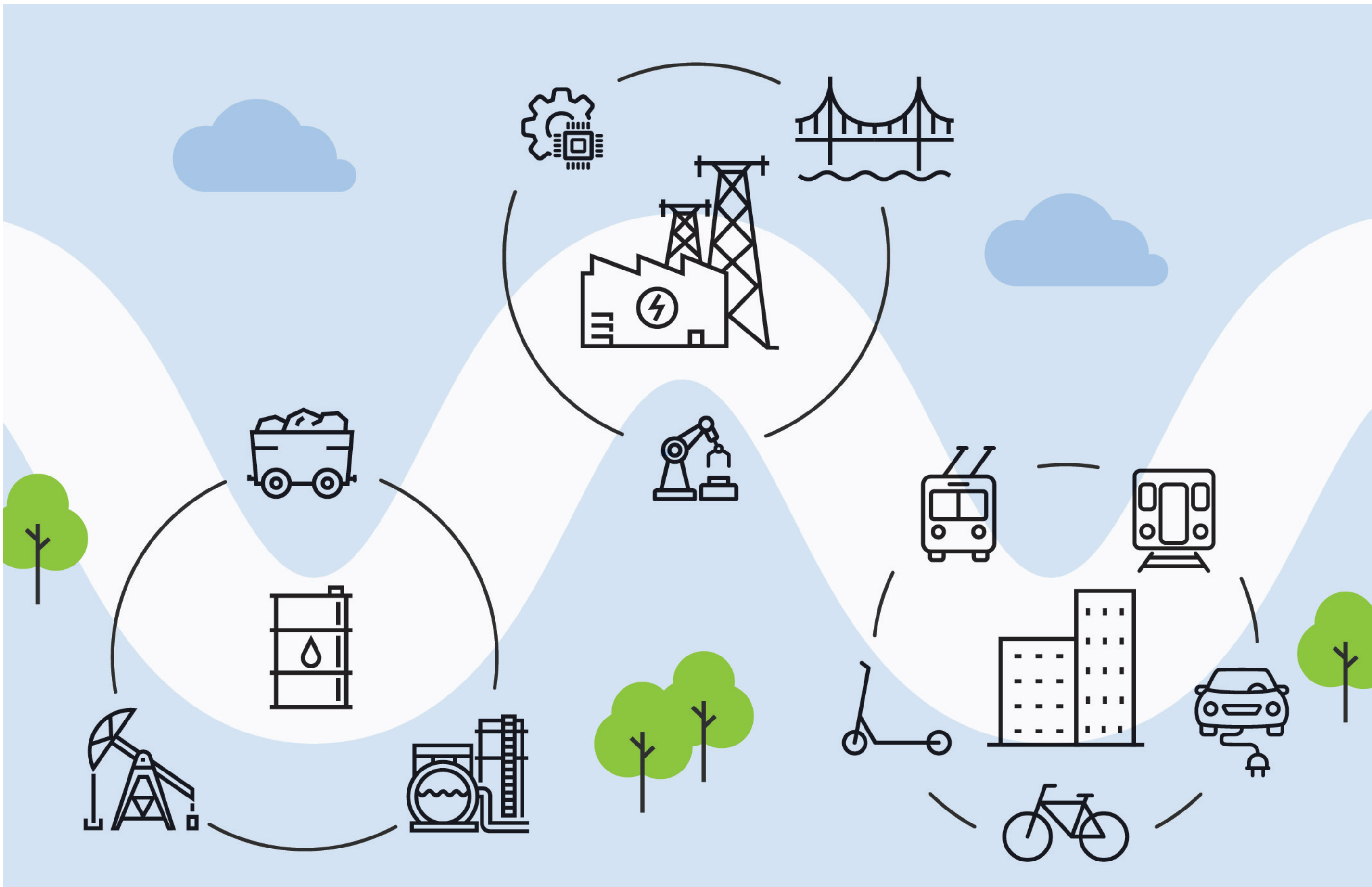


Good to Go?
Assessing the Environmental Performance of New Mobility

Corporate Partnership Board Report

Good to Go?

Assessing the Environmental Performance of New Mobility

Corporate Partnership Board Report

The International Transport Forum

The International Transport Forum is an intergovernmental organisation with 62 member countries. It acts as a think tank for transport policy and organises the Annual Summit of transport ministers. ITF is the only global body that covers all transport modes. The ITF is politically autonomous and administratively integrated with the OECD.

The ITF works for transport policies that improve peoples' lives. Our mission is to foster a deeper understanding of the role of transport in economic growth, environmental sustainability and social inclusion and to raise the public profile of transport policy.

The ITF organises global dialogue for better transport. We act as a platform for discussion and pre-negotiation of policy issues across all transport modes. We analyse trends, share knowledge and promote exchange among transport decision-makers and civil society. The ITF's Annual Summit is the world's largest gathering of transport ministers and the leading global platform for dialogue on transport policy.

The Members of the Forum are: Albania, Armenia, Argentina, Australia, Austria, Azerbaijan, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Canada, Chile, China (People's Republic of), Croatia, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, India, Ireland, Israel, Italy, Japan, Kazakhstan, Korea, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Mexico, Republic of Moldova, Mongolia, Montenegro, Morocco, the Netherlands, New Zealand, North Macedonia, Norway, Poland, Portugal, Romania, Russian Federation, Serbia, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Tunisia, Turkey, Ukraine, the United Arab Emirates, the United Kingdom, the United States and Uzbekistan.

About the Corporate Partnership Board

The Corporate Partnership Board (CPB) is the International Transport Forum's platform for engaging with the private sector and enriching global transport policy discussion with a business perspective. The members of the ITF Corporate Partnership Board are: AB InBev, Airbus, Alstom, Aramco, Bird, Bosch, Cruise, ExxonMobil, Grin, Iberdrola, Incheon International Airport, Kakao Mobility, Kapsch TrafficCom, Kyyti Group, Michelin, NXP, Penta Security, PTV Group, RATP Group, Siemens, SNCF, Spea Engineering, Total, Toyota, Uber, Valeo, Volvo Cars, Volvo Group and Waymo.

Disclaimer

Funding for this work has been provided by the ITF Corporate Partnership Board. This report is published under the responsibility of the Secretary-General of the ITF. It has not been subject to the scrutiny of ITF or OECD member countries and does not necessarily reflect their official views or those of the members of the Corporate Partnership Board.

Acknowledgements

The principal authors of this report are Pierpaolo Cazzola and Philippe Crist of the International Transport Forum (ITF).

The report is draws from contributions and insights that emerged at the ITF Corporate Partnership Board (CPB) Workshop "Lifecycle Assessment of Emerging Urban Transport Business Models", held on 1 October 2019 at the Organisation for Economic Co-operation and Development (OECD) in Paris, France (https://www.itf-oecd.org/lifecycle-assessment-emerging-urban-transport-business-models). Participants in this workshop are listed in Annex B.

Special thanks for further contributions and insightful comments during the review process go to: Sarah Badoux (Voi), Björn Bröskamp (Tier Mobility GmbH), Adam Cohen (University of California, Berkeley), Anne De Bortoli (Eurovia and ENPC/IFSTTAR/UPEM), Pierre-Olivier Calendini (Aramco), Matt Chester (independent), Eppler Steffen (Bosch), Nicolas Erb (Alstom), Lina Fedirko (ClimateWorks), Patrick Gaillard (Aramco), Victor Gordillo (Aramco), Adam Gromis (Uber), Melinda Hanson (Bird), Agnès Jullien (IFSTTAR), Alex Jung (Bird), Kazunori Kojima (Toyota), Marion Lagadic (6t), William Lilley (Aramco), Lucien Mathieu (Transport and Environment), Michiko Namazu (Uber), Nicolas Rankovic (Aramco), Eddy Van Bouwel (ExxonMobil), Yi Wen (University of Tennessee), Michael Wang (Argonne National Laboratory), Laurence Wilse-Samson (Bird) and Marta Yugo (Concawe).

The work for this report was carried out in the context of a project initiated and funded by the International Transport Forum's Corporate Partnership Board. CPB projects are designed to enrich policy discussion with a business perspective. They are launched in areas where CPB member companies identify an emerging issue in transport policy or an innovation challenge to the transport system. Led by the ITF, the project development is carried out in a collaborative fashion in working groups consisting of CPB member companies, external experts and ITF staff.

Members of the Corporate Partnership Board companies that have been involved in this work include: Alstom, Aramco, Bird, Bosch, ExxonMobil, Grin Scooters, Michelin, RATP Group, Siemens, Toyota, Uber and Valeo.

At the International Transport Forum, credits go to Jari Kauppila and Luis Martinez for their contributions during the workshop and their review of the report. Sokob Challener supported the project and Hilary Gaboriau edited the draft.

The project was managed by Pierpaolo Cazzola and Philippe Crist. Sharon Masterson manages the Corporate Partnership Board and its activities.

Table of contents

Figures

Tables

Boxes

Executive summary

What we did

People in cities across the globe are rapidly adopting new mobility forms, helped by digital connectivity and electrification technologies. This report examines the energy and climate impact of such services, including personal and shared electric kick-scooters, bicycles, e-bikes, electric mopeds. It also covers ridesourcing, i.e. for-hire vehicle services with drivers that use smartphone apps to connect drivers with passengers.

The focus of the study is twofold: First, it assesses if current life cycle assessment methodologies are fit for purpose and able to address full life-cycle impacts of new mobility services, and proposes methodological improvements where they are not. Second, the report analyses the life-cycle performance of a range of new vehicles and services based on their technical characteristics, operation and maintenance, and compares it with that of privately owned cars and public transport. The scope of the analysis expands beyond usual life-cycle assessments of transport vehicles to include impacts due to the operation and maintenance activities that are specific to these new mobility services.

Drawing on these analyses, the report identifies solutions to make new mobility a useful part of the urban transport mix while helping to increase energy efficiency and reduce greenhouse gas (GHG) emissions in order to address climate change.

What we found

Private bicycles and e-scooters use significantly less energy and emit much less GHG per person-kilometre over their life cycle than cars. Mopeds, metros and buses are the next most efficient urban modes. Energy use and GHG emissions from shared micromobility (involving e-scooters, bikes, e-bikes and mopeds) are comparable in magnitude to those of metros and buses. This is the case especially when actions are taken to extend lifetime mileage and minimise energy use and GHG emissions from operational services.

Ridesourcing vehicles and taxis have the highest energy and GHG emission impacts per passenger kilometre of all urban mobility options, despite the clear value they provide to users and the contribution they can make to make travel more multimodal.

Energy use and GHG emissions depend on the propulsion technologies and their energy vectors, ridership characteristics, the frequency with which infrastructure (e.g. roads, railways, bike lanes) is used, as well as operational practices.

A range of actions can improve the environmental performance of new mobility services. Enhancing capacity use, i.e. increasing in the number of passengers transported per kilometre of vehicle travel, is especially relevant for ridesourcing and taxi services.

Fostering a rapid transition towards more efficient powertrains and energy vectors (such as electric vehicles) will reduce energy use and emissions.

Design solutions that extend vehicle life are especially important for improving the environmental performance of shared micromobility.

Incentives that encourage the use of smaller and lighter cars over operating large and heavy ones are powerful tools to reduce energy use and emissions. However, large size is not an issue if it enables significant increases in occupancy, as can be the case with vans and minibuses that provide on-demand ridesourcing services.

Improvements in operations can reduce energy use and GHG emissions of new mobility thanks to lower servicing requirements per kilometre of service. The reduction of “deadheading”, i.e. the empty vehicle travel necessary to provide transport services with passengers on board, is crucial in this respect.

The effective integration of new mobility services with public transport can strengthen the capacity of new mobility and public transport to replace travel with personal single-passenger cars. This can do much to help new mobility make a positive contribution to transport’s environmental performance, rather than a detrimental one.

The smooth integration of new mobility services into the existing policy frameworks for more sustainable transport requires a mix of both general and specific policies. Beyond environmental objectives, these should support industrial development and innovation, and enhance economic productivity, for instance in battery manufacturing. Two types of policy interventions are well suited for this purpose. First, requiring accurate information on the full life-cycle impacts of new mobility services to increase transparency and inform further policy decisions. Second, setting incentives through regulatory, economic and voluntary measures that stimulate improvements in the life-cycle energy and climate impacts of new mobility options.

What we recommend

Leverage existing reporting obligations and introduce new requirements for micromobility providers to make evidence-based policy decisions

Public authorities should inform their decisions by making fuller use of data and other information micromobility providers share under existing reporting obligations. Where this is not possible, additional, tailored reporting requirements should be introduced. Regulatory reporting requirements should be accompanied by robust policies to protect privacy and commercially sensitive information. Reporting mechanisms – whether direct or indirect (via a trusted third party or secure shared data platform) – should be adapted to the diversity and dynamism of business models and vehicle types. They will also depend on the authorities’ processing capacity. Reporting requirements can also be integrated into licensing frameworks imposed by public authorities.

Focus interventions aiming at clean mobility on ridesourcing vehicles with high lifetime travel

A range of policy actions will support the transition of ridesourcing vehicles to clean mobility and clean energy. These include setting limits on pollutant emissions, requiring improved energy efficiency and reduced GHG emissions, or mandating the use of low- and zero-emission vehicles. This latter intervention should be complemented with access restrictions for high-emission vehicles and the introduction of road or access charges for all vehicles. Specific characteristics of new mobility services should be taken into account, in particular the uneven distribution of lifetime travel for different ridesourcing vehicles and their high driver turnover. Vehicles with elevated levels of lifetime travel should be the focus of targeted measures aiming to cost-effectively minimise life-cycle energy use and GHG emissions.

Set incentives to increase occupancy of ridesourcing vehicles

Low vehicle occupancy is a widespread and durable feature of private car travel. Increasing occupancy improves the energy efficiency and environmental performance of cars over their life cycle. Differentiated levies on ridesourcing vehicles based on occupancy are in place in various cities in the Americas and in Europe. If applied, these should not be limited to ridesourcing. Minimum occupancy standards for ridesourcing services offer greater flexibility than levies to increase occupancy rates. They also incentivise the use of high-capacity vans and minibuses on pop-up routes, a solution that offers important advantages in terms of reduced energy use and GHG emissions. Curb access rules for pick-up and drop-off with preferential access for highly occupied vehicles could also encourage better capacity use, similar to high-occupancy vehicle lanes. Affordable, high-quality alternatives including public transport can address equity impacts.

Standardise methodologies for the evaluation of shared micromobility’s life-cycle emissions and introduce minimum performance requirements via market entry rule and/or operating licenses

Most of the impacts of shared micromobility related to energy use and GHG emissions are not directly linked to vehicle use. Therefore, defining common methodologies to evaluate life-cycle emissions and requiring third-party verification of the resulting assessments is important. Standardised methodologies are a prerequisite for setting environmental and energy-related performance requirements for micromobility vehicles. Market entry rules and operation licenses are important to maximise the benefits of common standards, as they are well suited to promote good practices or require minimum performances from the operators that are active in the market.

Strengthen synergies between public transport and shared micromobility

Enhancing the collaboration between micromobility services and public transport to create synergies should account for local contexts and different interaction effects between public transport, car use as well as walking and cycling (active trips). The focus should be on encouraging combined trips where these can reduce energy use and GHG emissions. Tax rebates, differentiated fees or subsidised feeder trips to public transport stations can support this objective. Structural interventions can also reinforce the integration of public transport and new mobility services, for instance the provision of adequate and safe road space for shared and owned micromobility Mobility as a Service (MaaS) platforms can help integrate public transport and micromobility.

What is new about new mobility?

The convergence of digitalisation, ubiquitous connectivity and emerging business models – all served up on our smartphone screens – is having a significant impact on the way in which people access and use transport services. So, too, is the rapid pace of growth of electric vehicles, which accounted for more than 300 million two-wheelers (mostly in the People's Republic of China), 7.2 million cars and almost 0.6 million urban buses on the road by the end of 2019 (ITF, 2020a).

