparing the impacts on cities' sustainability of two full vehicle electrification pathways: *like-for-like full vehicle electrification* and *broader uptake full vehicle electrification*. It explores transport-related effects, such as street space use, safety implications, electricity demand, public charging infrastructure requirements, and battery capacity needs for both pathways.

Imagining two different fully electric cities: like-for-like vs broader uptake

This work develops two full-electric scenarios, laying the groundwork for discussions about the type of vehicle electrification policy that authorities decide to support based on the urban futures they could envision. The *like-for-like* pathway presents full vehicle electrification while maintaining dependency on larger vehicles. Conversely, *broader uptake* aligns four-wheeler electrification goals with policies that promote mode shift to more sustainable modes and electric vehicle types. Fully electric urban transport is not expected to be the norm in the near future in most cities around the world. Yet, comparing these two pathways can frame discussions on what would happen if authorities decided to incentivise a much wider range of smaller EVs as fleets electrify – and what could happen if this is not the case. Results are not to be understood as definitive outlooks of fully electric futures but rather as the basis for discussions on where EV uptake public action should go.

The two pathways to full vehicle electrification are defined as follows:

Like-for-like full vehicle electrification: All vehicles are electric; however, mobility systems maintain current levels of dependency on larger vehicles, so no change in passenger and freight travel behaviour is observed. Mode choices and vehicle sizes are identical to the baseline (as observed in the synthetic mobility dataset (ITF, 2018)).

Broader uptake full vehicle electrification: In this scenario, all vehicles are also electric. Full EV uptake is combined with ambitious policy packages that promote smaller vehicles and higher vehicle capacity use. In doing so, it serves the same mobility needs as *like-for-like*. It relies on highly plausible mode shift assumptions (implemented in the lexicographic travel demand framework described in the previous section). Consistent with previous ITF work, it assumes that policies favouring the use of more sustainable modes lead to considerable mode shifts (ITF, 2022a; ITF, 2022c). In addition to this, the scenario foresees a decrease in vehicle sizes due to promoting micro and small EVs. As a result, smaller passenger cars significantly increase their market share as large passenger cars reduce theirs. Increases in shared modes resulting from these packages deliver higher vehicle capacity use. In the case of freight transport, the improvement of vehicle capacity use is due to changes in operations that favour load consolidation. These include the increased use of urban logistic hubs for eLCV deliveries and break-bulk operations between these vehicles and e-cargo bikes.

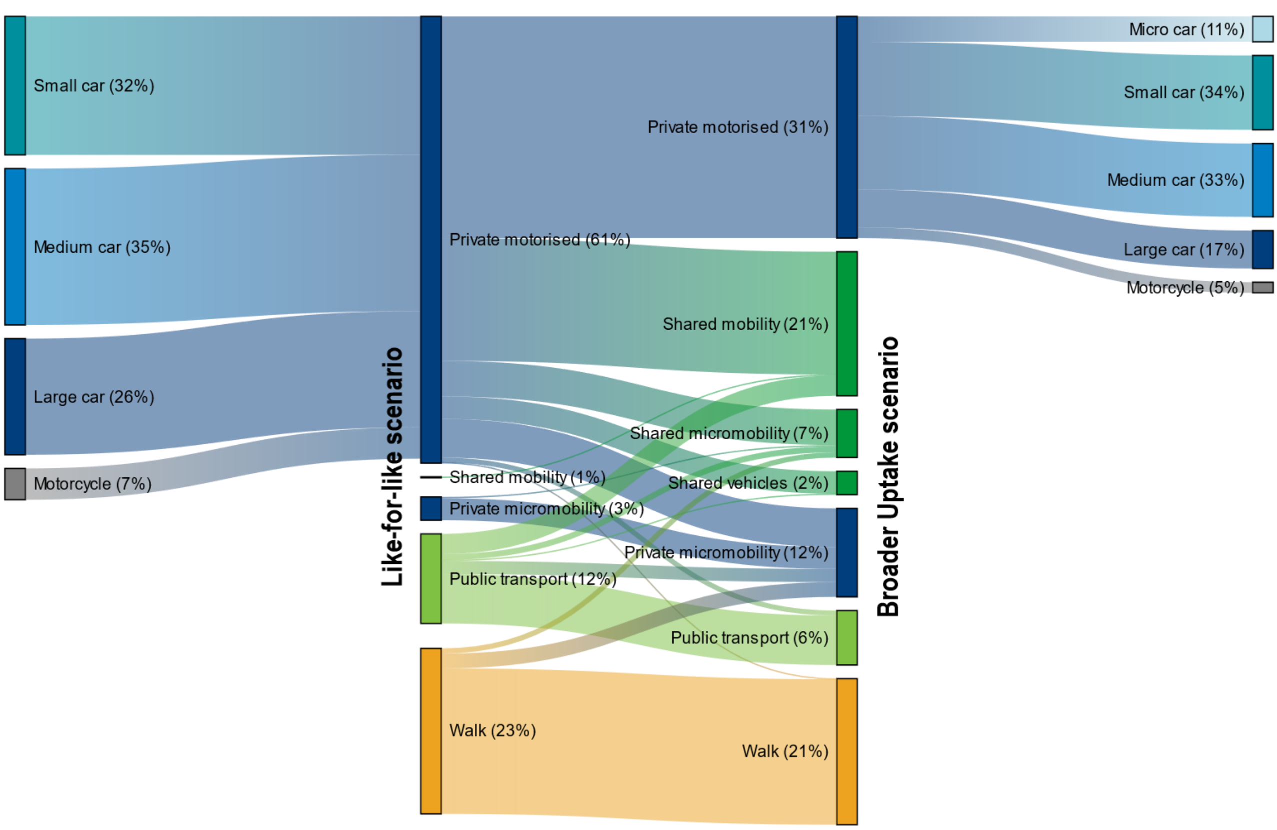
Figure 8 shows the changes in mode choice to shift from present mode shares (equivalent to the *like-for-like* scenario) to a *broader uptake* scenario for passenger and freight transport.

With increased sustainability, passenger micromobility rises while private mobility decreases. Under the *broader uptake* scenario, the share of private and shared micromobility trips within passenger activities are 12% and 7%, respectively. Mode shares of shared mobility and shared vehicles are high (23%) as they replace a large share of private motorised trips and public transport trips to a lower extent. In the *broader uptake* scenario, trips travelled by private car decrease by 30%, reducing its mode share to less than one-third of passenger activity. This scenario also shows a shift in private passenger cars towards smaller vehicle sizes. Among passenger cars (private motorised), the share of electric micro EVs increases to 11%, while large ones decrease by 9%.

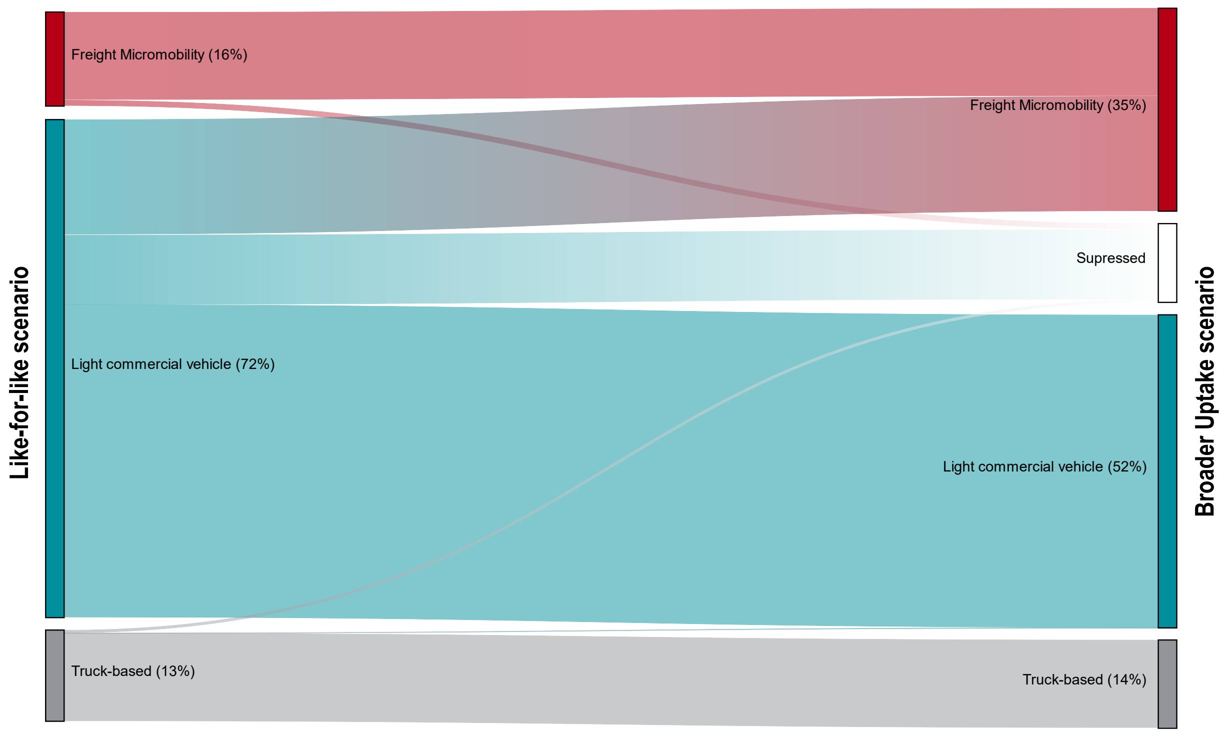
For freight transport, the *broader uptake* scenario shows that the mode share of freight micromobility increases by 19%. LCV travel is the most affected mode, decreasing the number of trips by almost half. LCV trip reduction is mainly led by shifts to freight micromobility and from suppressed trips due to the increase in LCVs trips load factors driven by urban logistic hubs that foster load consolidation.

Figure 8. Mode (trips) and vehicle type shares in full-electric scenarios: Like-for-like vs broader uptake

Passenger transport



Freight transport



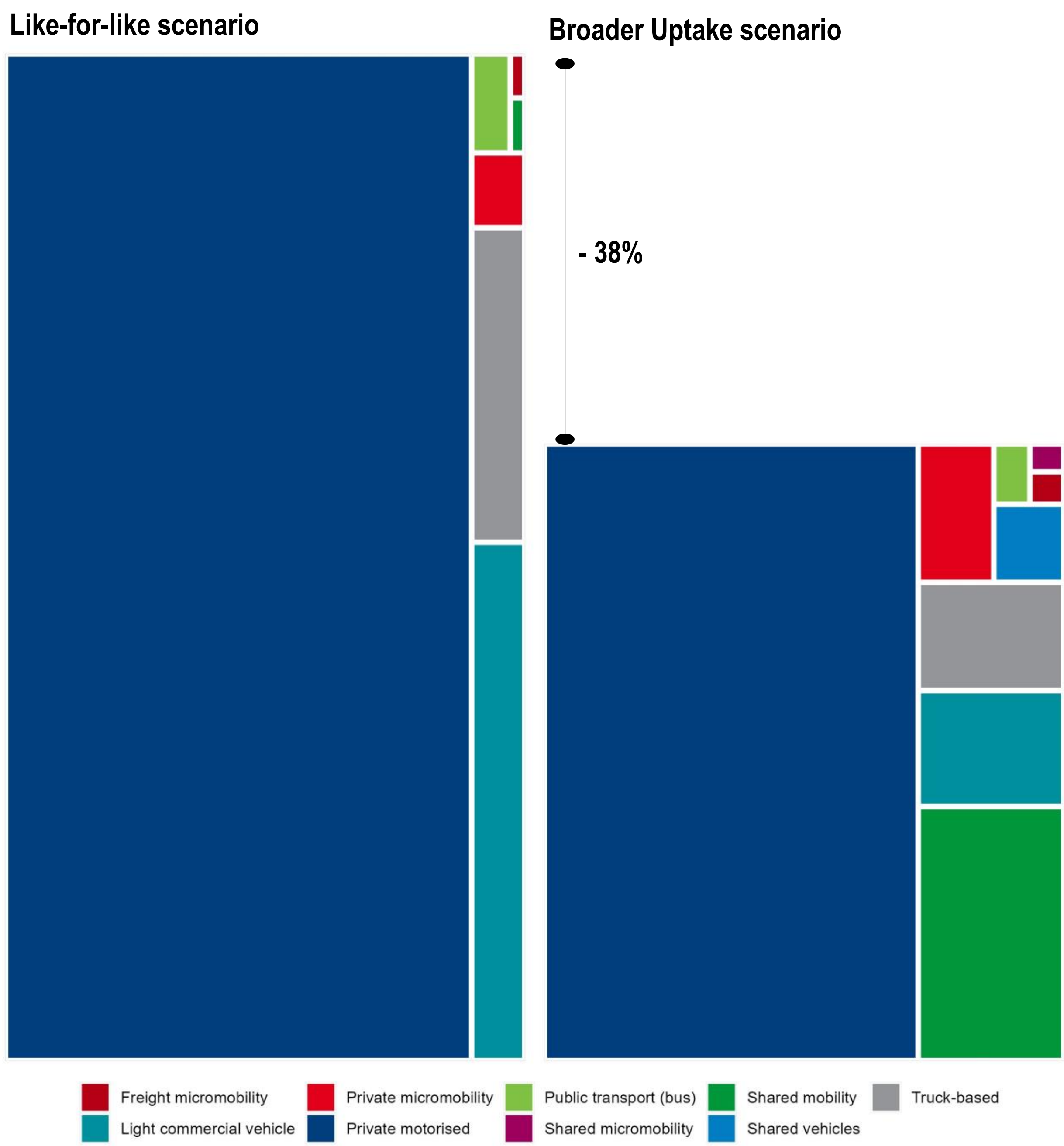
Mode shift at the basis of broader electric vehicle uptake reduces street space consumption

Street space consumption is calculated based on the mobility patterns, number of trips, modes and trip durations resulting from the model. The space consumption measure incorporates four main components: (1) static space consumed when vehicles are not in use (e.g., parking or parking while charging), (2) dynamic space consumed by vehicles while travelling, (3) space used by public transport or shared modes travellers while waiting for the vehicles to arrive, and (4) while travelling to and from public transport. This approach is based on the work and equations from Héran and Ravalet (2011). A detailed discussion on their components and rationale can be found in (ITF, 2022a) and the extension for freight vehicles in (ITF, 2022b). The method for calculating street space consumption is extended to new vehicle types included in this report.