Notwithstanding the recent challenges posed by the Covid-19 pandemic, these developments have led to a broad range of new mobility services, for both passengers and goods, that took hold around the world. As public authorities seek to balance public health and mobility imperatives in light of the pandemic, these services may not only return to their pre-pandemic importance, but could possibly gain relevance. Cities will need to meet a growing demand for urban mobility as sanitary restrictions limit the capacity in public transport, thus creating increased congestion from a partial transfer of those trips to private cars. New mobility services could help fill the gaps and contribute to the achievement of greater resilience for urban transport systems.

This convergence raises a few key questions. The first relates to the uncertainty about the scope, scale and endpoints of the changes that can be observed, as it is hard to determine the extent of rapid technological and behavioural changes as they are underway. At present, there is little clarity as to the durability or final configuration of many emerging business models. This has repercussions on policy, since acting now may lock in sub-optimal outcomes or, alternatively, prevent the emergence of better ones. This is especially relevant now as many new mobility business models have been sorely hit by health-related Covid-19 mitigation measures, despite efforts underway to handle its economic impacts.[1]

The second question relates to the nature of the innovations that are driving this revolution. As with prior transport revolutions (e.g. from animal to steam to fossil power) there is a strong technological component at play. Unlike prior transport revolutions, however, this revolution's technological innovation relates largely to the method of accessing and operating new mobility services. In fact, many of the vehicle technologies that underpin new mobility services have been around for decades (albeit in continually improved forms) as have many of the basic service delivery models at the heart of these services. Digitalisation has served as a catalyst and an accelerant for new combinations of vehicles and services. This has driven the growth of new mobility. Thus it is the "how" more than the "what" that is truly new about new mobility services.

The third question relates to how this revolution interfaces with existing technologies. Of course, much of ridesourcing relies on the use of existing vehicle technologies, namely vehicles operating on traditional internal combustion engine technology (cars and mopeds). In some instances, (e.g. London), ridesourcing companies have incentivised their drivers to use lower-emission technologies such as hybrid or battery-electric vehicles. In many other new mobility service deployments, services have been built on electrified drivetrains by default. This represents a real opportunity to deliver on lower-emissions and lower-carbon transport if a number of conditions are met. These include the extent to which these services replace other more polluting trips, the extent to which these services lead to new or induced trips and the full life-cycle impacts of these service delivery models, not just of the vehicles themselves.

So what are these services? The most dynamic of these in terms of uptake include ridesourcing and bikesharing and e-scooter sharing. Other forms of shared vehicle use include carsharing and shared e-mopeds or motor scooters.

Ridesourcing consists of on-demand ride services delivered by ride-matching platforms such as Didi, Uber, Grab, Ola, Lyft and GoJek (for moped rides). This type of service targets primarily short passenger trips, often of less than 15 km, but it also includes a number of longer ones – up to 50 km, e.g. to and from airports. The service also focuses on metropolitan areas, where ride frequency is usually high and distance travelled short (Mittal, 2019).[2] Ridesourcing is organised by centralised platforms that dispatch rides to individual drivers in return for a commission. A variant of these ridesourcing services involves pop-up van services that focus more on collective rides along popular trajectories. These types of on-demand van services have proven more challenging to operate but platforms such as Via or Jetty (i.e. offered by larger-capacity vans and minibuses providing pop-up routes designed to have less empty-vehicle travel distances and higher occupancies) seem to have found promising models.

Prior to the Covid-19-related travel restrictions, growth in ridesourcing was rapid and extensive, reaching into all global regions. The major global players in ridesourcing were founded only five to ten years ago: Uber in 2009, Ola in 2010, and Didi, Grab and Lyft in 2012. In that relatively short time, they have managed to reach between 15 and 20 billion rides in 2018[3].

E-scooter and bicycle sharing services, along with the sharing of other light mobility devices, are part of a broader range of **shared micromobility** options[4]. **Dockless e-scooter sharing** entails platform-facilitated access and the use of electric kick scooters at a variety of pick-up and drop-off locations, in a free-floating arrangement (i.e. without an obligation to return them to a specific location) and within a predefined geographic region. **Bikesharing** consists of similar services provided by dockless or docked bikes and or e-bikes. Other shared services involving **e-mopeds or motor scooters** are similarly organised. Compared with ridesourcing, e-scooter, bike, e-bike and e-moped sharing services have a stronger focus on metropolitan areas, since an even larger share of their trips are short distance, high frequency trips in line with urban travel patterns. Since short passenger trips (i.e. those having the greatest appeal for bicycles and e-scooters) still account for the vast majority of trips made by individuals[5], the scope of adoption of these new mobility options is potentially significant.

Bikesharing is the first form of micromobility that was subject to a rapid emergence during the last decade, as evidenced through data on the number of self-service public-use bicycles across the world, which grew from less than 400 000 in 2010 to more than 1.2 million in 2015, more than 10 million in 2017 (Schönberg, Dyskin and Ewer, 2018), and to almost 18 million in 2020 (Meddin et al., n.d.). The vast increase in bikesharing schemes from 2015 onwards has been led by very rapid deployment in China. Despite the contraction or exit of many major players (Chinese-based OFO rapidly shed its international operations in 2018 to re-focus on China, and Bluegogo, China's third-largest bikesharing company with 20 million users, ceased operations in 2017) bikesharing remains an active and dynamic form of shared micromobility. This is particularly the case with the deployment of the most recent systems, including local systems in London, New York, Mexico City and other cities and the international deployment of services like Jump bikes. Bikesharing continues to remain relevant and on the rise today, despite negative developments that saw many schemes closed down due to financial or operational failures, with negative implications for bikesharing's image and concept (Nikitas, 2019).

Dockless e-scooter sharing is a form of micromobility that has experienced rapid growth since its first deployment towards the end of 2017. Dockless e-scooter sharing started in the United States by companies like Lime and Bird (both established in 2017) and is now provided by many other companies[6], some of which integrate their offer within app-based platforms (e.g. Jump – and now Lime – in the Uber App, Lime in the Google Maps app). Data from Lime reported in Ajao (2019) and Base10 (2019) show that the use of e-scooters grew very quickly after their initial deployment (primarily in the United States), reaching one million rides after 31 weeks and six million rides after 58 weeks. This growth indicates that supply and demand grew very fast, exceeding what has been observed for car- or van-based ridesourcing (one million in 61 weeks). Several other players announced large financing rounds in 2018-19 (Ajao, 2019). Despite a number of issues (e.g. e-scooters ending up in lakes and oceans, congesting sidewalks, being stolen and causing injuries) and remaining challenges to ensure that business models are economically sustainable, e-scooters have successfully responded to a desire for a viable last-mile alternative to current transport options.

Shared e-mopeds and motor scooters were also rolled out in a number of cities, namely in Europe, at roughly the same time as dockless e-scooters but at a far slower pace. By now, shared e-mopeds are available or planned in more than 40 European cities (Friedel, 2020) and signs of expansion of this form of micromobility have also been reported in the United States (Toll, 2019).

Traditionally, **carsharing** consisted in allowing access to vehicles through a service provider that maintained a fleet of cars deployed in lots or on-street spaces providing fuel, parking, and maintenance (Cohen and Shaheen, 2016). This concept dates back to the 1950s in Switzerland, primarily through round-trip schemes, and was popularised in the 1990s with developments in telematics technologies that allowed automation of its use. By the late 2000s, a number of new entrants and business models emerged, including, in particular, one-way schemes (station based and free-floating). These new service providers included automakers (e.g. BMW's DriveNow, now merged with Daimler's Car2go in the Share Now joint venture, offering one-way service); car-rental companies (such as Avis Budget Group's Zipcar) and nonprofit organisations (Cohen and Shaheen, 2016). Peer-to-peer carsharing, where online platforms allow for private individuals to connect to share rides, is also a recent development contributing to a growing popularity of carsharing (Erich, 2018).

Globally, professional fleet-based schemes had an estimated membership base of 4.8, 7 and 15 million in 2014, 2015 and 2016 respectively and a fleet of 104, 112 000 and 157 000 cars in the same years (Frost and Sullivan (2016) for 2015; Shaheen, Cohen and Jaffee (2018a) for 2014 and 2016). The success of professional fleet-based schemes is linked to:

- high income levels (and, therefore, greater capacity to move by car: carsharing is sizable in the United States and Europe)
- high urban densities and (consistently) greater modal diversification (Asia is the largest carsharing region measured by membership, followed by Europe[7])
- lower safety concerns (Latin America is lagging behind other markets).

In Europe and North America, peer-to-peer carsharing schemes have a membership base that is similar in magnitude to professional schemes (roughly 1.5 times larger), with larger amounts of cars involved.[8]

Both professional and peer-to-peer schemes are subject to a dynamic growth: Shaheen, Cohen and Jaffee (2018a) show upwards trends for membership and cars used in professional schemes across all global regions, with a strong acceleration in 2016, especially in Asia. In North America, Shaheen, Cohen and Jaffee (2018b) report an increase from 1.3 million members and 72 000 cars in early 2016 to three million members and 130 000 cars in early 2017 for peer-to-peer schemes in North America. For Europe, Erich (2018) reports a growth for professional and peer-to-peer schemes combined, from 5.1 million to

11.5 million members between 2016 and 2018. Cars used for these services increased from 132 000 to 370 000 in the same timeframe.

Erich (2018) sees factors like urbanisation and policy promotion (such as changes in the availability of space/road space allocation resulting in reduced parking availability, parking pricing, the restriction of access to certain areas of the city to privately owned vehicles) as key determinants of a rise in supply and demand for carsharing. Digital connectivity has also helped in addressing limiting factors of carsharing, such as the increased need for planning (loss of convenience) and the potential lack of availability of vehicles (or high cost), as well as other barriers to entry (membership requirements). These factors, combined with connectivity increases, changes in consumer preferences (also influenced by greater exposure to digitally-enabled shared mobility business models) and reducing costs of electric cars, are expected to contribute to increasing global adoption in the future. On the other hand, the volatile state of the global mobility landscape and operating cost have recently (but before the Covid-19 pandemic) led to the key carmakers with an important presence in the carsharing market, like BMW and Daimler, abandoning the North American market to refocus activities on specific cities in Europe (Shepardson, 2019b).

Aim of this report

This report has a dual focus. The first is to evaluate if current life-cycle assessment methodologies are fit for purpose and able to address full life-cycle impacts of new mobility services – and if they are not fit for purpose, how these methodologies may be improved. The second is to leverage life-cycle assessment to identify solutions to make new mobility a useful part of the urban transport mix while helping to reduce energy use and limit climate change.

Taking into account that users in cities across the globe are rapidly adopting these new forms of mobility services, a number of analyses have started to assess the energy and climate impacts of shared e-scooters, bicycles, e-bikes, electric mopeds, as well as car-based ridesharing services. Key examples include the analyses of Hollingsworth, Copeland and Johnson (2019) and Chester (2018) for dockless e-scooters, Cherry, Weinert, and Xinmiao (2009) for bicycles and e-bikes, Anair et al. (2020) for ride hailing.

This report builds on information available from these and other tools and literature sources to analyse the life-cycle performance of these new vehicles and services, with a focus on energy and greenhouse gas (GHG) emissions. To do so, it uses an assessment tool that has been specifically developed for this project, expanding the usual scope of life-cycle assessments to include impacts due to the operation and maintenance activities that are specific to these new mobility services. It offers a unique advantage to provide a single and consistent accounting framework for all forms of mobility.

This report also compares energy and GHG emission impacts assessed for new mobility options with those of privately owned cars, public transport and other conventional urban mobility modes, such as privately owned bikes and e-bikes. Having looked into central estimates and a range of possible alternatives to assess the variability of results to changes in key input parameters, this analysis identifies solutions to make new mobility more sustainable. It outlines policy actions that could steer the development of new mobility towards net improvements in terms of energy use and GHG emissions.

How to measure environmental impacts of new mobility

Truly understanding the energy and environmental impacts of products and services requires a "cradle to grave" analysis. This entails tracking every stage of the product or service, from conception and creation to execution, utilisation and extinction. This is called a life-cycle assessment (LCA).

The easiest way to get a sense of a product's or service's environmental implications and energy requirements is by accounting for its direct energy use and emissions. This, however, offers only partial indicators of overall energy requirements and environmental impacts. A fuller understanding requires taking into account:

- the manufacturing processes needed to ensure that the service can take place (i.e. the production of the vehicles needed for it)
- the properties of the final energy vector[9] (e.g. with respect to carbon content) used by the vehicles performing the service
- the characteristics of the device used by these vehicles to convert energy into motion (e.g. internal combustion engines, electric motors)
- the production process (e.g. oil extraction, coal mining, electricity generation from solar panels or wind farms), the energy transformations (e.g. taking place in a refinery or a thermal electricity generation plant), and transport and distribution steps needed to make the energy vectors available for these vehicles.

The full environmental impacts for each of these components also extends beyond energy use and GHG emissions alone – they may entail emissions of other pollutants, water use, habitat change, etc. These additional impacts are not assessed in this report.

What is a life cycle assessment?

An LCA is a calculation method that evaluates energy use and environmental impacts of a product or a service, taking into account the different contributions enabling its existence, use and disposal: design, production (including materials and energy acquisition and its transport to the production facilities), use and operation, maintenance and repair, and end-of-life treatment (such as reuse, recycling or disposal).

According to the International Organisation for Standardisation (ISO), an LCA is composed of four phases:

- the definition of the goal and the scope of the assessment
- the inventory analysis (involving data collection and the calculation of energy inputs and emission outputs)
- the assessment of impacts (i.e. regional and global environmental and human health effects related with the energy inputs and emission outputs)
- the interpretation of the results with respect to uncertainties (e.g. with sensitivity analyses) and their documentation. (ISO, 2015)

The scope of an LCA is inherently defined by the boundaries of the system (i.e. the product or the service) being analysed. These boundaries define the resources – including primary energy and materials – and the technical systems needed to extract, use and convert those resources to ensure the final delivery of the product or service.

In the case of transport, products taken into account are typically vehicles (e.g. cars, bicycles, buses, motorcycles, trucks, trains, aircraft and vessels) and infrastructure (e.g. roads, railways, airports, ports). Services are typically related to the delivery of passenger and freight mobility (e.g. trips, hauls).

A key advantage of LCAs used in transport is that they provide some understanding of where action or policies can have the greatest impact in addressing some of the measured outcomes – not just at the final step of resource use (i.e. fuel consumption). Key examples include the fuels or energy sources that are used to produce and transport the fuels, the materials required for the construction of vehicles and transport infrastructures and the resources needed for their maintenance.

While the use of LCA in transport can inform policy decisions, it is important to bear in mind that all LCA results are grounded on technical estimations and are influenced by methodological choices. As such, they should be seen as instruments allowing a *better understanding* of the system considered, under given assumptions, and not as the *absolute truth* (which is very much case-specific). [10]

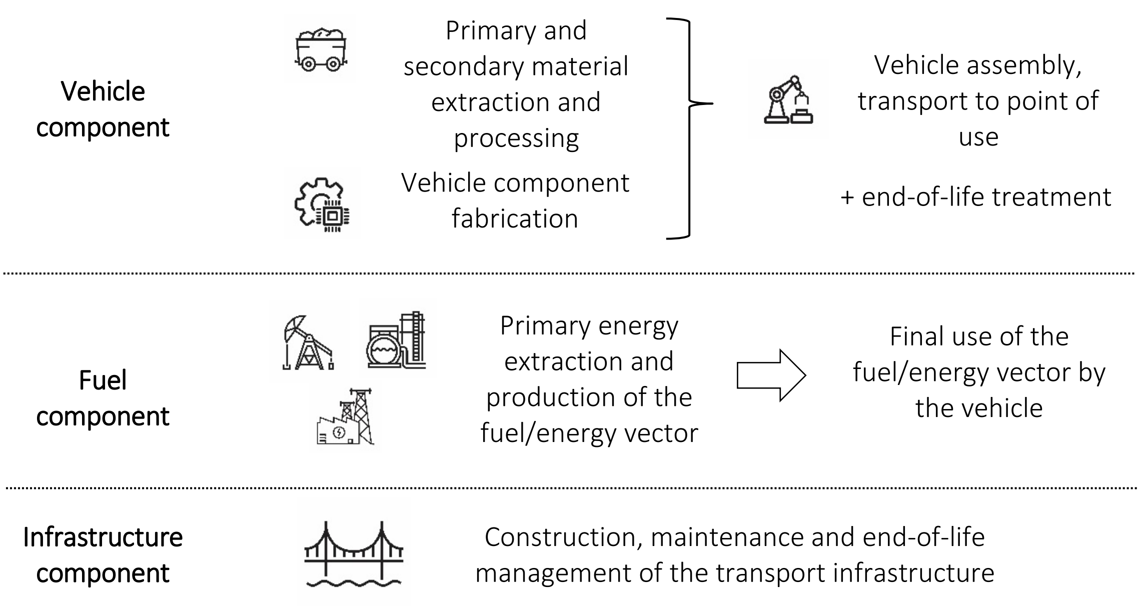
Key components of life cycle assessments in transport

Transport-focused LCAs typically account for energy needs and environmental effects occurring across different stages of the life cycle of the transport products or services. This consists of three main components:

- The vehicle component: related to the manufacturing, delivery at the point of purchase, maintenance and disposal of vehicles. This includes material extraction, processing, vehicle component fabrication (e.g. battery production), the assembly of vehicles and components, the production and use of fluids (e.g. lubricants, coolants), the delivery of the vehicle to its point of purchase, and its end-of-life treatment when it is scrapped (i.e. the re-use, recycling or disposal of the vehicle parts).
- The fuel component: related the production and distribution of the fuel/energy vector used by the vehicles – i.e. the well-to-tank (WTT) phase, and its actual end-use – i.e. the tank-to-wheel (TTW) phase.
    - The WTT phase includes production, processing and delivery of a fuel or energy vector to the on-board energy-storage device of a vehicle (e.g. the fuel tank or the battery).
    - The TTW phase is directly influenced by the daily distance travelled by the vehicle and it is essentially related to the in-vehicle conversion of energy into motion.
- The infrastructure component: related to the construction, maintenance and end-of-life management of infrastructure (e.g. the road, rail, airports, ports) required for vehicle operations. Similar to the vehicle component, this includes materials extraction, processing, construction, operation, maintenance and end-of-life treatment.

Figure 1 provides a graphical representation of the three components.

Figure 1. Key components of life cycle assessments used in transport



Key examples of LCA tools and/or reviews performing this type of evaluation include:

- The Greenhouse Gases, Regulated Emissions, and Energy use in Transportation (GREET) model developed by the Argonne National Laboratory, which covers both vehicle and fuel components in two different modules. It focuses on the United States and large scale technology deployment. (ANL, 2020a and ANL, 2020b)
- The well-to-wheel assessment developed in a collaborative effort of the Joint Research Centre (JRC) of the European Commission, the European Council for Automotive Research and Development (EUCAR) and the European Oil Company Organisation for the Conservation of Clean Air and Water in Europe (Concawe). This effort targets primarily the evaluation of energy use and GHG emissions of the combination of different road fuel and powertrain configurations (fuel component) and focuses on Europe (JEC, n.d.1).
- Recent academic research on the LCA of transport infrastructure, with a particular focus on road and rail in North America (Transportation life-cycle assessment, 2020), building on earlier research by some of these same researchers (Chester and Horvath, 2009).

Many analyses and reviews have focused on both vehicle and fuel LCA components for different types of cars[11]. There are many reasons for this. The first is that cars matter from a global emissions and energy use perspective – there are over one billion cars in circulation today and their global impact is significant. The second is that the re-emergence of electric mobility has catalysed attention on the use of LCA because of the shift in the balance of impacts when comparing electric vehicles (EVs) to those powered by internal combustion engines (ICE). This shift includes: 1) higher material requirements in vehicle manufacturing (and thus, embedded carbon) for EVs as compared to ICE vehicles; 2) differences in the respective fuels/energy vectors energy for these vehicles; and 3) differences in the use-related environmental impacts of ICE vehicles and EVs.

Key impacts that life cycle assessments can assess

LCAs allow accounting for a wide range of possible flows and impacts, including energy consumption and emission outputs. Other indicators, such as water requirements, water eutrophication and acidification impacts, waste outputs, mineral resource depletion, ecotoxicity and human toxicity impacts, human health impacts and impacts on ecosystem quality from land transformation and occupation can also be tracked with LCAs (Impact World+, n.d.).

Energy consumption refers to primary forms of energy (e.g. coal, crude oil, natural gas, nuclear energy, renewable energy – biomass, hydro-, solar- and wind electricity) and depends on the amount and type of final energy vectors (e.g. electricity, petroleum fuels and hydrogen) needed for the different LCA components, combined with the transformation processes that convert primary into final energy.

Emission outputs occur essentially from the combustion of fuels, leakages (fugitive emissions) occurring across the supply chain and material transformations (e.g. due to heating), most relevant for the case of infrastructure. Emission outputs include greenhouse gases (GHGs, including carbon dioxide [CO_2], methane [CH_4], and nitrous oxide [N_2O], typically grouped thanks to the use of global warming potentials [GWPs][12]) and local pollutants (carbon monoxide [CO], sulphur dioxide [SO_2], nitrogen oxides [NO_X], volatile organic compounds [VOCs], and particulate matter [PM]) that have consequential impacts like acidification, ozone formation, and human toxicity.

In the case of transport-focused LCAs, for which the characterisation into a vehicle, fuel and infrastructure component applies, as discussed earlier, the impacts are typically calculated for each of the components.

- The impacts associated with the vehicle component are typically evaluated per each vehicle manufactured.
- Those related with the fuel component are typically calculated per each unit of fuel/energy vector.
- The impacts resulting from the infrastructure component are generally evaluated on a project basis (and, therefore, for a given length of infrastructures such as roads and railways), and they can also be normalised per unit length of the infrastructure (e.g. lane km or track km, for the road or rail example).

Measuring the life cycle assessment impacts of transport vehicles and services

While the effects associated with a transport vehicle or service are measured in terms of energy inputs and emission outputs, indicators allowing comparative evaluation *among* vehicles or services vary for each life-cycle component. The functional unit, i.e. the parameter used to define the purpose of what is being assessed, is the key element explaining these variations.

- For the vehicle component, the most obvious functional unit is the vehicle itself. Energy inputs and emission outputs are typically assessed for each vehicle, taking into account the manufacturing, maintenance and disposal phases.
- For LCAs focusing on the fuel component (WTW analyses), the most obvious functional unit is the amount of energy carried in the energy vector taken into consideration.

- For LCAs looking specifically at transport infrastructure (in particular road or railways), the functional unit is the length of a representative indicator characterising the infrastructure itself (e.g. lane km for roads, or track km for railways). Alternatively, relevant functional units could refer to specific infrastructure components (e.g. metro stations, airport terminals, airport runways).

The way to account for the impacts of each component may need to change if the different components need to be brought under a single metric.

In this analysis, the purpose taken into account is the provision of a passenger transport service, with passenger vehicles, in an urban environment (and therefore using transport infrastructures, such as roads and rail networks, available in cities). Energy consumption and environmental impacts calculated for each of the components identified earlier need to be attributed to the functional unit of passenger movements, measured in passenger kilometres (pkm).

Doing this requires conversion mechanisms that account for additional elements characterising the provision of transport.

For the vehicle component, evaluating energy inputs and emission outputs per pkm requires identifying vehicle capacity (i.e. the number of people that the vehicle is capable of moving), its utilisation rate (i.e. how many people are actually moved in each vehicle trip), the distance travelled per unit of time (resulting from the combination of the number of trips per unit time – e.g. per minute, hour, day or year – and the length of these trips) and the lifetime of the vehicle (i.e. the number of days or years during which the vehicle is operational). Given that these parameters may vary over time, LCAs aiming to compare impacts on a pkm basis typically take into consideration averages that are representative of what happens across the whole vehicle life.[13]

In the case of the fuel component, the key parameters are the energy use per vehicle km (i.e. an indicator of the efficiency of the powertrain technology, which, in most cases, changes depending on the energy vector[14]), the vehicle capacity and its utilisation rate (allowing to evaluate the amount of pkm per vkm).

In the case of urban infrastructures such as roads and railways, for which impacts are assessed per km of network extension, the parameters needed include infrastructure lifetime (to allow estimating impacts per network length and per unit time), the rate of use of the network for different vehicles and the respective relevance of different vehicles in terms of network use (to allow estimating the impacts per vkm) and, once again, the vehicle capacity and utilisation rate.[15]

The importance of assessing energy use and carbon dioxide emissions in transport

The United Nations has called climate change the defining issue of our time. Several scientific assessments have consistently flagged a number of social and environmental pressures associated with climate change, spanning from droughts, rising sea levels that threaten low-lying regions with the risk of catastrophic flooding, extreme and less predictable weather, and loss of biodiversity with potential impacts on human health, food security, water supply and economic development (Stocker et al., 2013; IPCC, 2018).

Recently, the 2020 World Economic Forum in Davos, Switzerland, which had sustainability as a core theme, provided growing evidence that climate change has also become a defining factor in the way investments are taking shape, with increasing recognition that climate risk is also an investment risk. This is due to a rising uncertainty in the assessment of risks for investments concerning long-lasting assets and the inherent tendency of capital markets to pull future risk forward (due to the need to make decisions today on cash flows that are set to materialise in the future). This leads to expectations of changes in capital allocation towards assets that are perceived as most resilient to climate and other sustainability-related risks, in combination with a pace that is expected to be quicker than the changes occurring to the climate itself (Fink, 2020; Hildebrand and Donilon, 2020).

The European Green Deal is the most ambitious package of measures that should enable European citizens and businesses to benefit from sustainable green transition (EC, 2019). It is also an important example of the reflection of the growing relevance of climate change mitigation for economic development.

Due to the central role that climate change has in economic and policy debates, the LCA developed for this report focuses on GHG emission impacts.

The analysis also gives priority to the analysis of energy impacts. This is due to several considerations, including:

- the link between fossil fuel use and GHG emissions and the dominant and persistent share that fossil fuel use represents in overall GHG emissions[16]
- the importance of energy for economic growth (as an essential input into goods and services)
- the importance of energy efficiency and alternative fuel mixes as conjoined strategies to decouple economic growth from energy use (see, for example, Sharma, Smeets and Tryggestad, 2019).

The energy and GHG emission focus of the LCA undertaken here is also justified by the relevance of transport in the total amount of energy-related CO_2 emissions (24% in 2019, according to the International Energy Agency [IEA, 2020a]), as well as its strong historical dependence on fossil sources for its energy demand (93% in 2017, according to the International Energy Agency [IEA, 2020b]).

A further consideration motivating the GHG and energy focus of the LCA developed here is the relevance of urban areas, which are not only at the core of changes taking place in the new mobility landscape, but are also actively working on climate and sustainability (as illustrated by the actions and scope of work of networks such as C40, International Council on Local Environmental Initiatives (ICLEI), POLIS in Europe and the National Association of City Transportation Officials (NACTO) in North America. In particular, the report provides valuable insights to local authorities that are currently dealing with the integration of new mobility services in our cities.

As countries and cities look towards a green and inclusive recovery post-Covid-19, and as more measures are implemented to include new mobility and electrification in the transport and energy mixes, it is also an opportunity to take a deeper look at the energy consumption and environmental impacts of each of these, and include recommendation for its optimisation.

Does new mobility challenge existing life cycle assessment methods and practice? How so?

The core components of traditional transport LCAs are relevant to digitally-connected and shared transport services that characterise new urban mobility options since these services require vehicles, fuels (or other energy vectors) and infrastructure to operate.

Given their shared nature, however, LCAs of these services require an expansion of the system boundaries typically used for traditional modes. This expansion extends to servicing (including refuelling or charging) and repositioning (and parking) for shared vehicles and the integration of vehicle movements occurring without passengers but necessary to enable operation. The former are most relevant for forms of new mobility that use free-floating vehicles, but also in use for the rebalancing of docked vehicles. The latter matters the most for public transport, taxis and on-demand, door-to-door services such as those offered by ridesourcing companies, and also found in privately owned cars, e.g. in cases of cruising distance while searching for parking or escorting others (for a more detailed discussion on deadheading and how it applies for different transport modes, see Box 1).

Taking into account the relevance of the impacts due to these services for new mobility (discussed in the next chapter), this report expands the scope of transport-focused LCAs. It accounts for energy needs and environmental effects due to a new *operational* component, in addition to the three (vehicle, fuel and infrastructure) already mentioned earlier.

Box 1. Deadheading across different modes of transport

Deadheading refers to empty vehicle travel necessary to provide passenger transport services. Depending on the mode considered, it can take different forms.

For public transport vehicles with fixed routes, such as urban buses and rail services, the most straightforward form of deadheading consists of the travel needed to move the vehicles from the depot to their area of operation or from that area of operation to the depot. In case of uneven passenger travel demand, deadheading in the “light” travel direction (i.e. the deliberate use of buses not stopping in the direction with lower demand) can also be used as a strategy to reduce the number of buses operating the service and, therefore, limit overall service costs (alternative strategies involve express services with a reduced number of stops) (Furth, 1985). For scheduled services, the importance of service reliability to ensure higher ridership overall may also come with requirements for trips with low capacity utilisation (or even empty), but this is a concept that relates to average loads, going beyond the concept deadheading.

Quantitative estimates of the relevance of deadhead travel for urban bus service suggest that the share of kilometres run empty to enable the provision of scheduled services typically range between 1% and 28%, (Adra, Michaux and André, 2004; Mahadikar, Mulagni and Sitharam, 2015; Nasibov et al., 2013). Among the limited amount of values found in literature, the lowest records were found in Bangalore, India at 1-3%, followed by Izmir, Turkey, with estimates in the 5-6% range. Paris, France recorded values (6-8%) that are lower than the French average (10-11%). The highest value of 28% was registered in Brisbane, Australia. In this last case, deadheading in the “light” direction of traffic movement is reported as a widespread practice. This value compares relatively well with the estimate of close to 20% for deadheading shares in the total of all km driven by coaches in France (Adra, Michaux and André, 2004).

For on-demand, door-to-door services such as those offered by ridesourcing cars, deadheading includes travel needed to reach an area where a driver expects ride requests (*cruising*), as well as the travel that follows the receipt of a ride request and precedes the passenger pick-up (*overheading*). Henao, Marshall and Janson (2019) flag that these add to commuting travel from/to the driver’s residence. According to Wang (2019), ridesharing platforms have the capacity to track the extent to which deadheading is needed to deliver services, but this task does not come without unsolved complications. These relate to double counting vehicle distances travelled across different platforms (drivers may simultaneously be operating on multiple platforms – a practice called multi-apping – to increase the chance of finding a ride)[17], difficulty in estimating driver off-trip mileage purpose (e.g. in cases where the driver is connected to platforms even when the vehicle is used for personal purposes or, alternatively, when the driver is not connected to the platform as they drive to where they expect ride requests). Additional accounting complications occur when adjustments are needed for pooled trips requiring detours to pick up and drop off additional passengers.

Studies with quantitative estimates of deadheading in the United States reported by Henao, Marshall and Janson (2019) indicate a range of 42% to 81% of deadheading travel (i.e. travel without passenger on board – cruising and overheading – divided by travel with a passenger on board). Balding et al. (2018) used TNC data to estimate an average of 45% across Boston, Chicago, Los Angeles, San Francisco, Seattle and Washington, DC. Correcting for multi-apping, the California Air Resources Board indicates 38.5% (CARB, 2019). In the most conservative estimate, Henao, Marshall and Janson (2019) also estimate a distance of about 0.3 km per km travelled with a passenger on board for commuting.

Cramer and Krueger (2016) obtain values in the range of 0.55 to 0.81 deadheading km per each km with passengers for ridesourcing services in Los Angeles and Seattle. The same authors also estimate deadheading travel for taxi services at an average of 1.35 times the amount of travel with passengers on board in four major cities of the United States (with actual values of 1.05 in New York, 1.42 in San Francisco and Seattle and 1.57 in Los Angeles).

Even if the concept of deadheading is not usually applied to personally owned and operated vehicles, it is fair to acknowledge that these vehicles are not exempt from activities that are similar in nature to deadhead travel. Key examples include occasions when drivers makes substantial unintentional or intentional deviations from the intended route, such as to find parking (estimated at eight minutes on average in central business districts of major cities [Shoup, 2007]) and/or when car owners drive to pick people up or get groceries or other goods (estimated to account for 5% of personal vehicle travel in the United States [Williams, 2019]).