A *like-for-like* pathway will consume more than 1.5 times as much street space as a *broader uptake* pathway (Figure 9). This significant difference is mainly driven by 50% of passenger car users who switch to alternative modes (mostly to shared motorised modes and micromobility), 23% of urban deliveries by motorised modes which switch to freight micromobility and 11% of trips of motorised urban deliveries that are suppressed due to an increase in vehicles' load factors. The difference in street space consumption between both scenarios is 39% for passenger transport and 23% for urban freight transport. Although there is a higher potential to reduce passenger transport space consumption than urban freight, the space consumption of freight transport is nine times smaller than that of passenger transport.

Private cars consume more space per day than any other mode. On average, private motorised transport has the highest space consumption per trip and per kilometre travelled, and therefore, it consumes more space per day than any other alternative mode. Shared motorised transport performs much better than private since more than 80% of the space consumed by private vehicles relates to parking (ITF, 2022a).

Figure 9. Street space consumed by mode per day (km^2): Like-for-like vs broader uptake



Electric futures and the need for on-street public charging add an extra complexity to the already challenged street space allocation. While on-street public charging occupies street space, vehicles tend to remain parked within their charging location for more time than the time required for charging. On average, slow on-street charging events last 140 minutes and fast charging only 47 minutes (in the *like-for-like* scenario). In contrast, the average parking duration for a vehicle is 630 minutes (177 minutes for vehicles with home parking and 1230 minutes for vehicles without), 4.5 times higher.

More sustainable and broader electric vehicle uptake can go in hand with safer streets

The road risk exposure indicator reflects how safe it is to move in public spaces and streets. This indicator measures the intensity of conflicts between different types of vehicles circulating at different speeds within the same street. A conflict represents the coincidence of two or more vehicles in the same position within the network. It represents a potential incident if any vehicles adapt their trajectory in time. As such, the indicator measures conflicts – or potential incidents, of pedestrians with freight vehicles, pedestrians with passenger cars, pedestrians with micromobility, micromobility with freight vehicles and micromobility with passenger cars. A detailed description of the method used for calculating the risk exposure indicator can be found in (ITF, 2022b).

The road risk exposure of pedestrians and micromobility users to conflicts with cars sharply decreases (38% and 63% decrease, respectively) from *like-for-like full vehicle electrification* to *broader uptake full vehicle electrification*, as shown in Table 4. For example, in the *like-for-like* scenario, one pedestrian out of 1 000 may have a conflict with a car, while the risk decreases to one out of 1 500 for the *broader uptake* scenario. Similarly, the risk exposure of micromobility to conflicts with freight vehicles reduces by 40% in the *broader uptake* scenario. The decrease stems mainly from the reduction of travel by larger and heavier vehicles and from the safer coexistence of modes due to lower travel speeds.

Table 4. Risk exposure indicator for vulnerable road users by scenario (daily average by conflict opponent pair)

	Like-for-like full vehicle electrification scenario	*Broader uptake* scenario	*Broader uptake* scenario + street infrastructure allocation	Δ from *like-for-like* to *broader uptake*	Δ from *like-for-like* to *broader uptake* + street infrastructure allocation
Pedestrians – freight	0.64‰	0.64‰	0.46‰	0%	-27%
Pedestrians – cars	1.03‰	0.63‰	0.52‰	-38%	-49%
Pedestrians – micromobility	0.04‰	0.31‰	0.11‰	614%	160%
Micromobility – cars	1.81‰	0.68‰	0.42‰	-63%	-77%
Micromobility – freight	0.88‰	0.53‰	0.36‰	-40%	-60%

Note: the vulnerable road user is the smallest agent in the conflict opponent pair (the one named first).

The risk exposure of pedestrians to conflicts with micromobility users increases by more than 600% in the *broader uptake* scenario. This result highlights that when micromobility uptake increases significantly, some road users (such as pedestrians) could be more exposed to potentially dangerous conflicts than they previously were. Although the risk exposure increases from one scenario to the other, notably, even in the *broader uptake* scenario, the risk exposure of one pedestrian to a conflict with a micromobility user is half the risk exposure of a pedestrian to a conflict with a car or a freight vehicle. Yet, by optimising street performance and correctly allocating street infrastructure to micromobility modes, the risk exposure of pedestrians to conflicts with micromobility users could be reduced by a factor of three. Optimally reallocating street infrastructure and speeds decreases road risk exposure for all road users.

Finally, it is important to note that the risk exposure indicator reflects, as its name suggests, exposure probability and does not account for the severity of potential conflicts. While in the *broader uptake* scenario, the risk exposure of pedestrians to conflicts with micromobility users increases more than the risk exposure of pedestrians to cars decreases, the road safety outcome is still likely to be positive since pedestrian-car crashes are more severe than pedestrian-micromobility crashes.

Broader electric vehicle uptake requires less electricity and public charging

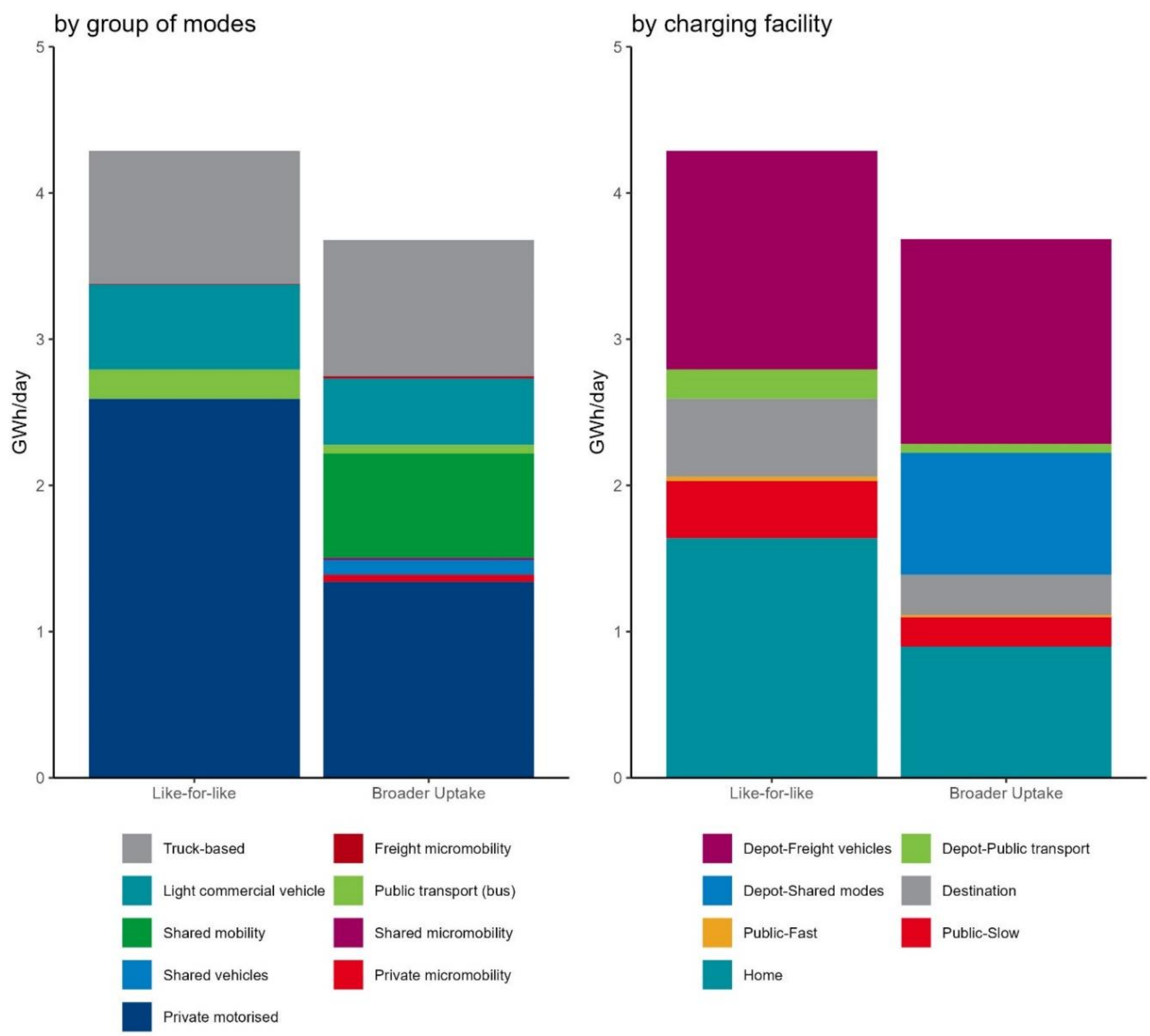
A *broader uptake full vehicle electrification* scenario, where the electric transition reinforces the opportunity to promote the use of smaller and shared electric vehicles, requires 14% less electricity demand than a *like-for-like full vehicle electrification* scenario, where the electric transition is only based on the technology of the vehicle powertrain (Figure 10). The total electricity demand required to supply the transport needs of the mid-sized European metropolitan area modelled in this study is 4.29 GWh per day in the *like-for-like* scenario, compared to 3.68 GWh per day in the *broader uptake* scenario. Or what is equivalent, 2.41 kWh per day per 1 000 inhabitants and 2.06 kWh per day per 1 000 inhabitants, respectively. A like-for-like scenario's total transport electricity demand could be as high as 25% of today's total electricity consumption for the same city, 20% under a *broader uptake* one.

With a more sustainable mode split, micromobility and shared motorised vehicles will require a greater share of electricity demand. Under a *broader uptake* scenario, the daily electricity demand of micromobility and shared motorised vehicles would amount to 2% and 22% of the whole transport systems, respectively. The total electricity consumption of freight e-cargo bikes will be five times higher than under a *like-for-like* scenario. Contrary to this, in a *broader uptake* scenario, the electricity demand required to supply private passenger cars is almost half that required for *like-for-like*. For LCVs, it is more than 20% lower. The specification of vehicle characteristics assumed for each mode is listed in Table 2.

The significant decrease in total electricity demand between both scenarios stems principally from the use of smaller vehicles and the improved use of vehicle capacity. Smaller vehicles are more electricity efficient, and their ranges are compatible with urban use.

Figure 11 shows each transport mode's average electricity demand per passenger-kilometre and tonne-kilometre. Micromobility has the most efficient electricity performance among all powered passenger and freight transport modes. Shared mobility, including ridesourcing and microtransit modes, maximise the ratio load factor-vehicle capacity, showing better performance than private cars, which travel with 1.2 individuals per vehicle on average. The performance of traditional urban buses within the public transport system depends on the size of the vehicles used, the frequency of the service and its demand. In this specific case, due to the low occupancy rate, public bus transport performs poorly. However, it should be noted that this result is case specific, and there could be significant variations between different systems.

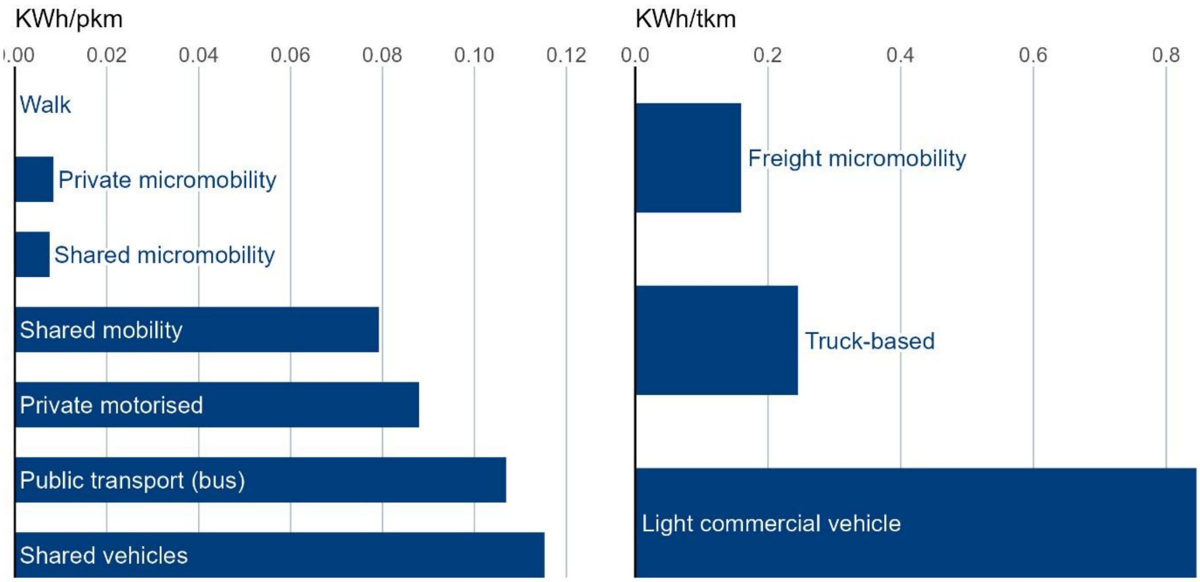
Figure 10. Daily electricity consumption: Like-for-like vs broader uptake scenarios



Different transport modes and vehicle types have different charging patterns, given the diversity in their daily use, vehicle range and efficiency. Furthermore, as explained in Section 2 (see Table 1) electric vehicles from different transport modes tend to charge at different types of charging infrastructure. Therefore, both scenarios not only differ in the total amount of electricity needed but also in the requirements for each type of charging infrastructure.