Ensuring that the functional unit used for the LCA (pkm) properly accounts for changes in occupancy is especially important for modes that carry more than a single passenger. To do so, the average passenger load attributable to each mode needs to be evaluated as 1) the ratio of the weighted average of the number of passengers occupying a vehicle and the travel distances associated with it (expressed in terms of pkm); and 2) the distance travelled (expressed in vkm), as is done for other modes with multiple passengers (e.g. buses and other forms of public transport). These calculations also need to take into account deadheading, which reduces the average ridership of shared vehicles.

Last, but not least, depending on the business model and the fuel or energy vector adopted, new mobility services may also have additional requirements, such as fixed infrastructure for parking (docking stations), as well as facilities allowing for battery recharge and/or swapping. Docking stations have been common in first- and second-generation bikesharing systems and now, with a greater uptake of electric bicycles, may also integrate charging ports. Facilities allowing for battery recharge and/or swapping are emerging as instruments aiming to deal with environmental impacts and durability of shared micromobility vehicles. Like other forms of transport infrastructure, these infrastructures come with impacts related with their construction, maintenance and end-of-life treatment and require the development of an allocation method that attributes these emissions to the relevant functional unit (pkm). As in the case of other infrastructures, this allocation needs to account for the rate of use by vehicles requiring them (in terms of pkm per docking station per year), a value that depends on parameters such as ratio of docking stations per vehicle, lifetime of the docking stations, daily rates of use of the vehicles and their average load.

Do new mobility services improve environmental outcomes?

This chapter shows estimates of life-cycle GHG emissions and energy use per pkm of urban transport modes. The first part of the chapter (in particular the results shown in figures 2-5) includes details on GHG emissions and energy use for the three main life-cycle components discussed earlier (vehicle, fuel and infrastructure), as well as the effect of other services needed for the operation of the vehicles, especially relevant for new forms of mobility.

These results are inevitably subject to a degree of uncertainty. This is due to the choices made to characterise the key assumptions (such as those outlined in Table 1 and Table 2), the need to define the technical aspects discussed in Annex A and the limitation imposed by the use of a single set of assumptions, given the heterogeneous characteristics of different countries and their cities.

In order to manage these uncertainties and broaden the scope of the analysis, the second part of this chapter considers a range of sensitivity results, exploring the variability of the results shown in Figure 2 to Figure 5 to changes in key input parameters.

Taken together, the two parts of this chapter inform the considerations developed in the following chapter, which focused on policies that can help ensure that new mobility improves is rolled out in a way that delivers net benefits for energy and climate outcomes.

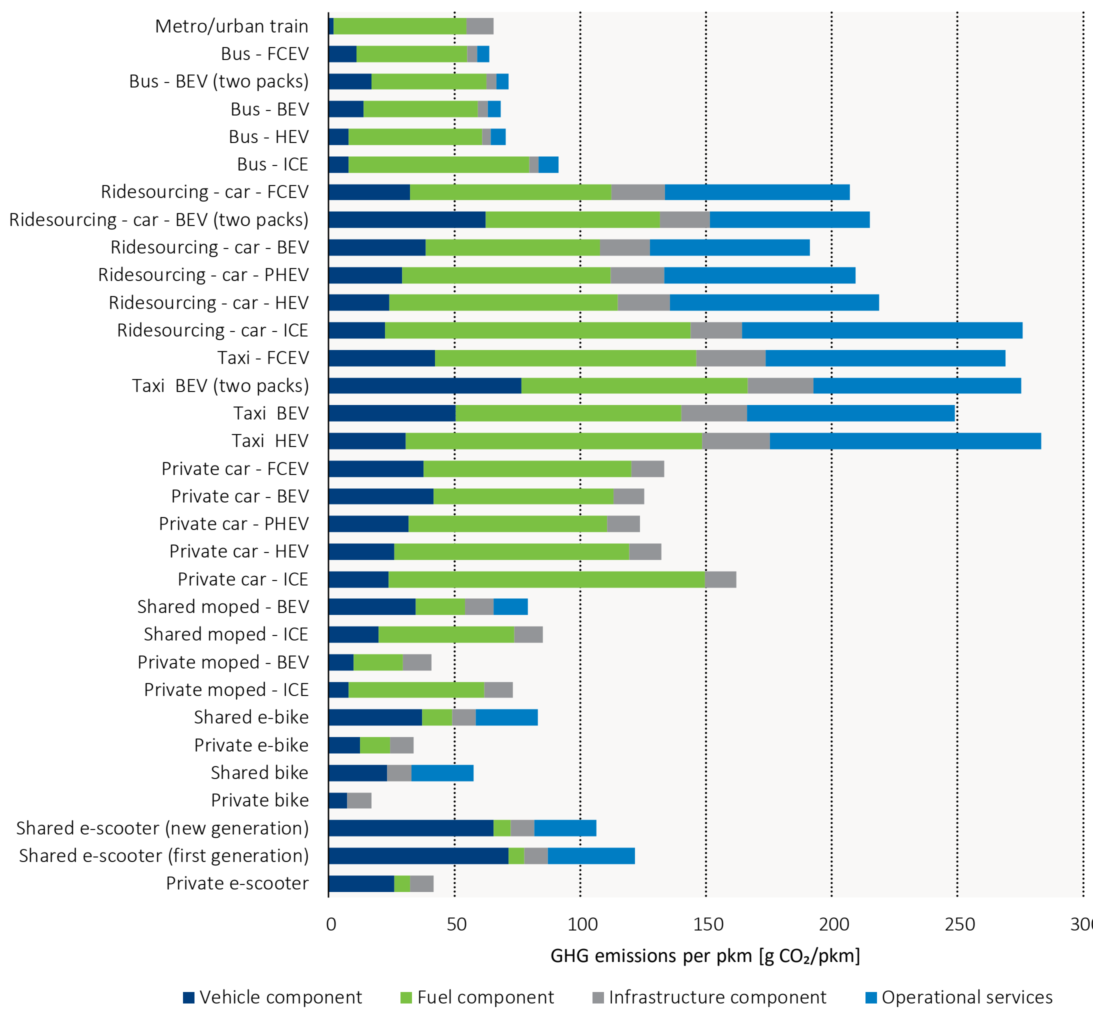
Energy use and carbon dioxide emissions of new mobility versus other transport options

The assessment shown in Figure 2 to Figure 5 was developed in an attempt to give a representative picture of the current situation of the global energy and transport system (hence the *central* estimate terminology), accounting for the following high-level assumptions (additional details are available in Annex A):

- The carbon intensity of petroleum fuels due to oil extraction and refining reflects a global average value of 15.4 g CO_2/MJ and does not differentiate between specific types of primary resources.[18]
- The electricity generation mix reflects the global average in 2017 (IEA, n.d.).
- Hydrogen is derived from steam methane reforming of natural gas, without carbon capture and storage.
- The carbon intensity of battery manufacturing accounts for a large reliance on coal-based electricity for aluminium smelting, which translates in a carbon intensity of 93 kg CO_2/kWh of pack capacity. This is due to the concentration of battery production in Asia, the large reliance of China on coal for electricity generation and the need for electricity to produce aluminium. Coal-based electricity has been considered also for the production of other aluminium used in vehicle manufacturing (this is a conservative assumption, given that aluminium is also obtained from hydroelectricity).[19]
- The vehicle weight and electric vehicle (EV) battery capacities are summarised in Table 1, vehicle mileages and lifetimes are summarised in Table 2, and the latter also includes information on passengers per vehicle and the type of vehicle required to provide operational service.

- All-electric driving shares for plug-in hybrid electric vehicles (PHEV) are assumed to be 66% in case of private cars (i.e. reflecting a sub-optimal use of the battery capacity, in comparison with the utility factors available from the Worldwide Harmonised Light Vehicles Test Procedure of the United Nations, which would suggest values closer to 90%) and 36% for ridesourcing cars and taxis (due to battery capacity limitations to cover daily travel).

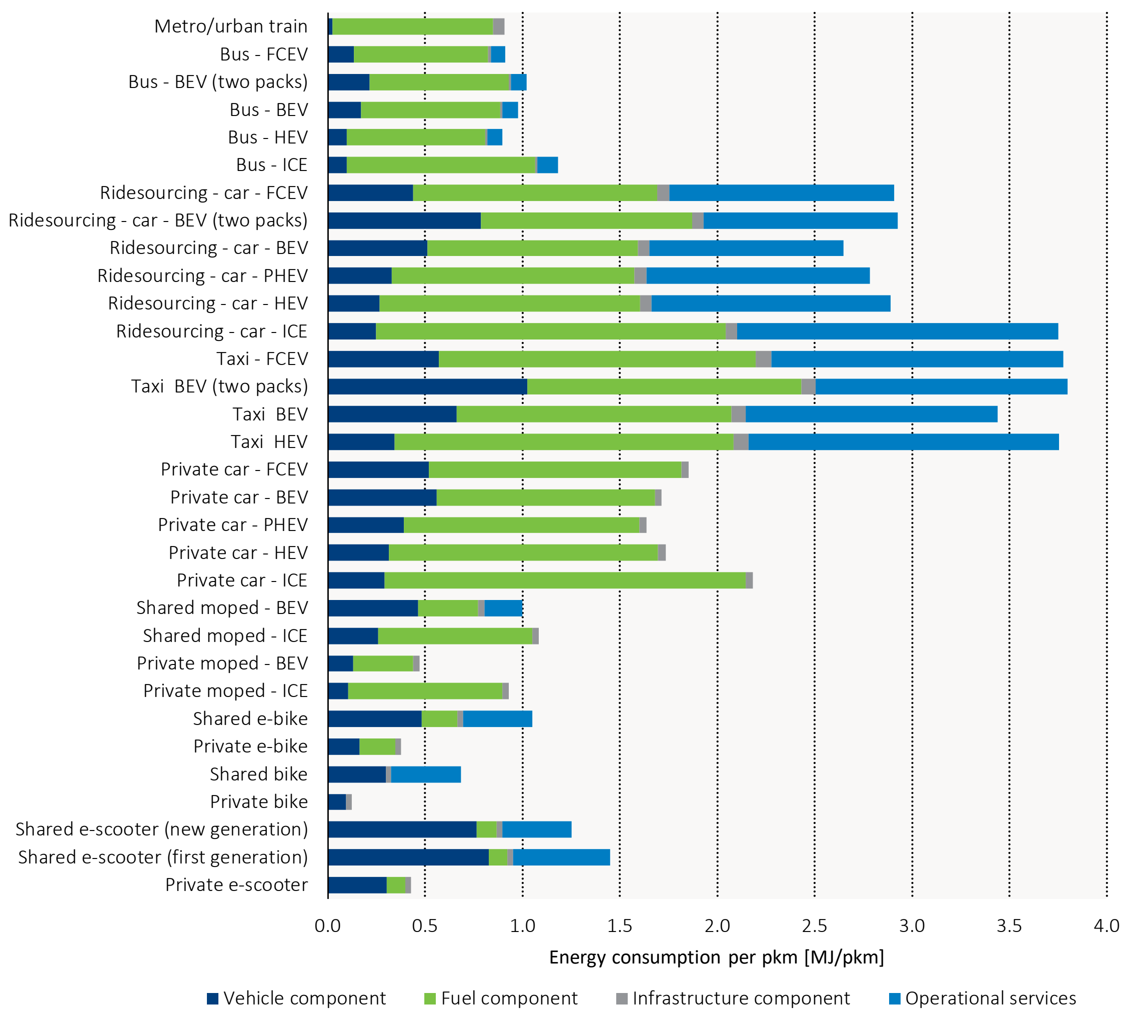
Figure 2. Central estimates of life-cycle greenhouse gas emissions of urban transport modes per pkm



Notes: BEV = battery electric vehicle; HEV = hybrid electric vehicle; ICE = internal combustion engine; FCEV = fuel cell electric vehicle; PHEV = plug-in hybrid electric vehicle. These estimates have been developed using key inputs (such as average number of passengers, the electricity mix and the ratio of operational km per active km) defined by global averages (see Annex A for further details and source used) observed prior to the Covid-19 pandemic. Specific circumstances occurring in different world regions, changes in operational practices and the Covid-19 pandemic should therefore be modelled as individual specific cases, modifying input data accordingly. Sensitivity results are presented in the following sections of this report.

ITF analysis is based on an assessment tool developed for this project and available at https://www.itf-oecd.org/good-to-go-environmental-performance-new-mobility. See Annex A for methodological details and data sources.

Figure 3. Central estimates of life-cycle energy requirements of urban transport modes per pkm

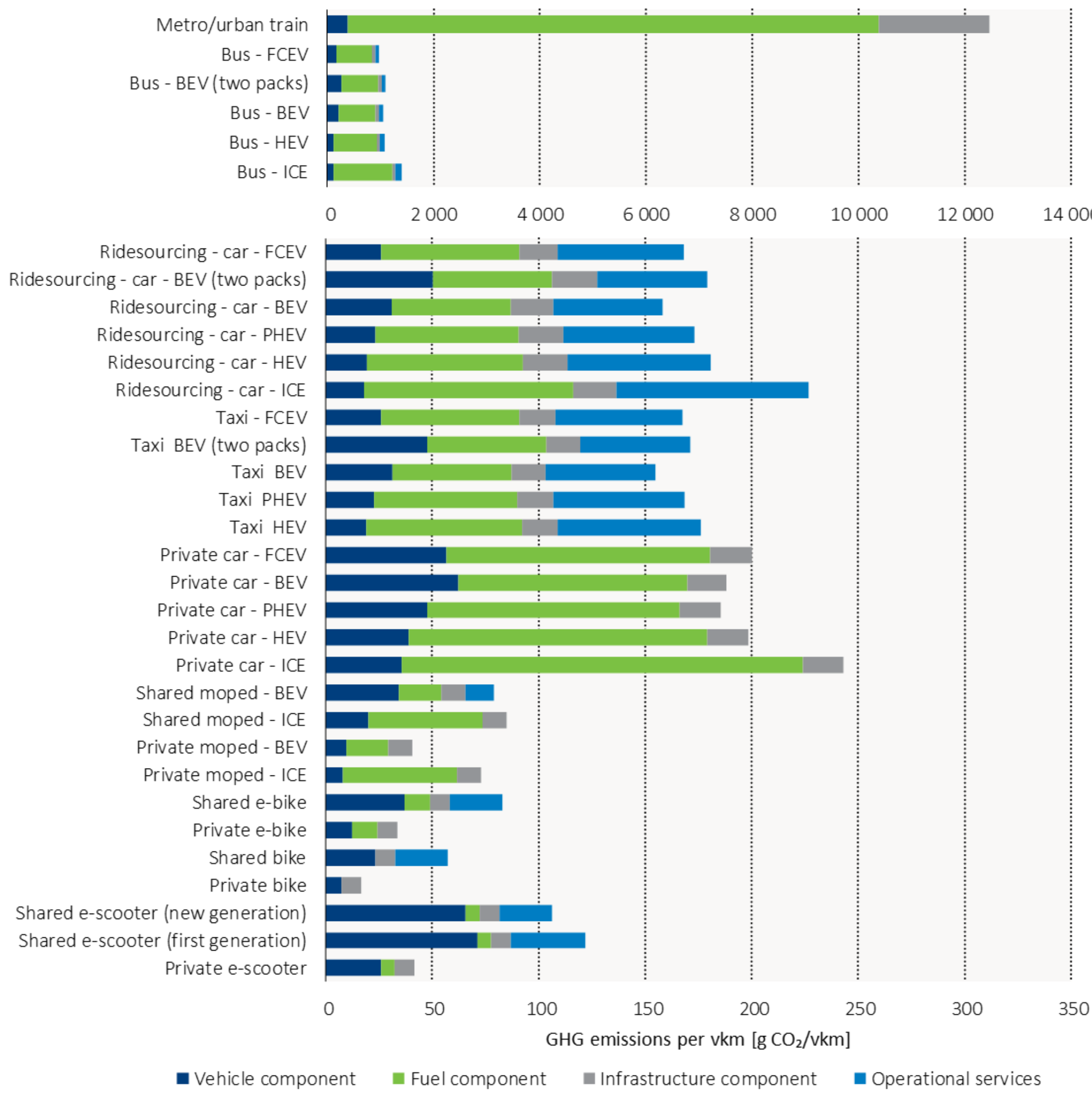


Notes: BEV = battery electric vehicle; HEV = hybrid electric vehicle; ICE = internal combustion engine; FCEV = fuel cell electric vehicle; PHEV = plug-in hybrid electric vehicle. These estimates have been developed inputs (such as average number of passengers, the electricity mix and the ratio of operational km per active km) defined by global averages (see Annex A for further details and source used) observed prior to the Covid-19 pandemic. Specific circumstances occurring in different world regions, changes in operational practices and the Covid-19 pandemic should therefore be modelled as individual specific cases, modifying input data accordingly. Sensitivity results are presented in the following sections of this report.