Both scenarios show significant differences in the public charging infrastructure required to serve the entire urban transport system (Figure 10). A *broader uptake* pathway would need 0.22 GWh per day from public chargers, including both slow and fast ones. This is almost half the electricity demanded under a *like-for-like* pathway and so 33% fewer public chargers are required. The number of public chargers is calculated to supply the maximum demand for charging encountered throughout the day. This permits a vehicle wishing to charge at a public charger to do so in the surroundings of its desired parking location at all times of the day. In lower-density urban areas with very low demand for charging, a minimum of one charger is supplied every 2.5 km^2 (on average).

Figure 11. Average electricity demand per km travelled by transport mode for passenger and freight transport (under broader uptake scenario)



Note: Values reported for shared modes do not account for the additional electricity required to power vehicles that support the operations.

Table 5 presents the total electricity demand and the number of public chargers required to supply the transport system of the mid-sized European city analysed. The table also shows the average by population and area to facilitate the extrapolation of the analysis to other urban areas.

Table 5. Public charging infrastructure requirements: Like-for-like vs broader uptake scenarios

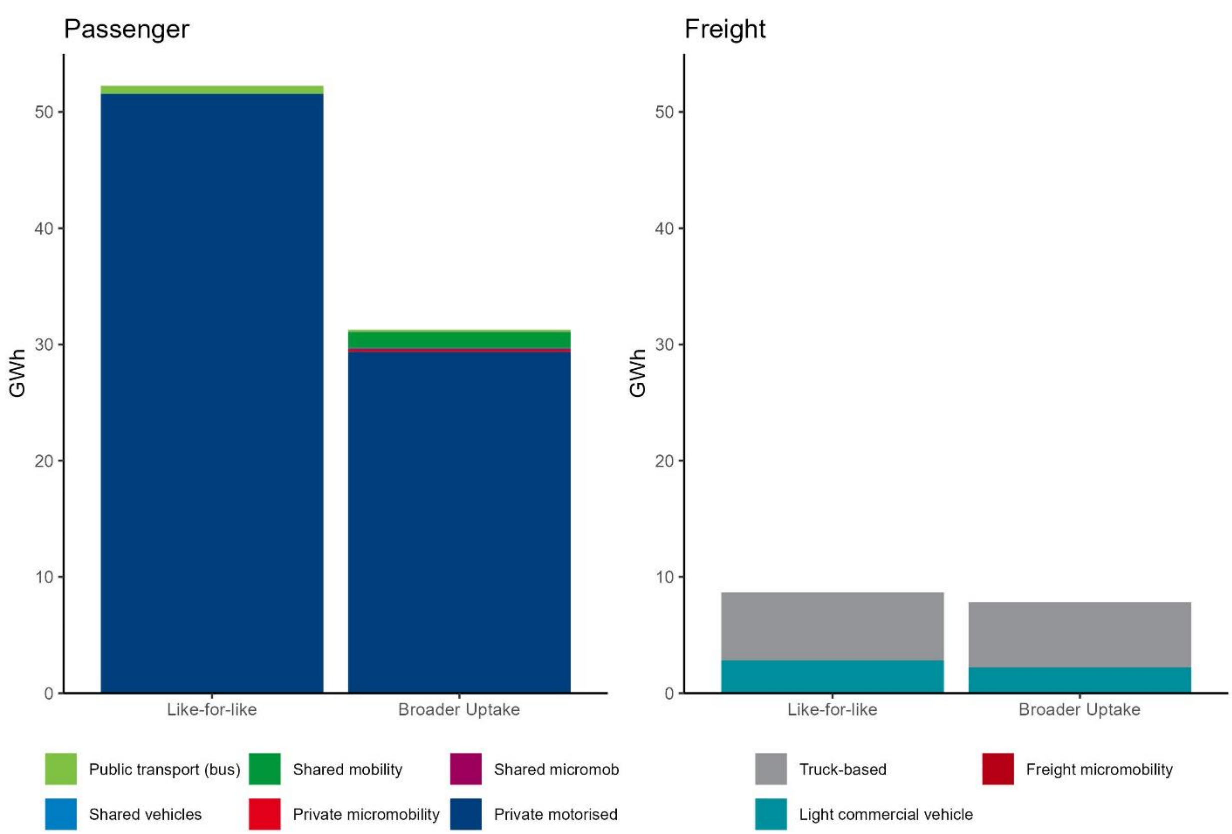
	Like-for-like full vehicle electrification scenario	Broader uptake full vehicle electrification scenario
Daily electricity demand		
Total GWh	0.42	0.22
Average KWh per inhabitant	0.24	0.12
Average KWh per km^2	430	223
Number of public chargers		
Total	5886	3926
Public chargers per 1 000 inhabitants	3.3	2.2
Public chargers per sqkm	6.1	4.0

Note: results drawn from the model for the Greater Dublin area (population: 1 782 771; average population density: 1 831 inhabitants/km2).

Sustainable broader electric vehicle uptake also reduces the need for batteries

The vehicle fleet in the *like-for-like full vehicle electrification* scenario requires 61 GWh of battery capacity, 52 GWh for the passenger fleet and 9 GWh for the freight fleet (Figure 12). In the *broader uptake full vehicle electrification* scenario, where the electric transition fostered the uptake of smaller and shared modes, the fleet battery capacity is reduced to 39 GWh – a 36% reduction. Shared modes, even if requiring the same battery capacity per vehicle, perform better than private motorised vehicles as one shared vehicle serves several trips and individuals. Notably, calculating battery capacity needs reflects a fleet's requirement at a given time. However, the higher use of shared vehicles compared to private cars could imply more frequent battery replacements, potentially lessening the difference between the two scenarios. The difference in battery demand between both scenarios is 40% for passenger transport and 10% for urban freight transport. The potential to reduce passenger transport demand for batteries is significantly higher than for urban freight, whose battery requirements, importantly, are six times less.

Figure 12. Battery capacity needs: Like-for-like vs broader uptake scenarios



4. How will faster electric vehicle uptake impact cities by 2030?

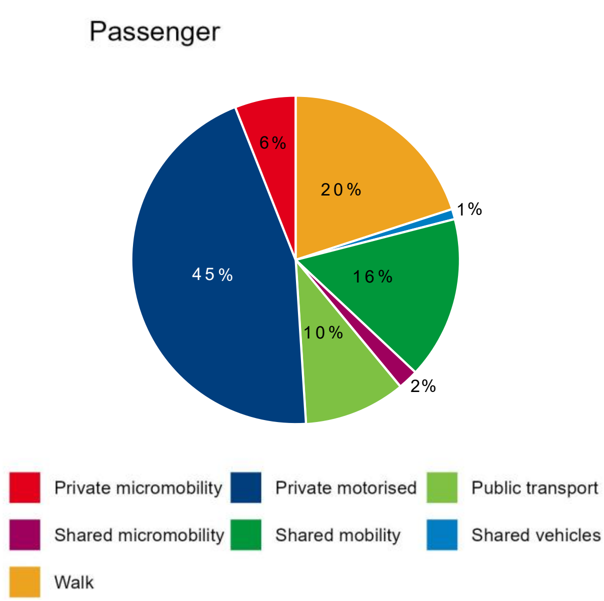
City authorities must understand the charging infrastructure requirements and electricity demand linked to their envisioned electric mobility futures. This chapter supports authorities by presenting the implications on electricity demand and charging infrastructure of three different levels of EV uptake, given different degrees of vehicle electrification ambition by 2030. It also gives insights into the impact of the three levels of electrification ambition on GHG and local pollutant emissions.

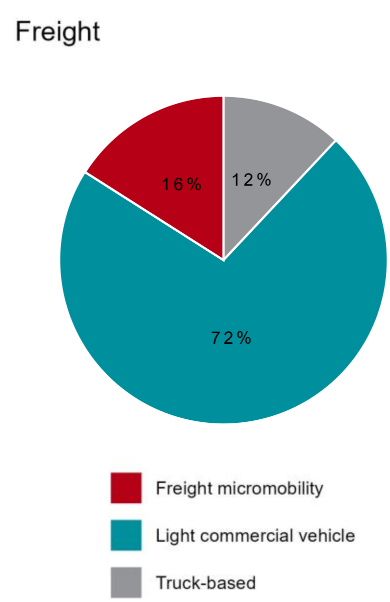
Defining urban electric vehicle uptake ambitions by 2030

This section defines three levels of ambition regarding vehicle electrification, each envisaging an alternative urban future for 2030. The mode shares (Figure 13) and the transport activity in the network (see Figure 7) are the same across the different electrification ambitions.

Mode shares are at a mid-point between those of the *like-for-like* and *broader uptake* pathways presented in the previous section. They represent a plausible split for a mid-sized European metropolitan area where a mode shift towards more sustainable modes and smaller vehicles has occurred, although not yet reached the level of the *broader uptake* pathway.

Figure 13. Mode shares (trips) by passenger and freight



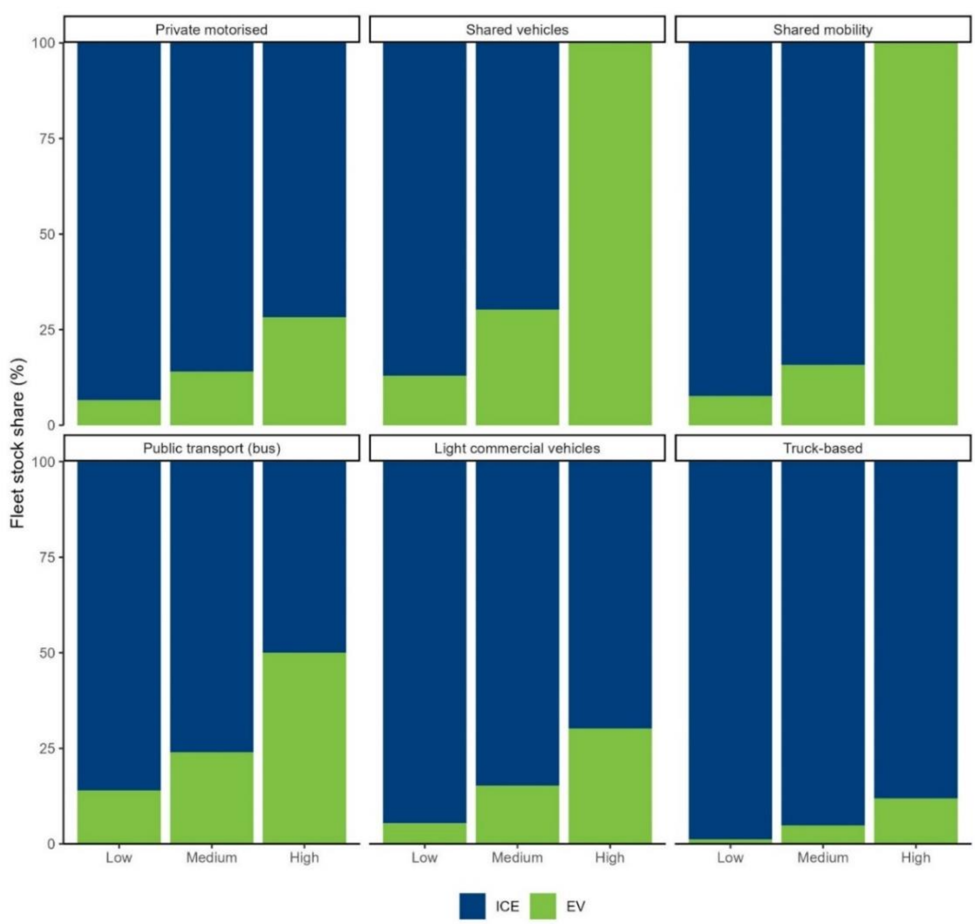


Within passenger transport, private cars account for 45% of the trips, private micromobility (e-scooters, bicycles, e-bicycles) for 6%, public transport for 10% and shared modes for 19% (shared mobility, shared vehicles, shared micromobility). Shared mobility includes ridesourcing and microtransit services conceived as centrally operated services that complement public transport networks. LCVs account for 72% of the trips for freight transport, medium and heavy trucks for 12%, and freight micromobility (bicycles, e-bicycles, cargo bicycles, e-cargo bicycles) for 12%.

Figure 14 shows the electric stock share for each vehicle type under the following electrification ambitions:

- ***Low ambition:*** This serves as the departure point of a plausible 2030 future, falling short of today's electrification targets due to constraints linked to high infrastructure costs, lack of vehicle availability and few policies promoting the EV transition. The level of electrification of the different vehicle types is coherent with recent trends.
- ***Medium ambition:*** Assumes that EV uptake will comply with today's EV uptake ambition. Motorised EV uptake rates still fall short of meeting the wider net-zero targets required by 2050.
- ***High ambition:*** This is a vision-led scenario that aligns with ambitions for decarbonisation and net zero emissions for 2050 (IEA, 2022). The uptake of electric motorised vehicles is high but plausible, following policies that support electrification.

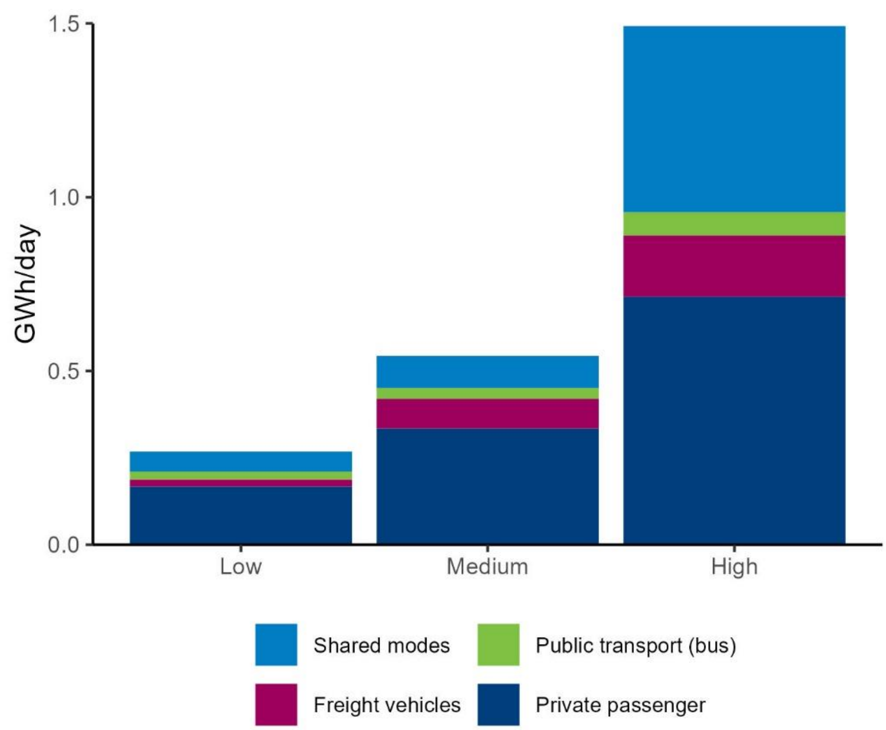
Figure 14. Stock share of electric vehicle and internal combustion engine (ICE) vehicle by type for three levels of electrification ambition by 2030



Electricity demand for electric vehicle charging will be the highest at nighttime

The total daily electricity demand required to supply the urban transport system of the mid-sized European city analysed is 0.27 GWh in *low ambition*, 0.54 GWh in *medium ambition* and 1.5 GWh in *high ambition* for vehicle electrification (Figure 15). Private passenger transport modes require the most electricity demand across all scenarios – 63% in *low ambition* and 48% in *high ambition*. A lower share in *high ambition* comes from there being a larger stock of electric vehicles in other modes than in private passenger four-wheelers. For example, *high ambition* considers 30% of the private passenger vehicle stock to be electric by 2030. It also assumes all cars serving shared mobility services will be electric by 2030 due to faster fleet turnover and greater availability of policy instruments to foster electrification (see the following section).

Figure 15. Daily electricity demand under the three electric vehicle ambitions



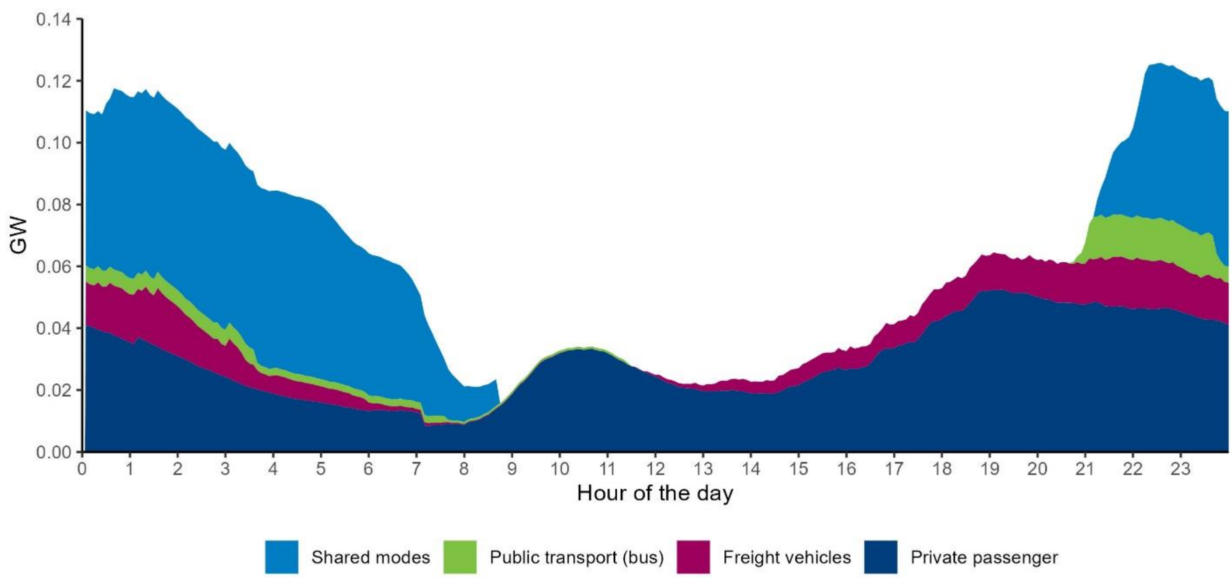
Under *high ambition*, the peak electricity demand is 0.12 GW (Figure 16). The electricity peak occurs overnight (between 9 p.m. and 4 a.m.). Urban freight carriers, public transport and shared mobility systems mostly charge where and when cheapest, i.e., overnight at their respective depots. The time that each vehicle starts to charge depends on their planned activity for the day. The charging time for each vehicle depends on the vehicle's SOC, travel activity, battery size, efficiency and the power rate and availability of chargers at the depot.

Electricity demand for depot charging facilities represents 66% of the overnight electricity demand required for EV charging. This demand is geographically concentrated in depot locations and highly constrained to times when charging does not interfere with vehicles' planned activities. Freight charging develops mainly in depots between 7 p.m. and 3 a.m., when vehicles are generally not in use. Freight vehicles charge within their depots at different power rates depending on the vehicle type. LCVs charge at

11 KW, trucks at 100 KW and freight micromobility at 0.2 KW. Public transport (bus) charging occurs mostly between 9 p.m. and 12 a.m. in dedicated public transport depots at 100 KW.

Shared modes mostly charge at depots since the shared mobility system represented is conceptually understood as centrally organised and managed. Hence, shared mobility charging happens mostly at depots between 9 p.m. and 7 a.m., where shared mobility services and shared vehicles charge at 11 KW and shared micromobility at 0.2 KW. These vehicles can also utilise on-street public charging infrastructure whenever their SOC during the day becomes too low, although it is not their preferred charging location.

Figure 16. Electricity demand profile under high ambition



Electric vehicle home charging could increase residential household electricity consumption by 10%

Private passenger modes either charge at home (3.6 KW), at destination (e.g., workplace, parking lots, shopping malls) (11 KW), at on-street slow public chargers (11 KW) or at on-street fast public chargers (50 KW). Home charging accounts for 67% of the daily private motorised electricity consumption, destination charging for 16%, on-street slow public charging for 15% and on-street fast charging for 2%. The charging profile of private passenger modes presents two peak periods during the day: a night period (7 p.m. to 1 a.m.) and a morning peak (9 a.m. to 12 p.m.) as shown in Figure 17. The night peak period of electricity demand builds up as individuals return to their homes after daily activities (see Figure 2 for travel activity profile). Most of the charging happens at home chargers (83% share during night peak), and 16% of the night peak share happens at on-street slow chargers close to the household's location. Destination charging (at workplaces and parking lots) accounts for 82% of electricity demand during the morning peak.

Under *high ambition* in 2030, EV home charging within urban areas could increase residential household electricity consumption in cities by almost 10% relative to today. This share will vary from city to city, depending on factors such as weather conditions or the type of heating in buildings. The total home charging electricity demand required in *high ambition* is 0.48 GWh per day, equivalent to 0.6 kWh per day per household. EV's home charging peaks at 9 p.m., which coincides with the residential electricity consumption peak. Even if during the whole day, EVs home charging represents an additional 10% of residential electricity demand, this value could more than double for the peak hour of residential electricity demand if EVs were set to start charging as soon as individuals arrived at their homes.

Figure 17. Electricity demand by charging infrastructure type for private passenger modes under high ambition

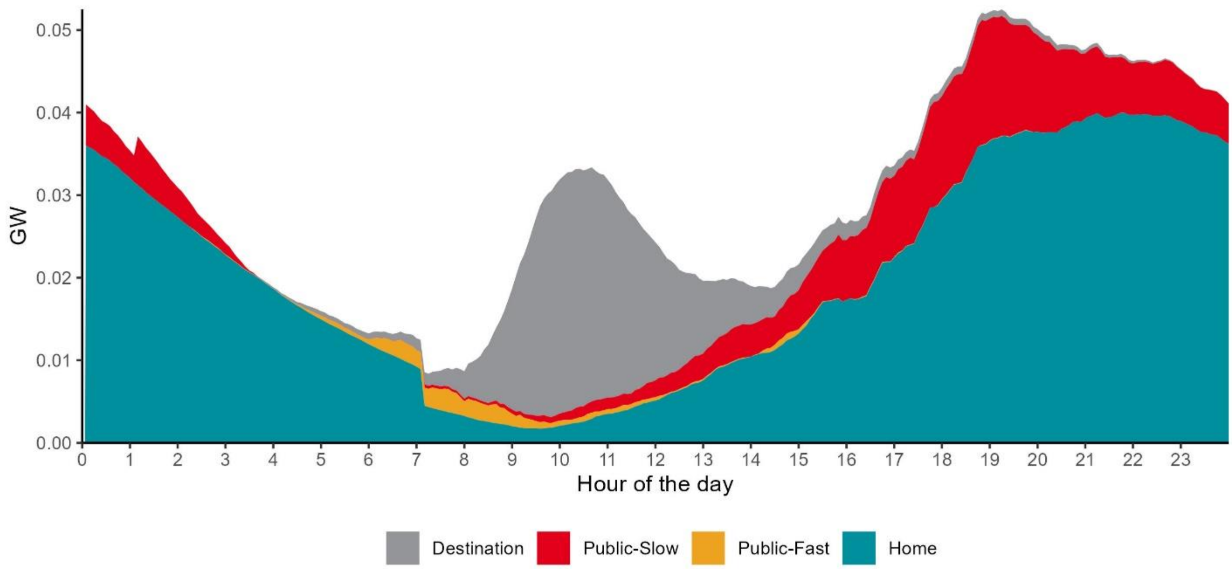
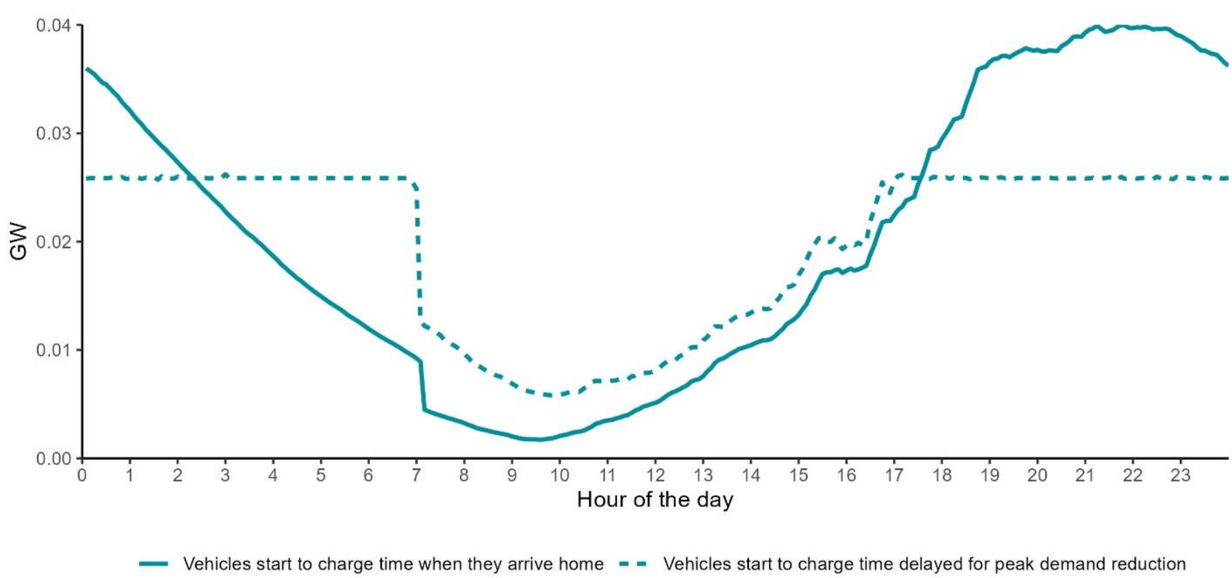


Figure 18. Home charging electricity demand under high ambition



Private passenger cars do not need to be charged over the complete night period. On average, they could require five to eight hours of charging at home. The electricity demand profiles shown in Figure 16 and Figure 17 reflect this analysis' underlying assumption: EVs that charge at home begin their charging activity as soon as they arrive. However, different home charging strategies that consider delaying the time at which some vehicles start to charge would enable the reduction of peak electricity demand and could be further explored in future work. For instance, Figure 18 shows one possible alternative that supplies the same electricity to each vehicle but where the charging starting time of some vehicles is delayed, provided such a delay does not interfere with the daily travel plans. This alternative reduces the peak electricity demand for EV home charging by 34%. Further research that jointly analyses residential electricity consumption and EV home charging strategies should be conducted to minimise the impact of EV charging on the electric grid.

The electricity demand required from home and public on-street charging depends on the possibility of households installing an off-street home charger in a garage or equivalent. Whenever possible, home charging is the cheapest and more convenient option. Public on-street charging would only become an alternative when home charging is unavailable.

The results presented in this analysis are driven by the specific characteristics of the study area. In the Greater Dublin Area, 57% of households (50% and 60% of households within urban and peri-urban areas) that own a private car have off-street parking and, therefore, the possibility to install a home charger. Results presented in Figure 15 to Figure 17 and Table 6 are contingent on this condition. The number of households with access to off-street parking significantly differs in other more compact and larger mid-sized European metropolitan areas where detached houses with off-street parking are uncommon. A reduction of 25% in the number of households with access to off-street parking is tested (43% of households owning a car have off-street parking) to facilitate the extension of the current analysis to other urban areas. The implications on electricity demand and charging infrastructure of such a reduction are that the amount of electricity consumed from home charging decreases by 36%, the electricity demand from public on-street charging increases by a factor of 2.4, and the total number of public chargers required to serve all the vehicles wishing to charge on-street increases by a factor of 1.9.