ITF analysis is based on an assessment tool developed for this project and available at https://www.itf-oecd.org/good-to-go-environmental-performance-new-mobility. See Annex A for methodological details and data sources.

Figure 4 and Figure 5 show central estimates of life-cycle GHG emissions and energy requirement using vkm rather than pkm as the functional unit and differentiating among the same components considered for Figure 2 and Figure 3.

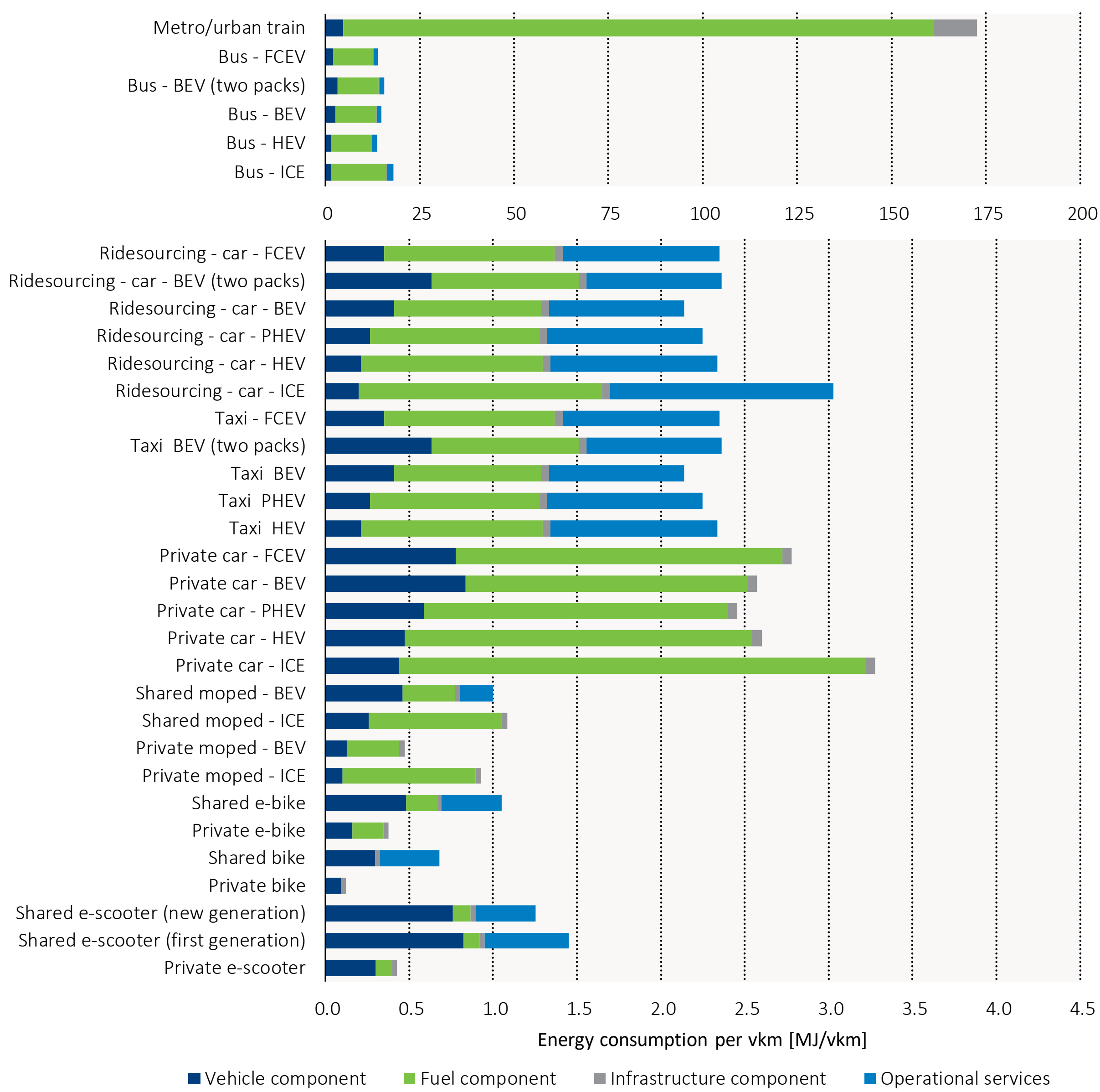
Figure 4. Central estimates of life-cycle greenhouse gas emissions of urban transport modes per vkm



Notes: BEV = battery electric vehicle; HEV = hybrid electric vehicle; ICE = internal combustion engine; FCEV = fuel cell electric vehicle; PHEV = plug-in hybrid electric vehicle. These estimates have been developed inputs (such as average number of passengers, the electricity mix and the ratio of operational km per active km) defined by global averages (see Annex A for further details and source used) observed prior to the Covid-19 pandemic. Specific circumstances occurring in different world regions, changes in operational practices and the Covid-19 pandemic should therefore be modelled as individual specific cases, modifying input data accordingly. Sensitivity results are presented in the following sections of this report.

ITF analysis is based on an assessment tool developed for this project and available at https://www.itf-oecd.org/good-to-go-environmental-performance-new-mobility. See Annex A for methodological details and data sources.

Figure 5. Central estimates of life-cycle energy requirements of urban transport modes per vkm



Notes: BEV = battery electric vehicle; HEV = hybrid electric vehicle; ICE = internal combustion engine; FCEV = fuel cell electric vehicle; PHEV = plug-in hybrid electric vehicle. These estimates have been developed inputs (such as average number of passengers, the electricity mix and the ratio of operational km per active km) defined by global averages (see Annex A for further details and source used) observed prior to the Covid-19 pandemic. Specific circumstances occurring in different world regions, changes in operational practices and the Covid-19 pandemic should therefore be modelled as individual specific cases, modifying input data accordingly. Sensitivity results are presented in the following sections of this report.

ITF analysis is based on an assessment tool developed for this project and available at https://www.itf-oecd.org/good-to-go-environmental-performance-new-mobility. See Annex A for methodological details and data sources.

Table 1. Weight, battery capacities and final energy consumption used for the assessment of life-cycle greenhouse gas emissions and energy intensities

	Vehicle weight (kg)	Battery capacity (kWh)	Final energy consumption (use phase) (MJ/km)
E-scooter (private and first generation shared)	13	0.33	0.04
Shared e-scooter (new generation)	29	0.55	0.04
E-bike	27	0.48	0.08
Shared e-bike	34	0.48	0.08
Moped	100	0	0.6
E-moped	90	1.30	0.13
Shared e-moped	90	2.6	0.13
Car - ICE	1 510		2.3
Car - HEV	1 600	2.1	1.7
Car - PHEV	1 770	15	1.0
Private car - EV	1 810	60	0.7
Taxi and ridesourcing car - EV	1 880	70	0.69
Car - FCEV	1 690	2.1	1.08
Bus - ICE	10 200		10.1
Bus - BEV	14 400	325	4.9
Bus - FCEV	12 300	20	6.5
Metro/urban train	186 000		63.8

Note: ITF analysis is based on an assessment tool developed specifically for this project and available at https://www.itf-oecd.org/good-to-go-environmental-performance-new-mobility. See Annex A for methodological details and data sources.

Table 2. Lifetimes, mileages, loads and service vehicles characteristics used for the assessment of life-cycle greenhouse gas emissions and energy intensities

	Vehicle lifetime (years)	Annual mileage (km/year - active km, including cruising and overheading)	Average number of passengers (pkm/vkm)	Vehicle required to provide operational services (type)
Private e-scooter	3	2 200	1	None
Private bike and e-bike	6	2 400	1	None
Private moped	10	4 900	1	None
Shared e-scooter (first generation)	0.8	2 900	1	Van - ICE
Shared e-scooter (new generation)	2.0	2 900	1	Van - ICE
Shared bike and e-bike	1.9	2 900	1	Van - ICE
Shared moped	3.7	5 300	1.0	Van - ICE
Private car	15	12 100	1.5	None
Ridesourcing car	7	48 000	0.95	Ridesourcing car
Bus	9	44 000	17	Bus
Metro	40	66 000	190	None

Note: ITF analysis is based on an assessment tool developed specifically for this project and available at https://www.itf-oecd.org/good-to-go-environmental-performance-new-mobility. See Annex A for methodological details and data sources.

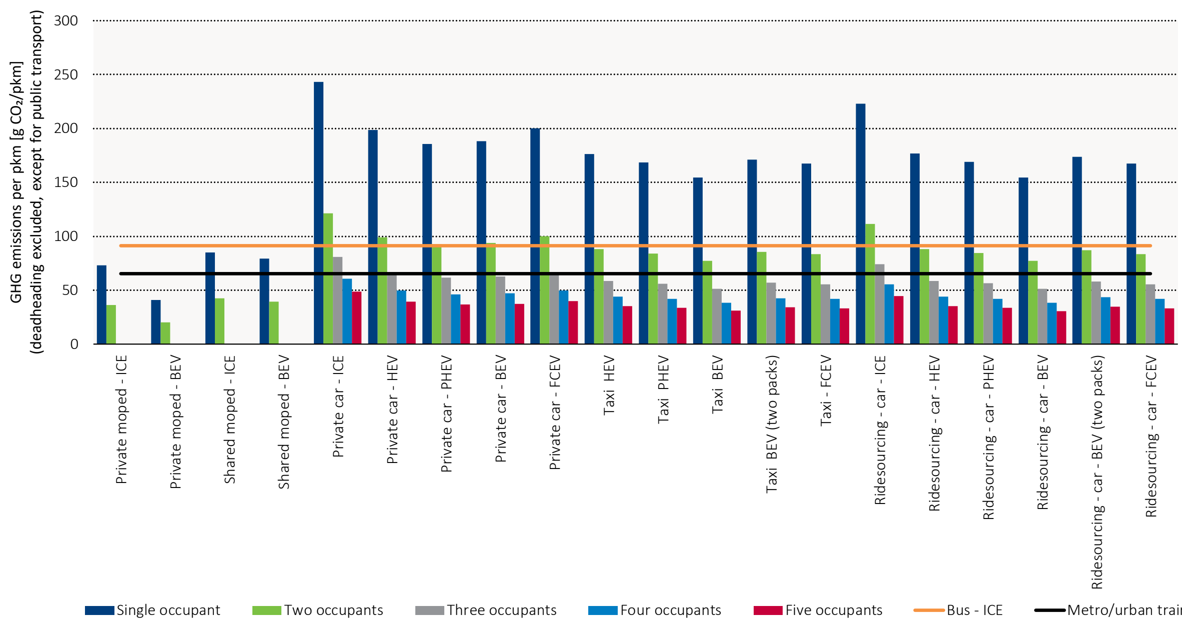
Figures 2-5 can help identify key insights characterising energy and GHG emission impacts for a range of different urban transport options.

- *Private bikes and e-bikes that are regularly used*[20] *have the lowest life-cycle energy requirements and GHG emission impacts per pkm.* This is the effect of low material requirements per vehicle, no external energy required for vehicle operation in the case of private bikes, energy efficient use of electricity for e-bikes and no energy needed for operational services.
- *Taxis and ridesourcing have the highest life-cycle energy requirements and GHG emission impacts per pkm.* This is the effect of impacts per vkm that are comparable with private cars (see Figure 4 and Figure 5: lower lifetimes for ridesourcing cars are more than compensated by higher annual mileage, resulting in higher lifetime mileages for ridesourcing), lower ratios of pkm per vkm due to overheading and cruising, as well as additional emissions for operational services that relate to the need for drivers to commute from/to their residence to/from the area of demand for taxis and ridesourcing services.
- *Private cars' energy and GHG emission impacts per pkm are more than double those of buses and significantly larger than those of any form of micromobility* (mopeds, bikes, e-scooters and metros). Across all private cars, electric and electrified vehicles perform better than vehicles burning fossil fuels in internal combustion engines.
- *Shared e-scooters, mopeds and e-bikes have similar energy and GHG emissions per pkm to private mopeds and buses using fossil fuels in conventional engines and slightly worse energy and GHG emissions per pkm than shared mopeds with the same type of motorisation.* The composition of energy and GHG emissions per pkm and vkm, though, is not homogeneous across these vehicles. Energy and GHG emission impacts per pkm for e-scooters are mainly imputable to the vehicle component (due to a rather low lifetime) and operational services (repositioning and charging).[21] The impacts per pkm are mostly due to the fuel component for vehicles using combustion technologies, and more evenly distributed between the vehicle and the fuel components for electric light vehicles. In addition to e-scooters, operational services also contribute to significant shares of emissions for shared mobility taking place on other types of light vehicles.
- *Energy and GHG emissions per pkm due to the infrastructure component are most relevant for individual vehicles requiring the use of significant amounts of lane km of roads, including parking* (i.e. for private cars)*, as well as taxis and ridesourcing* (not requiring parking, but penalised by the low pkm/vkm ratio). They are less relevant for lighter vehicles that share the road infrastructure with cars in cases with a low frequency of use and require smaller dedicated lanes for higher frequencies of infrastructure use. Buses have the lowest infrastructure-related impacts per pkm due to the high pkm/vkm ratio and intensities of material use per vkm that are similar to cars.
- *Metros and urban trains have a much higher absolute value of the energy and GHG emission impacts when they are measured per vkm than any other mode*.[22] This is essentially due to the large size of the vehicles. The high values are mitigated when measured per pkm due to their high loads.[23]
- *Small and light vehicles are paired with the lowest GHG emissions and energy requirements per vkm for urban transport infrastructure.* This is due to the combination of lower material requirements (due to vehicle and, therefore, infrastructure size and extension) and lower energy and GHG emissions needed for infrastructure maintenance. *Infrastructure-related impacts per pkm are also low for transport modes with high occupancies.*

Variability of results to changes in key input parameters

A first indication on the extent to which changes in the input parameters can affect results is shown in Figure 6, which builds on the information included in Figure 2 to Figure 5. It couples GHG emissions/vkm with a range of different assumptions on vehicle loads (pkm/vkm), clearly showing that increases in vehicle occupancy have the capacity to reduce GHG emissions (and energy)/pkm across all modes.

Figure 6. Life-cycle GHG emissions/pkm with different assumptions on occupancy



Notes: BEV = battery electric vehicle; HEV = hybrid electric vehicle; ICE = internal combustion engine; FCEV = fuel cell electric vehicle; PHEV = plug-in hybrid electric vehicle. Deadheading is excluded (except for public transport) by the way the number of occupants is defined, but these results could also be interpreted in a way that include deadheading travel (one occupant means that the vehicle is always transporting a single passenger or that it moves two passengers for 50% of the distance, while the other 50% is driven empty, for example).

ITF analysis is based on an assessment tool developed for this project and available at https://www.itf-oecd.org/good-to-go-environmental-performance-new-mobility. See Annex A for methodological details and data sources.