Faster electric vehicle uptake will require solid public charging networks

The total number of public chargers required to serve the EV charging demand is three times higher in *high ambition* than in *low ambition* (Table 6). The modelling results for the three ambitions show that the deployment of public chargers on the network must keep up as shares of EVs rise. The number of public chargers per 1 000 inhabitants required to serve all users wishing to charge at public charging points is 0.4, 0.7 and 1.3 in the *low*, *medium,* and *high ambition*s, respectively. Conversely, as the share of EVs increases, the number of public chargers needed per 1 000 EVs decreases from 12.2 in *low ambition* to 9.4 in *medium* and finally to 8.6 in *high ambition*. The simulation of EV charging considers that every vehicle willing to charge at a public charger will be able to access one in the surroundings of its desired parking location at all times of the day. The number of public chargers is calculated to supply the maximum demand for charging encountered in each modelling area throughout the day (the five-minute demand peak), and a minimum required of one charger is supplied every 2.5 km^2 (on average).

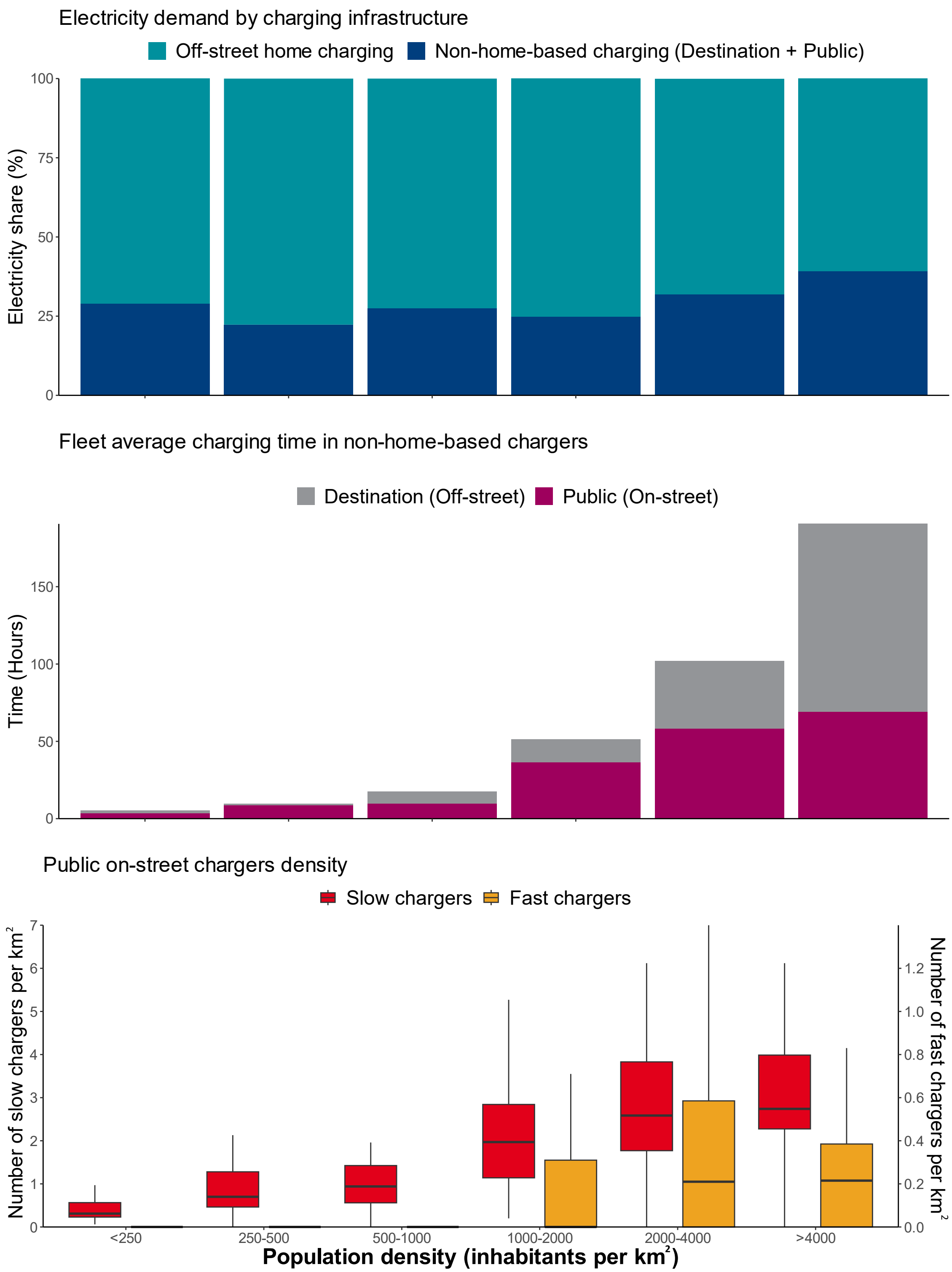
At early EV uptake stages, when EV stock shares are still low, a higher number of public chargers are required to provide network coverage, even if these are not fully used. In *low ambition,* the daily use of a quarter of the public chargers deployed within the network is lower than 5% of their rated power, showing a necessary, if sub-optimal, use of early-stage infrastructure provision. Whereas, in *high ambition,* only one in twenty of the deployed public chargers are used sub-optimally.

Table 6. Public charging infrastructure requirements

	Low	Medium	High
Total number of public chargers	740	1225	2252
Average public chargers per 1 000 inhabitants	0.4	0.7	1.3
Average public chargers per 1 000 EVs	12.2	9.4	8.6
Average public chargers per km^2	0.7	1.3	2.4
Ratio slow to fast chargers (1 fast charger for every x slow charger)	18	15	12

Denser areas require more public chargers, as shown in Figure 19. Typically, households located in denser areas suffer from a lack of access to off-street parking within their house. In less dense areas, 78% of the electricity used for EV charging is from off-street home charging, which drops to 61% in denser areas. This shows that people living in such denser areas are more likely to depend on non-home-based charging infrastructure availability, either on public on-street charging or at off-street destination charging (at workplaces or parking lots). The average time spent charging on non-home-based locations increases with population density. The average requirement of slow and fast chargers per square kilometre for the entire area is 2.2 and 0.2, respectively. Low-density areas (lower than 250 inhabitants/km^2) show a required average chargers' density of 0.4 slow chargers per squared kilometre, while high-density areas (higher than 4 000 inhabitants/km^2) have higher density requirements of 3.8. Fast chargers are mostly required in medium and high-density areas (higher than 1 000 inhabitants/km^2).

Figure 19. Public chargers in areas with different population densities (under high ambition)

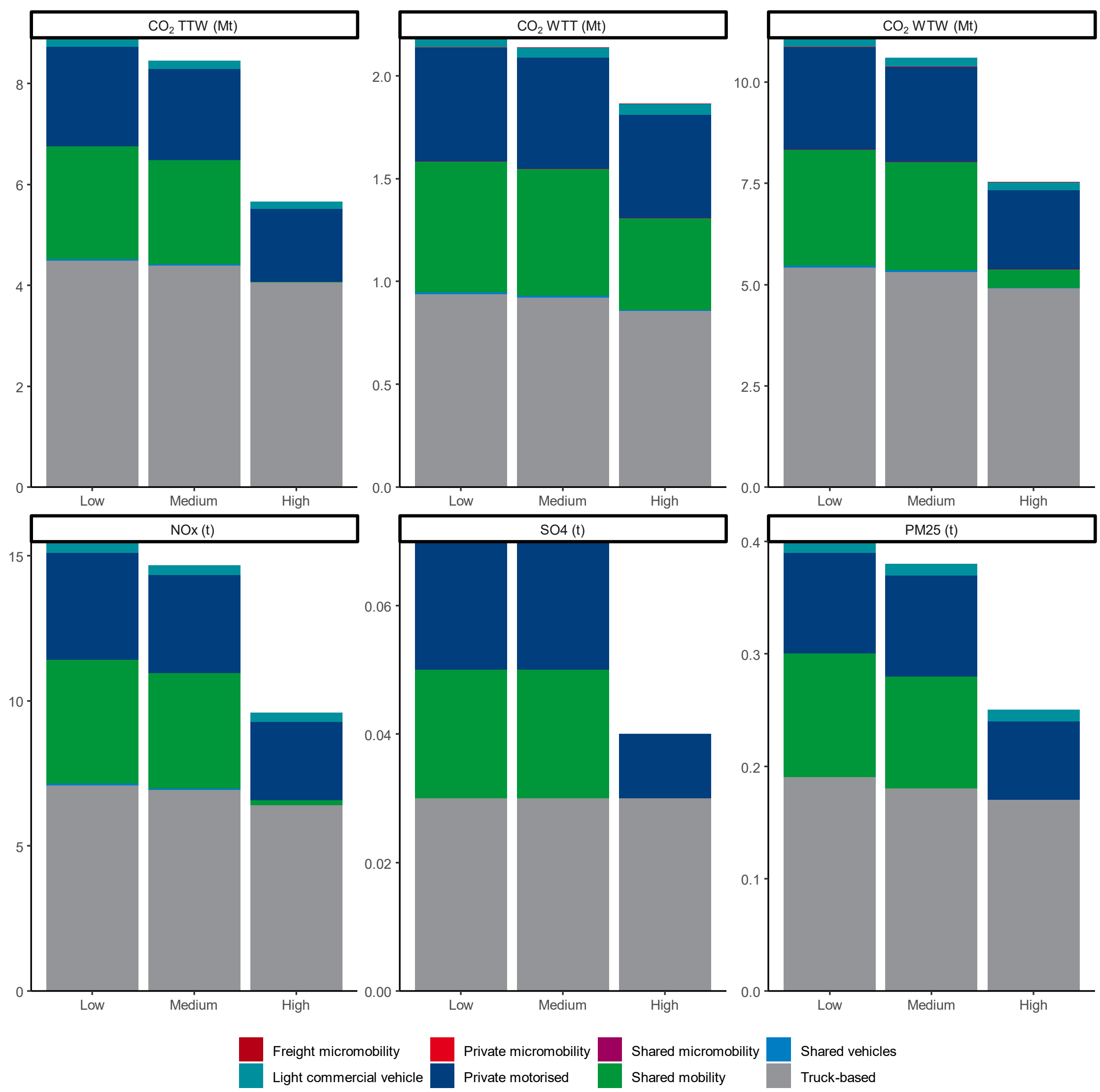


Population density	< 250	250 - 500	500 – 1 000	1 000 – 2 000	2 000 – 4 000	> 4 000
Total km^2	237	172	125	113	145	181

Ambitious and high vehicle electrification can strongly reduce emissions

The *high electrification ambition* for the 2030 scenarios delivers significant improvements in lifecycle CO_2, NOx, SO4 and fine particulate emissions compared to *low ambition* (Figure 20). Tank-to-wheel CO_2 emissions and tail-pipe local pollutants are reduced by 65% and 10% for passenger and freight transport, respectively. Well-to-tank CO_2 emission factors per vehicle-kilometre are constant across scenarios, corresponding to European countries' average energy generation profile by 2030 (ITF, 2023d). High reliance on a full electric fleet of shared mobility along with increasing levels of EV adoption for private motorised vehicles, deliver a high reduction of CO_2 emissions within passenger transport. EV adoption within freight transport, specifically truck-based transport, is still low by 2030. Therefore, the potential reduction of CO_2 emissions is 10%.

Figure 20. Daily environmental impacts and travel volumes by mode and scenario



Note: TTW: tank-to-wheel; WTT: well-to-tank; WTW: well-to-wheel

5. How to support a more sustainable and broader electric vehicle uptake?

Supporting more ambitious and sustainable EV uptake will require policy support. This section will shed light on three main areas where authorities can promote a broader EV uptake: facilitate the uptake of alternative and smaller EVs, enhance the offering of shared and public EV-based mobility systems and enhance solutions for EV charging. The section will draw from the modelling work presented in the previous two sections.

Facilitating the uptake of alternative and smaller electric vehicles

Policies can help diversify the composition of EV fleets to support sustainability outcomes. As the previous sections have reflected, emerging smaller EV types can support a more sustainable urban future. Yet, in many cases, vehicle electrification favours larger rather than smaller EVs (Cozzi et al., 2023; ITF, 2021a; IEA, 2022a). Countering this trend requires a comprehensive set of enabling policies, ranging from regulatory instruments and infrastructure investments to vehicle purchase incentives and barriers for the uptake of heavier and less sustainable vehicles.

Provide infrastructure for safer, smaller electric vehicle mobility

Higher uptake of smaller EVs could generate road safety concerns without the proper infrastructure and regulations. Although potentially more sustainable, introducing electric micromobility for passenger and freight activities can raise the risk of conflicts with other road users as all stakeholders use and navigate street space (ITF, 2022b). As Section 3 shows, a *broader uptake full vehicle electrification* pathway, where the use of electric micromobility goes up by 16%, increases the heterogeneity of the vehicle fleet, potentially heightening road conflicts. For instance, conflicts between micromobility and pedestrians can increase by a factor of seven if no segregated infrastructure is provided. Specific increases in the use of freight cargo bikes can also bring about higher conflicts with cyclists and other micromobility users sharing micromobility infrastructure.

The mode posing the greatest risk of road conflict with smaller vehicles is larger cars, as Section 3 results show. This is consistent with previous road safety analyses highlighting that fatal micromobility-involved crashes often result from a collision with larger motor vehicles (ITF, 2020c). Users of both micromobility and "car-like" light EVs have higher safety concerns in the face of potential crashes with larger private cars and LCVs, due to their size and design. Crashes involving smaller and larger vehicle users can lead to increased risks of injuries and fatalities for those using a smaller vehicle.

Separated infrastructure can support safer EV uptake. Micromobility users are among the most vulnerable road users and benefit from segregated micromobility lanes that reduce conflicts with larger vehicles (Schoner & Levinson, 2014). As micromobility use increases, separated infrastructure could protect pedestrians from potential conflicts when sharing the same spaces. Mandating protective gear such as helmets to facilitate the safe use of smaller EVs and to limit injuries could also be a way forward.

By increasing the feeling of safety, dense networks of separated micromobility lanes can promote the uptake of these vehicles (Schoner & Levinson, 2014). The quality of the infrastructure also plays a role. Quality factors include lane width and paving material. Asphalt, for instance, is preferred to materials such as cobblestones in areas where high use of small-wheeled vehicles is expected. The provision of micromobility-specific traffic lights and signalling is also important (Van den Steen et al., 2022). These changes will require street space reallocation in favour of emerging vehicle technologies (ITF, 2022b).

Increases in cargo bike deliveries will raise the need for dedicated parking infrastructure. In cities with high use of cargo bike deliveries, sidewalks serve as a common parking spot for these vehicles due to the lack of specific infrastructure and higher delivery speeds. While in some contexts this is allowed, in some cities, such as New York, the proliferation of cargo bikes has led to their ban from sidewalks. Bans without alternatives could decrease these vehicles' competitiveness compared to LCVs (Della Chiara et al., 2023). Reallocating street space away from larger vehicles and towards parking designed for these EVs could further motivate more sustainable logistics.

Approve smaller electric vehicles and regulate all vehicles for safer systems

Public authorities must ensure that the uptake of light mobility EVs is safe. “Car-like” light and micromobility EVs introduce new vehicle characteristics and use patterns that could affect road safety. For instance, many micro EVs do not include airbags. Regulating emerging vehicle types for passenger and freight activities is a complex but necessary task requiring new vehicle standards. For example, in Europe, vehicle standards exist for emerging forms of passenger micromobility but not yet for emerging freight cargo bikes. Such a lack of standards can create difficulties for governments to attribute subsidies and determine which cargo vehicles get to use micromobility lanes in cities (Cycling Industries Europe, 2021).

Regulations aiming at ensuring the safe use of light EVs should target all vehicles, especially the larger ones that pose the greatest safety risk. Authorities should ensure that the design safety standards of larger motor vehicles are adapted to the mixed-use with lighter EVs, as larger vehicles are involved in around 80% of crashes leading to micromobility user fatalities (ITF, 2020c). Regulations could include measures to adapt the design of cars so that their passive safety features integrate the new characteristics of upcoming smaller EVs and vulnerable road users (ITF, 2020c). Other regulations could include measures to change the design of the drivers’ cabins in larger freight vehicles to increase the visibility of smaller ones and decrease the speed limits in shared traffic streets to reduce the risk of road crash fatalities (ITF, 2020a).

Homologation (granting approval) and introducing rules for using smaller vehicles should maximise safety in adapted traffic environments. A first step forward includes homologating emerging micro EVs in urban areas, as these vehicles often fall outside national legislation, especially in developing countries. Second, authorities should adapt traffic regulations to allow for the simultaneous street use of a wider range of vehicles. This entails excluding certain vehicles in some areas and street types while de-prioritising some in others. The “Good Street” framework gives an example of how to set the conditions of when, where and how different vehicle typologies get to circulate in cities’ streets, including emerging EVs. In doing so, it addresses the simultaneous use of the same street space in a safe way for all road users (ITF, 2022a; ITF, 2023c). Concerning cargo bike deliveries, previous research in the Netherlands points towards allowing their use in segregated or temporary micromobility lanes on roads where experienced traffic speeds go beyond 30 km/h (Dutch Government, 2022). This example showcases the importance of regulating, furthering, and enforcing speed limits for all vehicles. More research is needed on the safe coexistence of emerging vehicle types in city streets, in both roadways and micromobility lanes.

Regulations should guarantee the safe shared use of road systems without putting a market barrier for newcomers. This could entail, for instance, authorising the use of electric micro EVs in street types that allow slower mobility – without unnecessarily compromising their capacity to serve the mobility needs and patterns of people living in metropolitan areas and needing to use faster roads to get to their destination. In Argentina, there is a current discussion on the interest of allowing the use of a new electric micro EV in provincial or regional road networks. New micro EV adopters are increasingly using these networks despite it being forbidden (Devincenzi, 2023; Ministerio de Transporte Argentina, 2018). In most of China, micro, low-speed EVs were forbidden in larger cities and public roads. Facilitating regulations in the Shandong province allowed for their use in rural areas and small towns of this specific area. This has allowed for the development of a local industrial and consumption market for micro EVs while allowing for an adaptative approach to vehicle safety regulations without hampering innovation (Zou et al., 2022).

Make smaller electric vehicles affordable and competitive

Authorities could support smaller EVs' increased affordability and cost competitiveness for passenger activities. "Car-like" light EVs, motorcycles and forms of micromobility tend to have a lower total cost of ownership (TCO) than regular-sized ICE-powered cars or motorcycles. This is because they have lower maintenance costs and, depending on the context, can also be cheaper to power (Box 1). Yet, there can be cost barriers to adoption if the upfront cost of the vehicle is too high or if users lack knowledge of the longer-term cost benefits of EVs. It can also occur in cases where users need to use public charging stations – as might be the case for electric motorcycle users in locations with low home charging availability (Rokadiya, 2021). Purchasing cost barriers can also exist in less dense urban areas where consumers might need more expensive, longer-ranged smaller vehicle types to cover their mobility needs. These situations could raise equity challenges, especially regarding lower-income households in these areas, where they cannot purchase smaller EVs due to lower purchasing power (Caulfield et al., 2022). Authorities need to address these equity challenges while ensuring that the cost of owning these vehicles is not lower than that of using shared alternatives, such as public transport or shared modes.

Box 1. Uptake of electric Boda Bodas in Kenya

Electric boda bodas are two- and three-wheeler bicycles and motorcycles in East African countries powered by rechargeable batteries instead of an internal combustion engine. In Kenyan cities, various initiatives aim to increase these vehicles' adoption. Among others, these include initiatives to sell locally built electric boda bodas and ventures to electrify an ICE boda boda by replacing an internal combustion engine (ICE) with an electric motor run by rechargeable batteries. Electric boda bodas have a top speed of 90 km/h, a driving range of 160-200 kms for fully charged dual batteries and a load capacity of 150 kg. The batteries take 3-4 hours to charge fully using an ordinary socket. Depleted batteries can also be swapped at swapping stations.

Electric boda bodas are more advantageous and competitive when compared to existing ICE equivalents. Regarding emissions and running costs, there is a 97% reduction in CO_2 emissions (from 10gm per 10km for ICE boda boda to 0.3gm per 10km for electric boda boda). In comparison, the running costs are cut by 50% (from USD 2.5 per 10km for ICE boda boda to USD 1.2 per 10 km for electric boda boda). This is because, while the initial purchasing cost of electric boda bodas is slightly higher than their ICE counterparts, they are cheaper to maintain in the long run. An electric boda boda can cost between USD 1 400 and 1 800, compared to USD 1 200 for ICE alternatives. Yet, the service cost of an electric boda boda is lower, at USD 0.3 per 10km, as compared to USD 0.5 per 10km for ICE equivalents. Favourable ownership financing schemes further support the high potential adoption rate for electric boda boda. One such scheme allows the purchaser to deposit 10% of the cost of the motorcycle and pay the balance over time as they use it. Kenya's largely renewable (green) electricity sources are another enabling factor for making boda bodas part of a sustainable vehicle transition.

However, certain challenges may impede the adoption of electric motorcycles in Kenya. These include a lack of sufficient supporting infrastructure, such as battery charging stations and reliable electricity supply and a general lack of awareness of e-mobility. Furthermore, it is cheaper to import fossil-fuel-based boda bodas than electric boda bodas. There are also challenges associated with the adaptability of imported electric boda bodas to Kenyan conditions and the e-waste management associated with electric mobility. This is worsened by a lack of supporting policies and quality standards for electric vehicles in Kenya.

Source: Written by Dr James Moronge.

Authorities can also facilitate liquidity for purchasing EVs through loans. In the Australian Capital Territory, for example, authorities are providing interest-free loans with ten years of repayment to households to decrease barriers to purchase (Australian Capital Territory Government, 2023). An upcoming, similar scheme in France targets predominately lower-income households (French Government, 2022; IEA, 2023). Also, the government aims to establish a "social leasing" scheme in France, thereby allowing lower-income households to pay 100€ monthly for an electric vehicle (Batteria et al., 2023). Developing schemes for urban logistics could be essential, as uncertainty over emerging vehicles' features, such as life duration, could block banks from financing their purchase.

Initial funding for financial aid programmes could come from various income sources. For both passenger and freight activities, road and parking pricing and urban vehicle access regulations could enhance the competitiveness of smaller electric vehicles in central and dense urban areas and provide initial funding sources for financial support programmes. For instance, in Lyon, France, authorities have increased parking prices for larger vehicles in electric and ICEs cities, aiming to curve larger vehicle use (Lyon, 2023). Authorities can also leverage feebates, or bonus-malus programmes, to foster EV uptake while obtaining revenue from fees on purchasing highly polluting vehicles. Adapting feebate programmes to market evolutions can promote EV uptake in a budget-neutral way (Wappelhorst, 2022).

Partnering with the private sector could also make smaller EVs more affordable and competitive. In Uganda, for instance, the national government has partnered with vehicle charging companies to guarantee free vehicle purchase of electric motorcycles for ICE motorcycle owners. In return, investors obtain licences for operating battery swapping and charging stations for these vehicles (Toll, 2023). Freight-wise, partnering up with private carriers to share the costs of micro hubs' constructions or maintenance can be a way forward. Finally, authorities can also support the competitiveness of smaller Evs by leading campaigns to support consumer and carrier's awareness of their cost and alternative benefits (Murugan & Marisamynathan, 2022).

Adapting road taxation instruments and fuel economy standards could also support reducing vehicle sizes. Road taxation in European countries is often based on GHG emissions, but taxation schemes based on weight could also support a reduction in vehicle sizes. In France, since 2020, ICE private passenger vehicles heavier than 1 800 kg need to pay EUR 10 per additional kg beyond the imposed limit (French Government, 2023). Applying similar schemes and extending them to electric vehicles could also be a way forward to combine EV uptake with vehicle size reduction objectives. Fuel economy standards could also be a tool for reducing vehicle sizes. In the United States, previous standards have contributed to increased vehicle sizes by giving larger vehicles more lenient fuel efficiency requirements (Whitefoot & Skerlos, 2012). The opposite could also be true: stricter fuel economy standards, more stringent for larger vehicles than for others, could also be set to motivate OEMs to reduce new vehicle sizes and not just to improve their fuel efficiency. Added to this, conditioning annual vehicle licensing fees to vehicle footprint rather than vehicle weight could also be a way of reducing vehicle sizes. It could come with the added value of not hampering EVs, often heavier than their ICE counterparts due to batteries' weights. More research is needed into these alternatives.

Finally, authorities could also support the local production of smaller EVs. Emerging smaller vehicle types offer a new market for vehicle-makers, where local industries can be developed to fit local needs. In China, for instance, measures set by national and local authorities have, to different degrees, supported the market entry of different types of local "Car-like" light EV manufacturers to meet an increasing demand since 2000. Support has allowed the consolidation and increasing maturity of these vehicles' production market. This is predominantly the case of developments linked to micro, low-speed EVs in the Shandong Province: their local production went from less than 20 000 vehicles in 2010 to almost 800 000 in 2017 (Zou et al., 2022). As the main OEMs in the United States and Europe have focused on larger EVs, promoting local smaller vehicle industries could cater to their growing demand and use. Supporting the local production of these vehicles can also foster local economic development. In Kenya, for instance, the local production of electric two- and three-wheelers has been a tool to support local industries while also reducing high vehicle import costs.

Supporting widespread electric shared mobility

Authorities could propel electric shared mobility services to be a strong component of future sustainable mobility systems, especially for passenger mobility. To this end, public agencies need to implement measures that guarantee that services complement public transport networks while pushing for the fleet electrification of emerging shared mobility services.

Manage shared mobility to complement public transport and optimise street space

Authorities need to ensure that shared mobility innovations complement existing public transport offers. Under an ambitious *broader uptake full vehicle electrification* pathway, as Section 3 shows, 7% of public transport trips could shift to shared electric micromobility modes while meeting the same travel demand. Mode shift from public transport to shared micromobility would come from shorter distance trips. This means there would be a complementary use between public transport for longer trips and shared micromobility for closer ones. Similarly, results highlight that increases in the use of microtransit and ridesourcing can substitute public transport in some contexts. Given that microtransit vehicles tend to be smaller than regular public transport buses and that they tend to have higher occupation rates, in certain routes, they can serve as a more environmentally and financially sustainable alternative than empty, larger buses (ITF, 2022a) (ITF, 2019b; Paternina Blanco, 2020).

Ridesourcing, microtransit and shared fleet services are well suited to act as the first/last mile of multi-modal trips. For this, the integration of networks and services is essential. Previous studies have shown that microtransit and ridesourcing services could increase public transport patronage if integrated with public transport services but create competition and reduce it if integration does not occur (ITF, 2018; ITF, 2020e).

An initial way forward to guarantee integration and complementarity is to identify, understand and seek working arrangements with commercial ridesourcing and microtransit. This can include voluntary initiatives to facilitate transport in lower-density areas and emerging mobility solutions that could extend the reach of public transport networks. In Mexico City, for instance, updating the city's public transport system's map was an opportunity to highlight places where routes of an emerging private microtransit platform system could complement the city's network (Jetty, 2019).