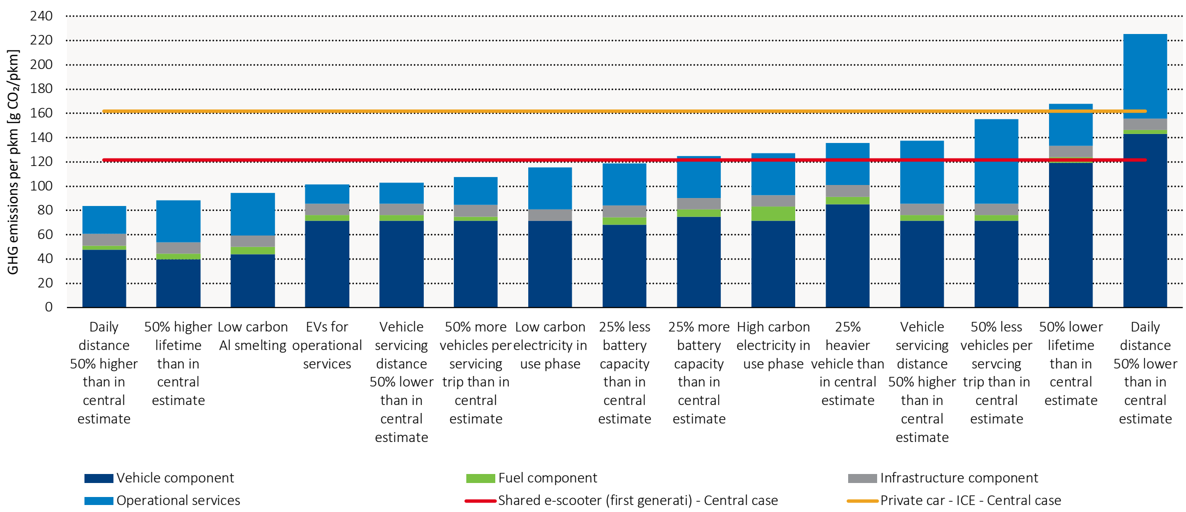
The following sections explore the effects of sensitivities of the results to changes of the input parameters, looking specifically at the cases of micromobility, private cars, ridesourcing and public transport.

The analysis developed here focuses primarily on changes related to average values that characterise different transport options. It also does not aim to discuss impacts due to the high variability of usage, e.g. due to peak vs. off-peak times, for public transport. The implicit consequence of these choices is that the analysis developed here excludes cases where the scope of adoption of different transport options is unlikely to be large. This is either because of poor quality (overcrowded and/or infrequently scheduled services) or because of a limited economic viability (e.g. public transport provision in low-density developments, with subsequent low rates of use of available seat km, and/or underutilised rail infrastructure).[24]

Micromobility

Figure 7 shows GHG emission impacts per pkm for a range of sensitivity cases related to first-generation shared e-scooters, a popular micromobility option, comparing them against the benchmark of the values identified for the central estimates of Figure 2 to Figure 5 for e-scooters and private cars powered by internal combustion engines.

Figure 7. Life-cycle greenhouse gas emissions of first-generation shared e-scooters: sensitivity to changes in key input parameters



Note: Al = aluminium; EV = electric vehicle.

ITF analysis is based on an assessment tool developed for this project and available at https://www.itf-oecd.org/good-to-go-environmental-performance-new-mobility. See Annex A for methodological details and data sources.

The sensitivity cases explored in Figure 7 look at changes in the average daily distance, the average vehicle life, the number of vehicles per servicing trip (i.e. each trip needed to pick up, charge and/or reposition the shared e-scooters), the average distance travelled by servicing trips and the carbon intensity of the electricity used by these vehicles. Figure 7 also explores the impact of: 1) changes in the powertrain technology of vehicles used for servicing purposes (and, in particular, a switch to EVs); 2) changes in the carbon intensities of batteries (by assuming that the aluminium needed in the batteries is obtained from low-carbon electricity, rather than coal); 3) changes in battery capacity and; 4) the effects of changes in vehicle weight (e.g. to reflect vehicle redesigns aiming to extend lifetimes).

Key insights emerging from Figure 7 include the following:

- Changes in the average daily distance covered by e-scooters have very significant impacts on GHG emission and energy impacts per km, so that a micromobility vehicle that is used more during the day will have a lower impact per km (all else being equal). These changes are primarily due to the way the impacts of the vehicle cycle and operational services are allocated to vkm and pkm, far larger than the direct impacts related with changes in energy use.
- Changes in the average life of the e-scooter also have significant implications for GHG and energy impacts. This is primarily due to the way emissions from vehicle production are allocated to each vkm, since lower lifetimes also mean lower lifetime mileages.

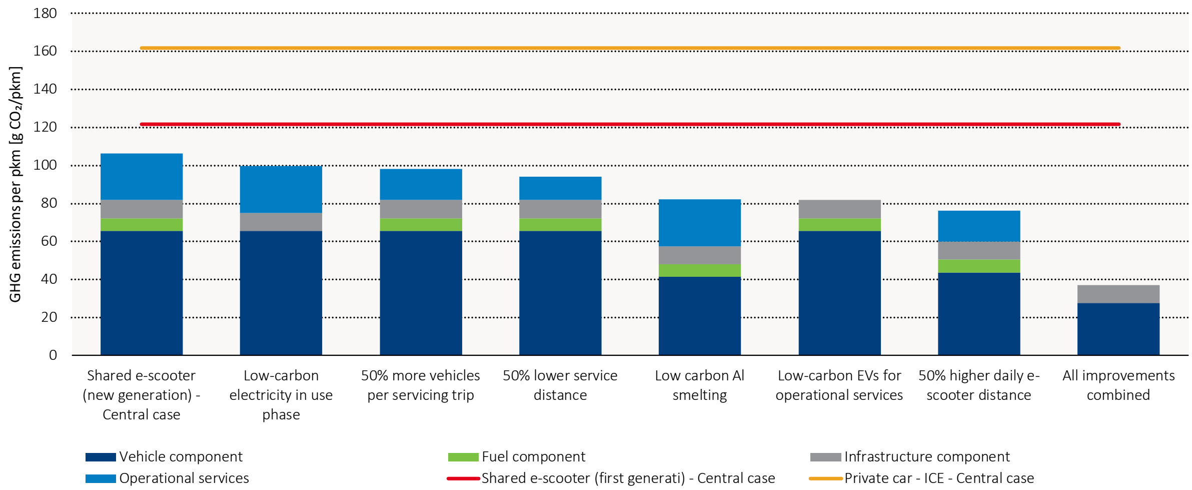
- Changes in operational practices, in particular the minimisation of the ratio of servicing vehicle km to e-scooter km (achievable with increases in the average number of e-scooters per service vehicle trip or the reduction of service trip distances, or both) lead to net improvements in terms of energy and GHG emission impacts.
- The adoption of technologies that reduce the carbon intensity of material production, such as a greater use of recycled metals (e.g. aluminium or steel) and low-carbon processes for the production of the materials needed in vehicles (with the case of a lower carbon intensity in aluminium smelting actually represented in Figure 7) can offer significant savings in terms of GHG emission/pkm. This is due to the high relevance, for e-scooters, of the vehicle component for the determination of life-cycle GHG emissions and energy use.
- Switching to service vehicles that consume less energy and emit no tailpipe GHG emissions per vkm (EVs rather than ICE vehicles, in the example considered in Figure 7) is also an effective way to mitigate energy and GHG emission impacts per pkm. Other vehicles – including dedicated ones such as cargo bicycles – can also be very effective, provided that they have a high enough usage rate (necessary to limit the emissions due to manufacturing and materials).
- Increases in vehicle weight lead to net increases in energy and GHG emissions/pkm, unless they are countered by effective improvements in terms of lifetime extension (a combination that is not explicitly represented in Figure 7).

These insights are aligned with some of the actions taken by many micromobility companies to reduce the energy and environmental impacts of e-scooters, including, in particular through, vehicle redesigns aimed at increasing vehicle lifetimes (Hawkins, 2020; Schuller and Aboukrat, 2019) and changes in servicing vehicles (e.g. switching to companies rather than freelancers, as reported in Dillet [2019]). Figure 8 illustrates the impact of a number of improvements recently introduced in the new generation of shared e-scooters. In particular, the central estimate of Figure 8 (also shown in Figure 2 to Figure 5) accounts for the higher weight of new e-scooters, design improvements aiming to extend vehicle lifetime (by reducing the impact of tampering and vandalising) and the reliance on larger batteries (with the option of making them swappable). Figure 8 also shows the effects of the application of further improvements to design, operational and use parameters, showing that there are margins to improve current energy and GHG emissions/pkm and that these margins are significant if multiple improvements are implemented at the same time.

The case of battery swapping as an option for reducing energy and GHG impacts of e-scooters per pkm (and reduce costs) is one of the design improvements that emerged recently in some of the new e-scooters (see, for example, TIER Mobility [2019] and Gauquelin [2020]). The actual impact of battery swapping on energy and GHG emissions/pkm depends on the details of how it is designed and implemented. Switching to swappable batteries increases the number of overall batteries (and battery management systems) required to operate the e-scooter fleet. This increases the overall energy and GHG emissions/pkm.

On the other hand, battery swapping can also lead to reductions in energy and GHG emissions/pkm. This happens if battery swapping reduces the ratio of service vehicle km per e-scooter km and eases the reliance on energy-efficient and low-emission vehicles. As such, it is also a potential enabler of e-scooter lifetime extensions and improvements in the efficiency of operational services.

Figure 8. Life-cycle greenhouse emissions of the new generation of shared e-scooters and effects of further improvements for their further reduction



Note: Al = aluminium; EV = electric vehicle.

ITF analysis is based on an assessment tool developed for this project and available at https://www.itf-oecd.org/good-to-go-environmental-performance-new-mobility. See Annex A for methodological details and data sources.

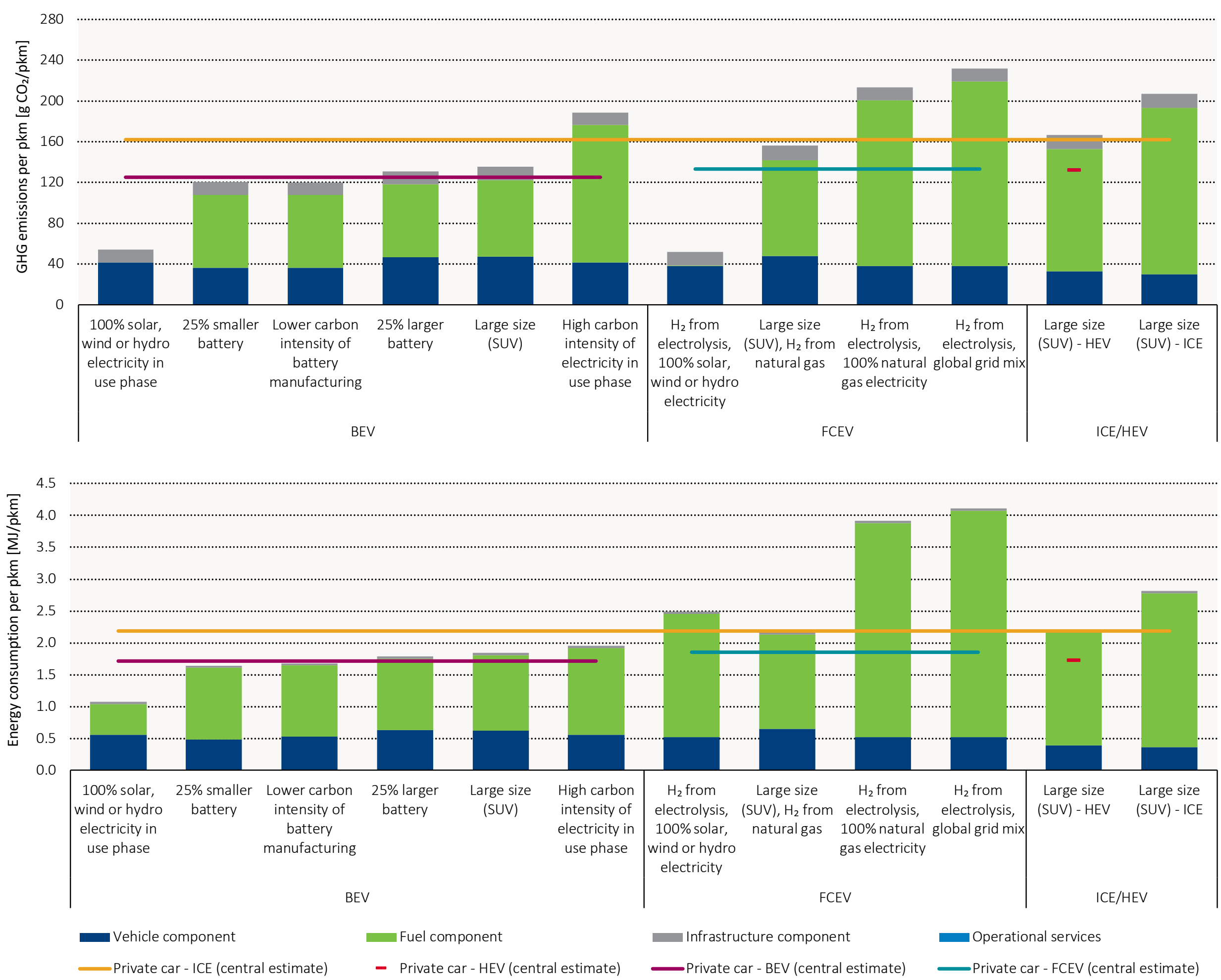
The capacity of battery swapping to lead to net energy and GHG emission savings also depends on details related to design characteristics. For example, swappable batteries can be targeted for theft and may be subject to a higher risk of damages related with their handling processes or water infiltration. The net balance for energy and GHG emissions also depends on the characteristics of design solutions that would be adopted as an alternative to battery swapping. For example, opting for larger battery packs as an alternative to battery swapping ends up increasing the CO_2 emissions due to the vehicle component of the life cycle.

Private cars

Figure 9 focuses on sensitivity results for private cars, exploring impacts of changes in:

- input values related to battery size, the carbon intensity of battery manufacturing (through changes in the production process of aluminium), the vehicle size and the carbon intensity of electricity in the use phase for battery electric vehicles
- inputs characterising the way hydrogen is produced and the vehicle size of fuel cell electric vehicles
- inputs related to vehicle size for hybrid electric and internal combustion engine vehicles.

Figure 9. Life-cycle greenhouse gas emissions and energy/pkm of private cars: sensitivity to changes in vehicle size, fuel production pathways and, for BEVs, battery pack size



Notes: BEV = battery electric vehicle; FCEV = fuel cell electric vehicle; HEV = hybrid electric vehicle; ICE = internal combustion engine; SUV: sport utility vehicle.

ITF analysis is based on an assessment tool developed for this project and available at https://www.itf-oecd.org/good-to-go-environmental-performance-new-mobility. See Annex A for methodological details and data sources.

The results illustrated in Figure 9 show that:

- Larger vehicles require more fuel to move and more materials – this is why increases in vehicle size (and weight) lead to more GHG emissions and energy use from the LCA fuel and vehicle components. These increments are largest for non-electrified powertrains and are lowest for battery electric cars. This is primarily due to the possibility, for electrified powertrains, to recover energy through regenerative braking mechanisms.[25]
- A shift to low carbon electricity significantly reduces GHG emissions/pkm in the in-use phase (fuel component) for BEVs and FCEVs, despite residual emissions due to manufacturing (reducing the latter requires a transition to low carbon industrial processes related to material extraction, refinement, processing and assembly to also experience reductions).
- Even if BEVs and FCEVs powered by hydro-, solar and wind electricity in the in-use phase have similar GHG emissions per km, life-cycle energy (mostly electricity) requirements per pkm are far higher in the case of FCEVs using "green" hydrogen (i.e. hydrogen derived from solar and wind energy). Energy per pkm is even higher for hydrogen production when accounting for electrolysis and the generation of electricity required for electrolysis, given the additional losses taking place in the upstream conversion of other primary energies into electricity.[26]
- For FCEVs to display similar life-cycle impacts as BEVs on GHG emissions, the carbon intensity of the electricity needed for the production of hydrogen must be much lower than the one needed by battery electric vehicles. This is due to the far better life-cycle thermodynamic efficiency of BEV electric motors, batteries, chargers, electricity production and transport versus FCEV powertrains, hydrogen storage tanks, refuelling infrastructure, production from electricity and transport.
- Lower battery capacities, as well as reductions in the carbon intensity of aluminium production (leading to carbon intensities of battery pack production, assembly and disposal of 75 kgCO_2/kWh, in the case shown in Figure 9) result in a net reduction of GHG emissions per pkm for BEVs. These effects are mitigated by the relatively small share of GHG emissions from the vehicle component (unless electricity is from low-carbon sources) and by the partial relevance of battery manufacturing within this component.