Authorities can also lead by establishing services to enhance existing public transport offers. In Orléans, France, for example, authorities set up a microtransit service to connect a lower-density sector of the metropolitan area to the core public transport network. Initially, the service had low ridership and entailed high costs for authorities. In this context, authorities launched a pilot partnership with a mobility operator and a data service provider to optimise routes and trips. The pilot's success increased the system's coverage to other low-density sectors of the metropolitan area while reducing operating costs by around 30% (PADAM Mobility, 2021).

Beyond shared services, authorities can look at the licencing or tendering process for shared fleet services to ensure they complement public transport in delivering access for all. Licencing and tendering processes for shared fleet operators can include requirements on zone-based operating rules; fleet size, specific vehicle parking locations and regulations; and per-vehicle annual fees (ITF, 2021b). Cities can make use of these licencing or tendering processes to ensure that the deployment of shared EVs and their eventual docks and stations is spread across the city in a way that complements the public transport network. For instance, parking stations and docks for micromobility could be placed close to public transport stations to facilitate multimodality. Equitable distribution of vehicles across an urban area is an important consideration. In places with low population density and public transport availability, authorities could consider adapting regulatory arrangements to reduce operational costs for fleet-sharing operators. As an example, per-vehicle annual fees could be adapted or even waived in lower-density areas where shared micromobility could connect inhabitants to far away public transport. Exploring subsidising certain micromobility trips when these meet established criteria, analogous to public transport service support, could be a way forward (ITF, 2021b). In tendering fleet-sharing services, authorities should also focus on selecting the most optimal EV size to cover the right distance. Fleet-sharing schemes can include vehicles of all sizes and ranges, from electric scooters to larger, shared SUVs. Tendering processes should aim at having the optimal vehicle size for shared Evs to serve local mobility needs while limiting street space use as much as possible.

Fast-track the electrification of shared mobility services

Public action could contribute to the increasing electrification of passenger ridesourcing and microtransit. Public regulations like vehicle technology requirements are a good way forward. In London, authorities required newly licensed ridesourcing vehicles to be zero emission starting 2021 (Hall et al., 2021). In California, starting in 2023, a Clean Miles Standard and Incentive Program (CARB) sets annual GHG reduction targets for transport network companies, asking and incentivising existing platforms to transition their fleets to Evs and other zero-emission vehicles (California Air Resources Board, 2023). Other forms of urban vehicle access regulations (UVAR) based on vehicle technologies and emissions, such as low-emission zones, can also be effective. For instance, in Spain, a Climate Change Law foresees that all municipalities with more than 50 000 inhabitants will need to set sustainable urban mobility plans that include, among others, zero emission zones as tools to reduce transport emissions in their areas of coverage (Spanish Government, 2022).

When it comes to shared fleet services, authorities have a wide array of contractual and regulatory tools to support fleet electrification. Electric fleet requirements can be part of a city's public shared fleet system's design, as with Madrid's BiciMAD bikesharing programme (Fluctuo Mobility enablement, 2023). EVs can also be brought on in the evolutionary phases of services. For example, in Marseille, authorities used the opportunity of a new tendering process for the bike-sharing system to electrify the whole vehicle fleet (Made In Marseille, 2022). This is also the case in La Rochelle, where authorities made the operation of shared e-bikes a requirement for the renewing of the shared bicycles fleet in the urban area (Ghiloni, 2020) (Figure 21).

Figure 21. Shared bicycles in La Rochelle, including an e-bike and a solar energy-based charging system

Source: Joshua Paternina Blanco.

Authorities can also support electrification by providing clear incentives. In Berlin, for instance, authorities are prepared to support the electrification of the free-floating car-sharing fleet by offering half-price parking for electric cars in the city (Fluctuo, 2023). Likewise, Paris' authorities extended concessions for shared Evs operators by seven years, as opposed to only five for operators of ICE fleets (Nicholas & Rajon Bernard, 2021). This difference is justified by the higher investments of shared EV providers and allows for more time for operators' return on investment. UVARs can also be a way forward for making operators electrify their fleets.

Privately led measures can complement public efforts. As part of its Environment, Social and Governance (ESG) programme, Uber provides financial incentives to drivers to help purchase or lease electric vehicles (Uber, 2023). Platforms are also pushing for electrification to decrease the longer-term vehicle costs for drivers (Pavlenko et al., 2019). This trend is also in urban logistics, where emerging app-based food delivery providers are increasingly electrifying their last-mile fleet because of ESG commitments. Various OEMs have also promoted their own electric fleet-sharing companies or built partnerships with existing ones to diversify their business operations, but also as a testing ground for promoting their EV fleets (Deloitte, 2017; Electronomous The International Mobility Summit, 2021). Electrification is further pushed for by electricity utility companies' increasing participation in vehicle sharing services (Gauquelin, 2021).

Fleet operators can leverage battery-swapping strategies to facilitate the deployment of electric fleets. For now, the main adopters of battery swapping are micromobility operators, while adoption for larger vehicles is still in an exploratory stage in most places. Limited examples of commercial deployment apply to electric mopeds and micro Evs. For micromobility, battery swapping can be a way to reduce travel and logistics costs associated with the recovery, recharging and repositioning of floating vehicles in cities (Finke et al., 2022).

Despite the various benefits linked to battery swapping systems for micromobility, they have drawbacks, such as requiring more batteries than vehicles. The number of batteries for a micromobility EV fleet could be around 1.35 batteries per vehicle, representing a higher use of materials than if a regular charging system were implemented (Telematics Wire, 2020). In all cases, as this report showcases, the battery capacity in KWh required for running a shared micromobility fleet is less than 1% of that which would be required for private cars. This reflects that, even with higher battery and material use, if battery swapping were to facilitate the deployment and uptake of shared electric micromobility, increases in materials could be offset by reduced demand for electric cars. Battery swapping systems could entail difficulties such as promoting battery standards to facilitate swaps between various operators and the high costs of building battery swapping infrastructure (Ibold & Xia, 2022).

Providing on- and off-street charging for passenger and freight

A sustainable and broader EV uptake will require deploying off- and on-street charging infrastructure for urban dwellers who do not shift to alternatives to private cars and motorcycles. Supporting households in their transition to electric mobility will require increasing off-street charging availability and a solid supporting public charging network. Actions targeting public transport providers, as well as logistics operators, will also be valuable.

Facilitate off-street home and destination charging for private and shared passenger electric vehicles

Most private passenger EV charging will be done off city streets. As Section 4 showed, in a mid-sized European city, by 2030, 67% of passenger daily private motorised electricity consumption could come from home charging. On-street public charging and off-street destination (workplace or parking lots) charging would come next with 17% and 16% of the daily consumption, respectively.

Authorities can facilitate the widespread deployment of home charging through regulations, including housing and building standards. Reaching the levels of home charging infrastructure to meet ambitious private EV uptake will require regulations that foster charging availability in new developments. In the United Kingdom, for instance, since 2022, an addition to existing building regulations has made it mandatory for new residential buildings with foreseen parking availability to have minimum charging infrastructure provision (UK Government, 2021a). The fact that the regulation does not ask new developments to have parking with charging per se but that it only requires charging infrastructure in those locations where parking is expected is important. This supports the objective of increasing off-street charging capacity without going against mode-shift policies that aim to reduce parking availability in denser areas (OECD, 2022). In addition, regulations can also support the deployment of smart home charging infrastructure, which is required to support efficiencies in electricity systems' costs and use (IEA, 2022b). Also, in the UK, starting in 2022, home and destination charging points are required to have smart functionality – being able to "receive and send information and respond to messages by increasing or decreasing the rate of electricity flowing through the charging point and shift the time at which electricity flows through [it]" (UK Government, 2021c). The regulation also sets security requirements for smart points, including protecting end users' personal data (UK Government, 2021c).

In addition to regulations, authorities can also give incentives and funding support for off-street charging infrastructure. Also, in the United Kingdom, public programmes can cover as much as 75% of costs linked to providing new charging points for residential developments and workplaces. The schemes subsidise a maximum of GBP 350 per socket for individuals and a limit of 40 sockets for companies (UK Government, 2021b). They can also cover up to GBP 30 000 for larger residential charging infrastructure projects (UK Government, 2016). These schemes can complement regulations by facilitating the development of off-street charging capacities in existing residential developments. Authorities can also aim to maximise charging points' use by fostering schemes that allow individuals to lease their charging points in hours of non-use and facilitate the connection between available off-street charging developments in residential areas and users needing charging. Setting tax credits for individuals, property managers, and companies can also incentivise the deployment of off-street infrastructure in workplaces, businesses and homes (Rajon Bernard et al., 2021).

A solid off-street charging network could also be essential for electrifying shared mobility. In this report's modelling, shared passenger mobility vehicles charge in depots, as services are centrally operated. EV charging for more fragmented ridesourcing and pooling services could increase home and on-street charging demand, as drivers would need to charge at their own houses or using the publicly available network. Such a situation would increase the importance of home charging. Previous estimates indicate that, by 2025, the average total cost of a ridesourcing operation that is not reliant on depot charging could be 20% higher if the driver did not have access to home charging than if they did, due to higher costs of off-street charging (Pavlenko et al., 2019).

Establish solid public charging networks for complementary private and shared passenger electric vehicle charging

Slow chargers allowing for overnight charging will constitute the backbone of most urban on-street public charging networks. This is especially due to the high costs linked to fast-charging infrastructure and the pressure it can put on electricity grids. Yet, developing fast-charging infrastructure is still important, both for responding to the needs of urban dwellers and for complementary specific uses, such as ridesourcing or taxi services for which daily travel can sometimes be higher than the vehicle range. Another potential use case is en-route long-haul freight charging for vehicles passing through an urban area, which is essential for electrifying long-haul urban freight.

The density of public charging infrastructure in cities will need to be highest in central and denser areas, where space availability could limit the possibility of having off-street, home charging infrastructure. As Section 4 illustrates, in the study area, the highest density in public charging availability is found for population densities higher than 4 000 inhabitants/km^2. Results in the previous section also show that in the highest-density areas, the high availability of public charging will need to be complemented by an even larger use of off-street charging, such as work or garage charging. This is because lower street space availability might not allow deploying a large enough public charging network in the densest of areas. Public charging infrastructure will also be required in peri-urban areas and other locations where home charging is common to fill eventual service gaps.

Authorities can foster infrastructure development with various degrees of engagement with private stakeholders. Authorities can own and operate the public charging infrastructure; set joint ventures with private actors for deployment and operations; set various forms of concessions for the operation of public charging points; licence the deployment of charging points upon certain criteria; or a mix of these tools in different parts of their cities (STF, 2021). Each of these arrangements carries different implications regarding financial risk for authorities, ease and speed of deployment and facility to innovate. Authorities need to select the contractual arrangement that best fits their needs. In all cases, subsidy provision can be a way to foster infrastructure deployment, given that it might not yet be a profitable business in many places. If available, the subsidy amount should be set at a price high enough to cover the cost needed but low enough to maintain value for money for authorities (STF, 2021).

In all cases, infrastructure deployment should be planned for at an early stage, given the lengthy periods for administrative requirements and feasibility studies linked to the setting of charging infrastructure, of up to a year for slow chargers and up to ten for fast ones (ITF, 2021a). Longer periods for building fast chargers are linked to the need to modify electricity grids for their installation.

For shared systems, authorities can support charging infrastructure for free-floating and station-based or docked services for electric micromobility and other EVs. When it comes to free-floating systems, authorities can allow service users to make use of existing public charging infrastructure. For docked or station-based services, authorities can support investments in charging infrastructure, especially in less populated areas where docked or station-based shared vehicle services are the most economically viable. The opposite is also true. Authorities can require shared vehicle providers, especially larger EVs', to make their station-based charging points available for others, thereby extending the available public charging network (Pavlenko et al., 2019).

Authorities can optimise the availability and location of existing charging infrastructure. Infrastructure development should respond to existing and forecasted needs. By identifying existing demand, authorities can support public charging availability in a planned-for manner (ITF, 2021a). In situations where authorities give concessions for charging infrastructure, chargers in high-demand and profitable locations could be bundled together with those in lower-density areas to ensure network deployment is spread well throughout the urban area (STF, 2021).

Authorities should also foster charging station interoperability through regulations that support charging socket standardisation or the mandatory availability of multiple socket standards. This is to ensure the maximum use rate possible for each public point. This is particularly important in cities where the vehicle market brings competition between OEMs with different regional charging point standards (ITF, 2023b).

Authorities can also regulate the time vehicles can spend parked in charging points to reduce idle time and increase their use rate. Vehicle electrification and public charging will increase the use of street space for parking, as vehicles stay parked in public charging spaces longer than their charging needs require (Borlaug et al., 2023; Hipolito et al., 2023). As technology and economies of scale evolve, faster on-street public chargers will likely be deployed, making this difference between parking and charging times even higher. In Paris, authorities aim to counteract idle time by requiring simultaneous fees for public charging, one for the time spent while charging and the other for the actual electricity used (Belib', 2023). It is essential to conduct further research to explore the effects of different charging policies on idle time at public chargers, as it decreases vehicle turnover per charger, thereby impacting the total number of public chargers required within an urban area.

Funding for charging infrastructure will likely come from a mix of public and private sources. National-level authorities can support local ones in deploying urban public charging schemes. In the United States, for instance, the Federal government has set a grant programme to support urban authorities in deploying charging infrastructure in their localities (ITF, 2021a; U.S. Department of Transportation, 2023). The grant supports infrastructure to fit the needs of dense urban centres and lower-density urban areas, as well as infrastructure that would fit the need of inter-urban operators, such as long-haul freight, and which falls under the remit of urban authorities (Aves et al., 2023). As EV uptake increases, local and national authorities providing EV purchase grants could shift available funding from these programmes to support wider deployment of off and on-street charging infrastructure (Conzade et al., 2022; IEA, 2023). Beyond public support, local authorities can also engage with private stakeholders, such as charging infrastructure managers, shared mobility operators and electricity providers, to strengthen public charging networks (Merle-Lamoot, 2019).