Other significant GHG reduction pathways include both technical and operational solutions that have not been represented in Figure 9. In particular, this is the case when:

- there are increases in vehicle loads, which can also deliver life-cycle energy efficiency improvements
- there is a transition to low-carbon fuels for combustion engines (also viable for hybrid electric vehicles), a possibility enabled by low-carbon fuels, including biofuels that meet carbon intensity criteria such as those included in Europe in the last update of the Renewable Energy Directive (RED II, 2018/2001/EU)[27] and synthetic fuels.[28] The latter include certain forms of advanced biofuels, as well as electrofuels (see Box 2 for additional details).

In the case of low-carbon fuels, it is also important to acknowledge that GHG emission savings are generally associated with higher life-cycle energy consumption. This is due to the higher amounts of energy needed for their production, in comparison with the extraction and refining of petroleum fuels.

Box 2. Low-carbon synthetic fuels

Synthetic fuels are obtained from the chemical synthesis of hydrogen and carbon (from different biological and non-biological origins) or nitrogen. There are many potential pathways available that produce fuels in gaseous (methane) or liquid forms (methanol, gasoline, diesel, kerosene and liquid ammonia) such as gasification, pyrolysis or the new concept of power-to-fuels or so called *electrofuels* (combining low-carbon hydrogen from either diluted or concentrated sources of renewable carbon).

Key advantages of synthetic hydrocarbons that can be direct substitutes for their fossil equivalents (e.g. synthetic diesel) include:

- A CO_2 abatement potential can be as high as approximately 85-96% during their production phase (JEC, 2019).
- The possibility to be used as drop-in fuels, i.e. direct substitutes of their fossil equivalents, thanks to properties that can be tailored to be fully compatible with existing infrastructure, storage, distribution and vehicles. This could come with important benefits for both energy and GHG emission impacts, since the use of existing infrastructure would effectively limit material and energy requirements that would otherwise be necessary for the deployment of new infrastructure.

However, there are still significant barriers in the chain to leverage the full potential of these synthetic fuels in the future. In the case of biomass and waste-based fuels, some of the key enablers are identified across the whole production chain, from ensuring and maximising sustainable feedstock availability and resource mobilisation to the production sites to additional research and development to boost development and scale up of the technologies with a lower technology readiness level. When the synthetic fuel routes are explored in detail, the main limiting factors are the large thermodynamic losses that take place across their production and use.

A first source of thermodynamic losses relates to the need to produce low-carbon hydrogen, since low-carbon hydrogen is a key feedstock for the synthesis process needed to produce low-carbon electrofuels. These losses are related either to the conversion of electricity into hydrogen through electrolysis or the synthesis of hydrogen from methane, only considered as a low-carbon route in cases where the capture and storage of fossil carbon is possible.

A second source of thermodynamic losses relates to the need to combine low-carbon hydrogen with carbon molecules that are part of a circular loop. Some of the main potential sources of carbon as feedstock include, for example, carbon derived from biomass (where the closed loop is achieved through the absorption of the atmospheric carbon while plants grow) or the "direct air capture" of CO_2 (consisting of processes that separate atmospheric CO_2 to obtain carbon that is then used for the chemical synthesis enabling the production of electrofuels). In both cases, additional thermodynamic losses arise from the need to convert the primary source of carbon (biomass or CO_2) into carbon monoxide that enters the synthesis process allowing the production of electrofuels.

A third source of thermodynamic losses relates to the fact that synthetic fuels are used in internal combustion engines, inherently subject to limitations with respect to thermodynamic efficiency, even if this is partly mitigated by the energy efficiency improvements offered by hybridisation.

Due to the significant thermodynamic losses and the multiple conversions required for their production, producing electrofuels at scale would require very large amounts of low-cost and low-carbon electricity, far beyond those needed in systems where electricity is stored in batteries and used in electric motors. Losses and production complexity are also important limiting factors in terms of production costs.

Nevertheless, there could be specific situations that could allow power-to-liquid fuels to be economically efficient when compared to alternatives with lower technical losses. An example is the case of hydrogen production in locations with high solar and wind energy endowment (given their declining costs) possibly complemented by nuclear or hydro-power generation, since these options could improve costs of production for synthesis options less able to cope with variable hydrogen supply. Also to be considered is the use of blue hydrogen (produced from steam reforming of methane and associated with a carbon capture and sequestration system), as natural gas is widely available at a low cost. These two options can be also combined in specific regions where they are available to facilitate a transition while the renewable electricity production capacities increase.

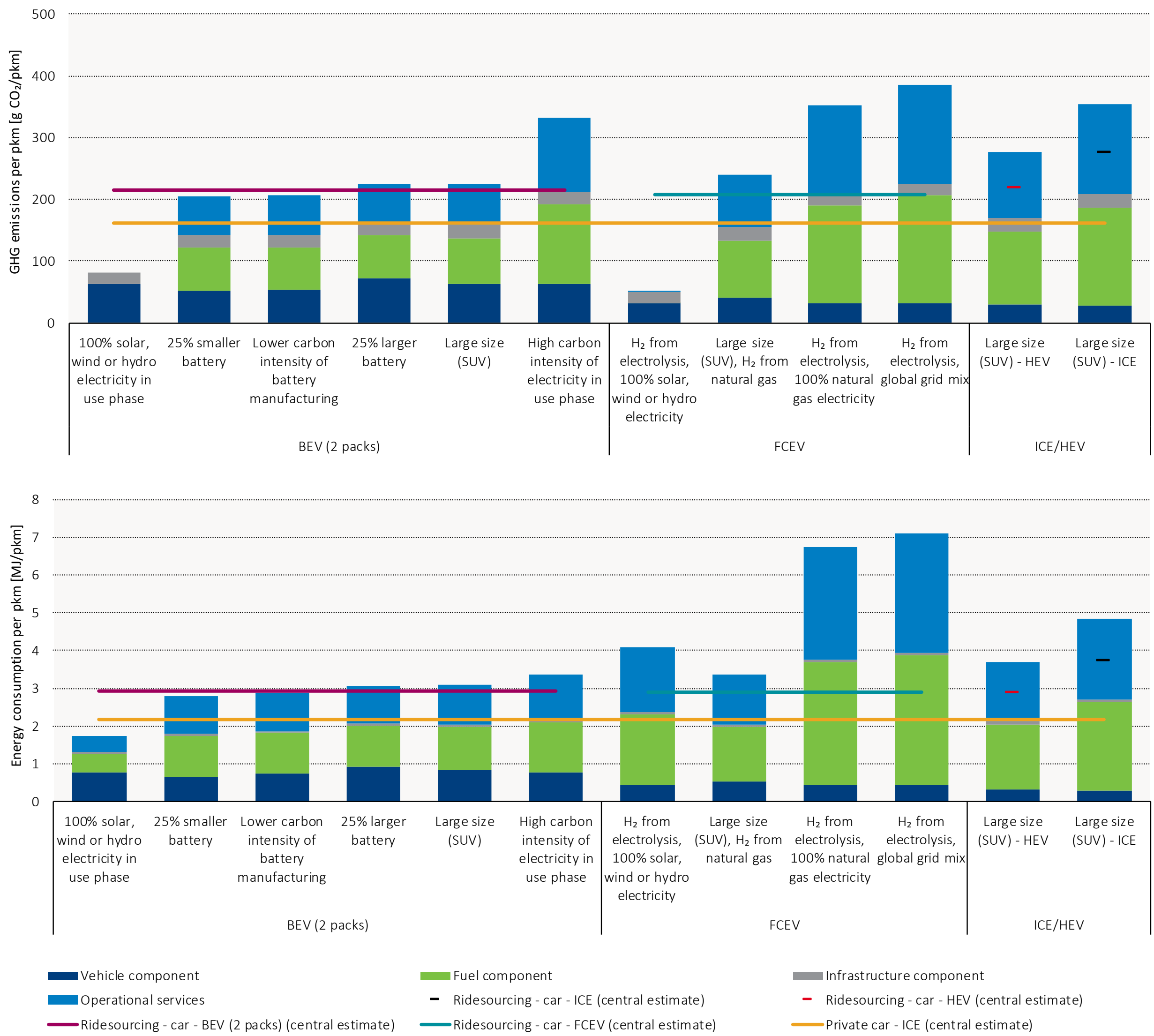
Due to the considerations mentioned above, both positive and negative, the potential role of synthetic fuels in the future is still debatable, but despite their high energy consumption, they are currently explored as a potential fuel alternative in the long-term strategy of different countries to achieve climate neutrality – e.g. the report issued by the European Commission in 2018 entitled *A Clean Planet for All* (EC, 2018), especially in the case of long-distance transport applications, such as aviation and shipping.

Ridesourcing

Figure 10 considers the same changes in input values already taken into account in Figure 9, but it focuses on ridesourcing services rather than private cars. As in the case of Figure 7 to Figure 9, Figure 10 includes reference benchmarks of the central estimates of GHG emissions and energy/pkm of private cars powered by ICEs (the latter are also shown in Figure 2 and Figure 3). Given the large mileage considered in the central case for ride hailing services (400 000 km over the full vehicle life), the case of a BEV represented in Figure 10 assumes the need for two battery packs across the whole life of the vehicle.

The results in Figure 10 are complemented by a range of additional sensitivity cases for ridesourcing services, shown in Figure 11. These take into account impacts related to changes in ridership and the ratio of deadheading distance and distance with passengers on board. Since the proportions of the impacts of these changes do not vary when looking at GHG emissions or energy/pkm, Figure 11 focuses exclusively on GHG emissions/pkm.

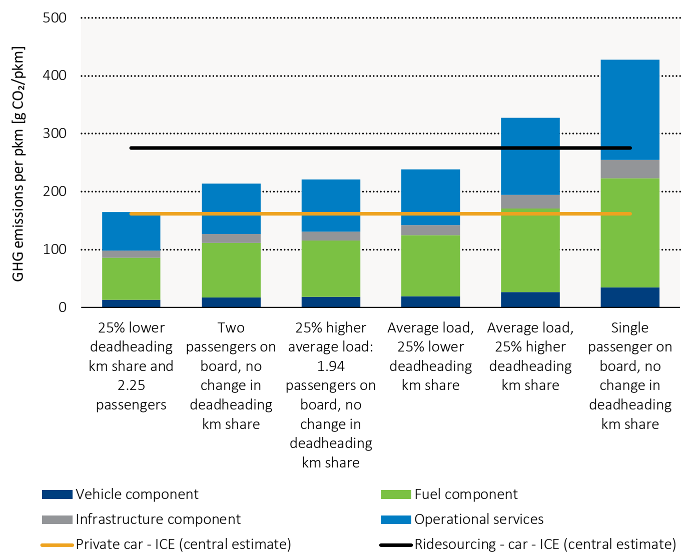
Figure 10. Life-cycle GHG emissions and energy/pkm of ridesourcing cars: sensitivity to changes in vehicle size, fuel production pathways and, for BEVs, battery pack size



Notes: BEV = battery electric vehicle; FCEV = fuel cell electric vehicle; HEV = hybrid electric vehicle; ICE = internal combustion engine; SUV: sport utility vehicle.

ITF analysis is based on an assessment tool developed for this project and available at https://www.itf-oecd.org/good-to-go-environmental-performance-new-mobility. See Annex A for methodological details and data sources.

Figure 11. Life-cycle GHG emissions/pkm of ridesourcing cars: Sensitivity to changes in ridership and the ratio of deadheading and total distance travelled



Note: all cases refer to ICE vehicles.

ITF analysis is based on an assessment tool developed for this project and available at https://www.itf-oecd.org/good-to-go-environmental-performance-new-mobility. See Annex A for methodological details and data sources.

The results in figures 10 and 11 show that four main strategies can provide effective contributions to reducing the high life-cycle GHG emission impacts per pkm of conventional ridesourcing services:

- a switch to BEVs or FCEVs, especially when electricity or hydrogen are obtained from renewable or other forms of energy with very low carbon intensity
- a significant occupancy increase during the portion of ride hailing trips carrying passengers
- a reduction of the ratio between deadheading and total distance travelled
- the combined adoption of all solutions cited above.

With the exclusion of FCEVs (which are limited by thermodynamic losses for hydrogen production), these solutions can also reduce energy use per pkm.

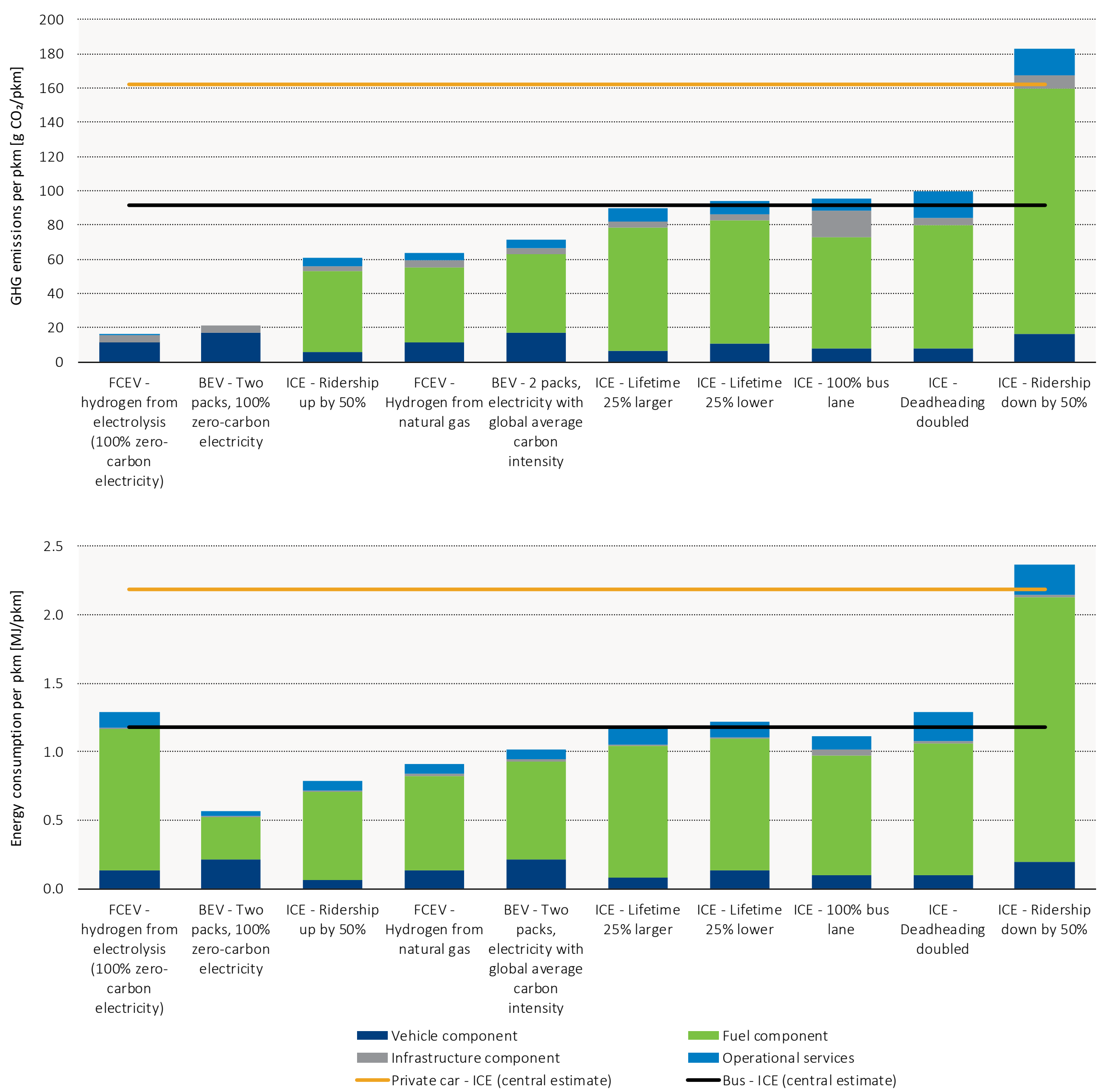
Figure 10 and Figure 11 also confirm the following conclusions of Figure 9: the net increases of energy and GHG emissions per car km a from size and weight increase; the net savings (even if limited in magnitude) due to reductions in battery capacity and the use of less carbon-intensive battery manufacturing technologies; and the much stronger requirements, for FCEVs, to rely on low-carbon hydrogen production pathways, in comparison with BEVs, for the same level of GHG emissions/pkm.