Provide depot and selected on-street charging for electric buses

Authorities should support the deployment of charging infrastructure for electric buses for both public transport and inter-city buses passing through cities. Charging infrastructure for electric buses can include both depot charging, stations where buses can use slow charging when not in operation, often serving also as maintenance and storage locations, and fast charging infrastructure, curb-side charging for speeding e-buses repowering – leading to 40-50 km range gains in as fast as 5 min charges (Daliah, 2023).

Depot charging tends to be the preferred option in denser urban areas. Depot charging takes up less street space and can require fewer construction interventions than fast charging options – something particularly appreciated in historical centres. Including charging solutions in existing bus depots can also entail lower building costs, especially when compared to the grid infrastructure investments needed to adapt the existing electricity network to fast bus charging alternatives. Fast charging can also carry higher operational costs due to higher electricity costs if charging times are not optimised for being done off electricity peak (Yi et al., 2020). Still, fast-charging infrastructure can be a charging alternative for longer e-bus routes, particularly in peri-urban and lower-density areas.

Support freight carriers with depot charging

Regarding urban logistics EVs, depot charging will be the backbone of electrified urban logistics. Around 80% of freight charging requires depot charging infrastructure due to the nature of freight activities and the high time and monetary costs of off-depot charging. This was shown to be the case in a recent study in the Amsterdam region, where in most logistic sectors, up to 85% of charging needs were met through depot charging. One of the few exceptions was the retail (non-food) sector, where higher (un)loading times at receivers allow for charging both at public fast charging stations, where around 10% of charged power was expected to come from, and customer charging, representing 30% of charger EV power (Top Sector Logistics, 2021).

Authorities will need to support depot charging to guarantee electrified urban logistics. This includes giving financial support for the purchase of charging points and covering infrastructure works required for changes in electric grids. Financing schemes do not always include grid investments, so this could be a way of reducing logistics' electrification costs (The Electricityst, 2019). Helping convert depots to break-bulk facilities – especially for distributing larger vehicle loads to cargo bikes – can help electrify logistics operations (ITF, 2022b). Beyond infrastructure investments, in some areas, building and zoning codes could need to be updated to allow for the setting up of charging infrastructure in freight depots.

Support for freight off-depot charging will be important. When developing public charging infrastructure, authorities will need to collect (anonymous) data to consider freight carriers' charging needs and practices. Authorities could further facilitate the electrification of urban logistics by facilitating and even ear-marking curb-side fast-charging infrastructure for logistics vehicles, at least during some parts of the day (ITF, 2022b).

Look further into transport electricity demand management

Authorities must also foster systems that optimise charging times to make the most of the existing electricity grid. As Section 4's results show, simultaneous and different EV charging use needs will put pressure on cities' electricity grids. With a *high ambition* scenario for EV uptake, in 2030, charging electricity demand for a mid-sized European city could require as much as 1.5 GWh daily, also doubling the peak hour demand.

Managing transport electricity demand could require smart charging and smart grid systems. In London, for instance, a logistics enterprise partnered with authorities to complement their operations with a smart grid system by a logistic enterprise, whereby charging times and conditions of vehicles were optimised. This led to reduced costs for the vehicle logistics operator that took part in the initiative (The Electricityst, 2019). More sustainable charging behaviour from users could also be critical to ensure a good temporal distribution of electricity demand. For instance, if not all home charging happened simultaneously at night, often just after the end of commuting time, our results show that peak home charging electricity demand could reduce by more than 30%. More research is needed in these areas.

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Annex

Vehicle choice for private cars

Individuals' propensity to choose the size (micro, small, medium, and large) and powertrain (ICE, EV) of private cars varies according to household income, home parking availability and persons within the household. Individuals are segmented into 14 profiles. The increase (or decrease) in the propensity of a given profile to choose a given car size and powertrain is calculated as the difference between the observed choice distribution for the corresponding profile and the entire sample in the Stated Preference survey presented in (Fjendbo Jensen et al., 2021). The car type allocation to individuals is determined based on sorting individuals' propensities and the scenario fleet composition shares.

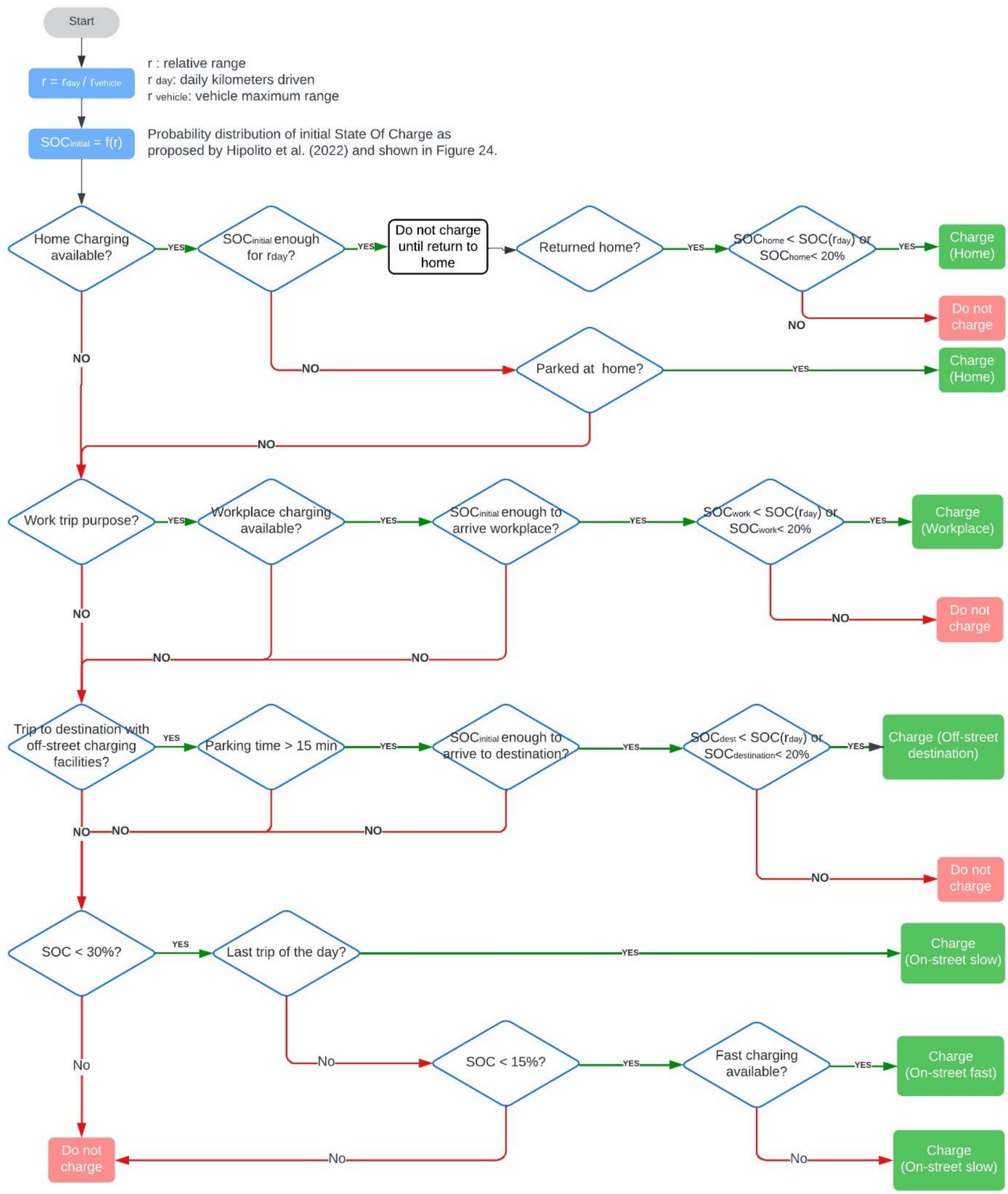
Figure 22. Propensity of each profile to choose a car size and powertrain

Profile	Parking Home	Income Group	Household size (number of persons)	Increased/decreased propensity of choosing the following alternatives						
				Small - ICE	Medium - ICE	Large - ICE	Micro - EV	Small - EV	Medium - EV	Large - EV
1	No	Low	2 or more	0.187	-0.032	-0.070	0.049	0.022	-0.061	-0.095
2	Yes	Low	2 or more	0.073	-0.057	-0.054	0.015	0.027	0.018	-0.023
3	No	Medium	2 or more	0.039	0.042	-0.017	0.012	-0.009	-0.015	-0.051
4	Yes	Medium	2 or more	-0.075	0.017	-0.001	-0.022	-0.004	0.064	0.021
5	No	High	2 or more	-0.056	-0.048	0.074	-0.020	-0.019	-0.024	0.093
6	Yes	High	2 or more	-0.170	-0.073	0.090	-0.054	-0.014	0.055	0.166
9	No	Low	1	0.346	-0.037	-0.136	0.106	0.056	-0.159	-0.176
10	Yes	Low	1	0.232	-0.062	-0.120	0.072	0.061	-0.080	-0.104
11	No	Medium	1	0.198	0.036	-0.083	0.069	0.025	-0.114	-0.132
12	Yes	Medium	1	0.085	0.011	-0.067	0.036	0.030	-0.034	-0.060
13	No	High	1	0.103	-0.053	0.008	0.037	0.015	-0.122	0.012
14	Yes	High	1	-0.011	-0.079	0.024	0.004	0.020	-0.043	0.084

Charging behaviour modelling framework for private cars

Four-wheeled EVs decision to charge is modelled in a rule-based manner as described in the decision tree.

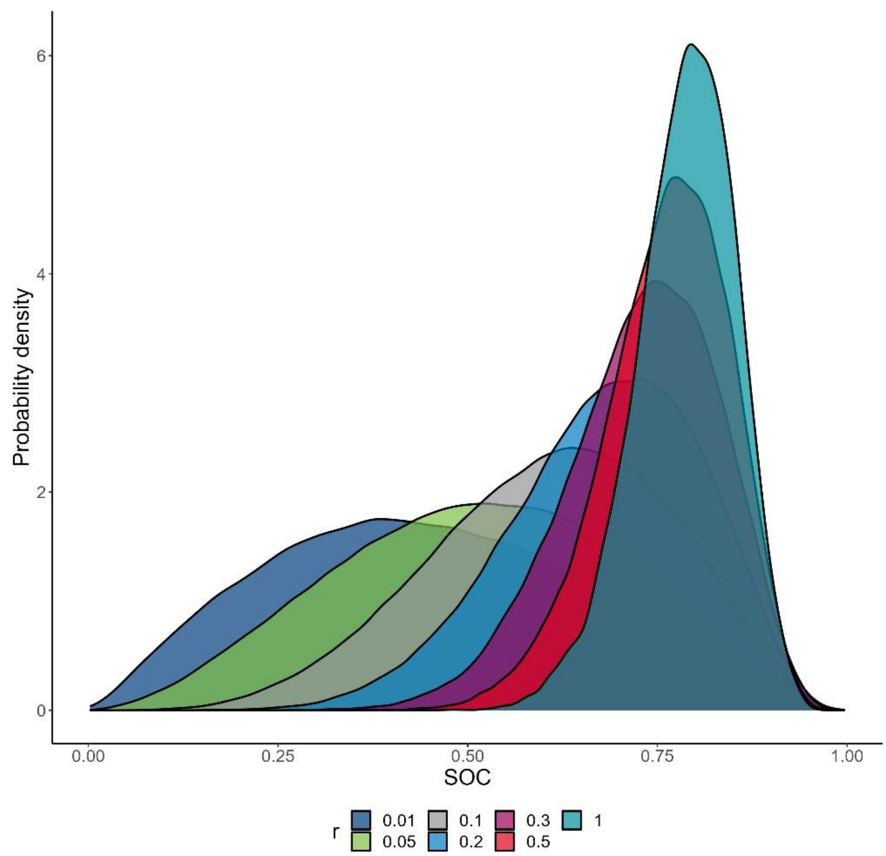
Figure 23. Charging behaviour decision tree for private four-wheeled electric vehicles



Initial State of Charge (SOC) definition for private cars

Figure 24 shows the simulated distributions of SOC levels at the onset of each day for increasing values of relative range r. Relative range r is defined as the ratio between the mean daily-driven distance and the maximum vehicle range. The solid lines represent the respective beta probability density function proposed by Hipolito et al. (2022) for each relative range value. The SOC associated with the maximum of each curve indicates the mean SOC of vehicles with a corresponding relative range value r at the onset of each day.

Figure 24. Distribution of initial state of charge of private four-wheeled electric vehicles



Shifting the Focus

Smaller Electric Vehicles for Sustainable Cities

Like-for-like replacement of fossil-fuel-powered vehicles by identical electric-powered vehicles is thought to be the main pathway for electric vehicle (EV) uptake. However, what characterises global passenger and freight EV markets is the emerging uptake of smaller, lighter and shorter-ranged vehicle types specially designed for urban areas. A shift towards a broader EV uptake could be an opportunity for more sustainable and electric urban mobility systems – with comparatively lower electricity and charging infrastructure demand and battery materials needs, lower emissions and safer city streets. This report identifies the main use cases that could be part of such a broader and sustainable EV uptake. It also quantifies the sustainability impacts of different EV uptake scenarios that vary in vehicle fleet composition and degrees of electrification ambition. Finally, it gives recommendations on how authorities could leverage the passenger and freight EV transition for more sustainable cities.

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