As in the case of private cars, a transition to low-carbon fuels can also help achieve net reductions of GHG emissions per pkm for ridesourcing vehicles. These include biofuels that meet sustainability criteria (namely advanced biofuels based on cellulosic biomass and biofuels relying on waste as feedstock – e.g. used cooking oil) and synthetic hydrocarbons, provided that the hydrogen is from low-carbon energy sources and the carbon is renewable or part of a closed loop. In the case of synthetic hydrocarbons, the energy/pkm limitations already flagged for FCEVs and hydrogen are further exacerbated by additional thermodynamic losses in the production process and the lower thermodynamic efficiency of ICEs.

Public transport

Sensitivity results for buses are illustrated in Figure 12. Figure 13 focused on metros and urban trains. Both look at the impacts on GHG emissions/pkm due to variations in ridership and vehicle lifetime. Figure 12 considers the cases of higher amounts of deadheading kilometres and a full reliance on dedicated bus lanes, it includes key examples of fuel/powertrain technology switching (namely to BEVs and FCEVs, also with zero carbon electricity) and also shows energy consumption per pkm of each case. Figure 13 also includes results related to changes in the lifetime of rail infrastructure.

Figure 12. Life-cycle GHG emissions/pkm of buses: sensitivity to changes in selected input parameters

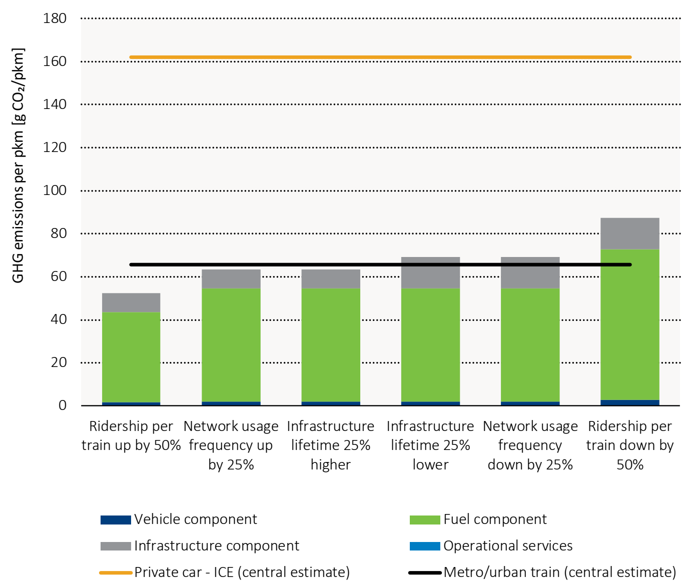


Note: BEV = battery electric vehicle; FCEV = fuel cell electric vehicle; ICE = internal combustion engine.

ITF analysis is based on an assessment tool developed for this project and available at https://www.itf-oecd.org/good-to-go-environmental-performance-new-mobility. See Annex A for methodological details and data sources.

Figure 12 and Figure 13 show that, in the case of public transport, most of the sensitivity changes lead to limited variations of the GHG emission impacts, especially if compared with the magnitude of GHG emissions for private cars. Lower ridership, higher deadheading, the use of dedicated lanes, lower vehicle life, lower infrastructure life and increased frequency all lead to small relative increases in GHG emissions per pkm. The impact of lower ridership is particularly relevant for public transport operators weighing responses to Covid-19. Increases in ridership, vehicle and infrastructure lifetime and decreased frequency all lead to relative reductions in GHG per pkm. Dedicated lanes come with net energy savings thanks to lower energy use per vkm due to smoother traffic, but also greater emissions and energy use from the infrastructure component due to lower frequencies of use of dedicated lanes vs. conventional road space.

Figure 13. Life-cycle greenhouse gas emissions/pkm of metros and urban trains: sensitivity to changes in selected input parameters



Note: ITF analysis is based on an assessment tool developed specifically for this project and available at https://www.itf-oecd.org/good-to-go-environmental-performance-new-mobility. See Annex A for methodological details and data sources.

The cases reflecting fuel/powertrain technology switching in Figure 12 broadly confirm the findings that already emerged in the case of cars and ridesourcing, in particular the possibility of BEVs and FCEVs using energy vectors produced from zero carbon electricity to abate signifcantly GHG emissions from buses, and the need for a far larger amount of low-carbon electricity in fuel cell buses if compared with a battery electric bus. A transition to low-carbon fuels for combustion engines (also viable for hybrid electric vehicles) is also a possibility applicable to buses, even if this is not included in Figure 12. When this transition is applied to buses, GHG emission savings are associated with higher life cycle energy consumption in comparison with buses using fuels obtained from oil refining. The extent of this increase depends on the specific low-carbon fuel production pathways considered, as well as the characteristics of the oil resources.

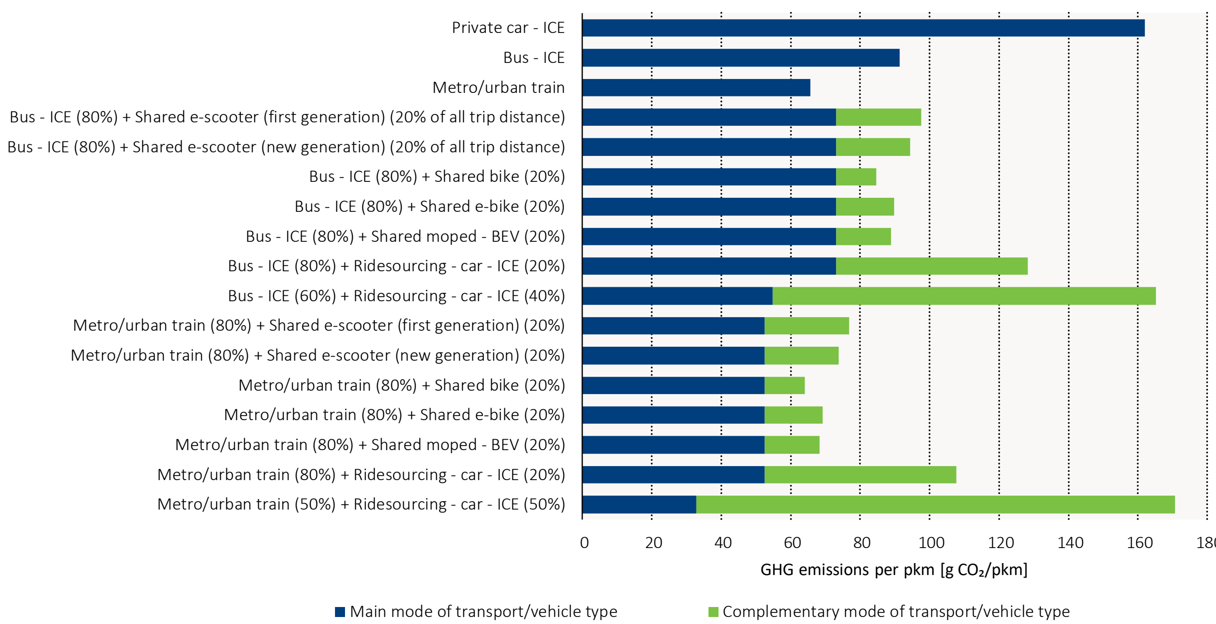
In all cases tested in Figure 12 and Figure 13 that do not concern changes in vehicle technologies or the energy mix, the percent changes in the energy impacts (with respect to the central cases) have the same magnitude of those observed for GHG emissions.

Figure 12 and Figure 13 also show that changes in ridership lead to the largest impacts on GHG emissions/pkm. This is because variations in pkm/vkm affect all the LCA components, while other sensitivity cases considered have impacts only on specific components (vehicle, infrastructure and operations). Reductions in ridership have greater impacts in terms of GHG emissions and energy use/pkm than increases in ridership. As with buses, the impact of lower ridership on metros and trains is particularly relevant in assessing Covid-19 responses in public transport.

Multimodal trips

Urban movements take place over different trip distances and, especially for longer trips, do not always rely on a single mode of transport. Looking at trips that combine different modes of transport adds value to the comparative results outlined in the earlier sections of this report. Figure 14 describes the impact of selected modal combinations on GHG emissions per pkm.

Figure 14. Life-cycle GHG emissions/pkm of selected examples of multimodal trips



Note: BEV = battery electric vehicle; ICE = internal combustion engine. The percentages in the labels refer to the fractions of the total multimodal trip distance.

ITF analysis is based on an assessment tool developed for this project and available at https://www.itf-oecd.org/good-to-go-environmental-performance-new-mobility. See Annex A for methodological details and data sources.

Multimodal trips in Figure 14 focus specifically on the combination of bus and metro or urban rail with shared e-scooters, bikes, e-bikes, electric mopeds and car-based ridesourcing services. This is due to the better performance of public transport in terms of energy and GHG emission impacts (see Figure 2 to Figure 5) and the natural synergies of public transport and shared mobility services in terms of improved accessibility. GHG emissions/pkm for private cars using internal combustion engines are also included in the figure, providing a comparative benchmark.

Two main insights emerge from Figure 14:

- Combining buses or metro and urban trains with different forms of micromobility (shared e-scooters, bikes, e-bikes, electric mopeds) results in a similar level of GHG emissions per pkm as single use of either buses or metro and urban trains, especially when most of the distance is carried out on urban buses (i.e. when other modes have a feeder function).
- Combining ridesourcing with public transport can mitigate the GHG emission and energy use impacts of these services provided that the combined trips actually expand public transport use by displacing car use. Under all the assumptions retained for the central estimates shown in Figure 2 to Figure 5, combining ridesourcing with high capacity transport services like metros and urban trains can maintain GHG emissions/pkm below those of ICE cars if the distance travelled in ICE-car-based ridesourcing services is below half of the total distance.

The replacement of more energy- and GHG emission-intensive taxi, ridesourcing and private car trips is essential to ensure that the combined use of public transport and new mobility actually results in net energy and GHG emission savings.

Even if there are tangible signs of people favouring combined public transport/new mobility trips, the likelihood of new urban transport modes to replace more energy- and GHG emission-intensive taxi and private car trips is far from given.

Modal substitution

This section discusses quantitative indications emerging from surveys of users of ridesourcing, carsharing and micromobility services and related modal substitution, offering an indication of the implications of current consumer preferences. Key indicators are summarised in Table 3.

Table 3. Modal substitution from ridesourcing, carsharing and micromobility

Mode	Country	Modal substitution effect					
		Taxi	Public transport	Cars	Walking	Cycling	Induced travel
Ridesourcing	United States	-39%	-33%	-6%			8%
	France	-27% to -32%	-38% to -45%	-5%			9%
Carsharing	United States		Slight reduction	-10%			-10%
	France		Slight increase	-10%			-10%
Micromobility	United States	-15%	-10%	-15%	-37%	-9%	8%
	France	-4% to -5%	-29%	-4% to -5%	-47%	-12%	3%
	Brazil	-26%	-20%	-14%	-52%		

Note: This review builds entirely on information gathered before the development of the Covid-19 pandemic and does not account for a number of specific effects that the pandemic has had and will likely induce, such as the decline and structural modification of transport demand for rides (including a greater relevance of the delivery segment over passenger movements) during lockdowns, the consequences of social distancing on modal choices during reopening, impacts on cash flow and balance sheets, nor on capital constraints for fast-growing new mobility companies.

Source: ITF analysis basis on Cohen and Shaheen (2016), 6-t (2016), Franckx and Mayeres (2016), Clewlow and Mishra (2017), Rayle et al. (2014), Erich (2018), 6-t (2014), Shaheen and Cohen (2016), Martin, Shaheen and Lidicker (2010), PBOT (2018), Kwak, Alves and Greco, (2019), 6-t (2019a), 6-t (2019b), Bird (2019) and Chen, van Lierop and Ettema (2020).

Bearing in mind the importance of integrating public transport and new mobility to achieve net reductions in energy and GHG emissions per pkm, key insights emerging from this brief overview indicate that:

- Key determinants of public transport supply and demand, including the nature of the built environment and, in particular, public transport infrastructure, population density, job density, street design and land-use mix influence modal choices and the capacity of new mobility modes to complement or compete with established ones.
- Ridesourcing has been used mainly as a substitute for traditional taxi services. It has been competing with public transport and, to a lesser extent, displaced private car travel. This effect is stronger in more car-centric urban environments. While some indicators also show the existence of intermodal travel combining public transport (in particular urban rail) and ridesourcing, to date the extent of this use has been limited.
- Carsharing has proven effective in reducing personal vehicle travel in favour of public transport, even if the extent of its adoption has been less dynamic than that of other new mobility options. Individuals who abandon private vehicle ownership once they join carsharing schemes generally rely on public transport for intermodal trips. This is more effective in compact urban environments where public transport is an economically viable option.
- Micromobility options have limited capacity to displace car travel, but they also have a genuine capacity to be relevant as a segment of longer intermodal trips, increasing the catchment area of public transport (and, therefore, strengthening their capacity to compete with car travel). For micromobility, this is not only true for rail, but also for bus services. Nevertheless, more efforts are needed to ensure the integration of micromobility with public transport.

Ridesourcing

Ridesourcing has been used mainly as a substitute for traditional taxi services. Cohen and Shaheen (2016) report that this is the case for 39% of the trips in San Francisco. 6-t (2016) puts the percentage at 27-32% in Ile de France (the metropolitan area around Paris). Franckx and Mayeres (2016) also argue that the replacement of taxis is the primary effect of ridesourcing.

Public transport is the second mode most replaced by ridesourcing services: about 33% of trips in the United States (Cohen and Shaheen, 2016) and 38-45% in Ile-de-France (6-t, 2016). Clewlow and Mishra (2017) find that ride-hailing users experienced a net decrease in their transit use in the United States, and 6-t (2016) find the same for Ile-de-France. Clewlow and Mishra (2017) find mixed results, depending on the type of transit service, with increases in heavy rail and reductions in other transit services in the United States. 6-t (2016) finds declines in both trains and other public transport services (but considers that the substitution of train rides with ridesourcing tends to be associated with structural developments, such as changes in the place of residence). Net reductions in public transport due to ridesourcing emerge even if some of the ridesourcing trips started or ended in public transport stations: in the survey carried out in San Francisco, a public transport station was reported as the origin or destination of a trip by 4% of respondents (Cohen and Shaheen, 2016).

Ridesourcing was also found to induce travel that would not have taken place otherwise. Cohen and Shaheen (2016) state that in the survey carried out in San Francisco, 92% of respondents replied they still would have made the trip, suggesting that ridesourcing has an 8% induced travel effect. 6-t (2016) states that 22% of trips would not have taken place (primarily late-evening ones), 40% of which were irreplaceable by other modes, even if the hour of the trip were modified. Despite the induced travel, ridesourcing is also estimated to have contributed to a reduction of car ownership in Ile-de-France (3% according to 6-t [2016]), a result that is consistent with the indications available from Clewlow and

Mishra (2017) for the United States, which found that 9% of ride hailing users (which account for 21% of adults) indicated that they had disposed of one or more household vehicles as a result of ridesharing options made available.

Finally, ridesourcing was found to only marginally replace private cars trips: 6% in the United States (Cohen and Shaheen, 2016) and 5% in Ile-de-France (6-t, 2016). Rayle et al. (2014) also refer to a survey carried out in San Francisco where 6% of ridesourcing users said they would have driven their own vehicles if ridesourcing was not available.

Carsharing

Carsharing has been found to reduce car ownership, due to either sales or deferred purchases, with a ratio of personal cars replaced by one shared car ranging mostly around five to ten, with countries with more modal diversification at the bottom of the range. According to Erich (2018), one car used in professional round-trip sharing schemes replaces ten owned cars. Cohen and Shaheen (2016) give a range of nine to 13 cars in the United States, six to 23 in Canada and four to ten in Europe (where vehicle ownership and private car reliance is lower) for round-trip schemes. The European estimate is broadly confirmed for France in a recent report by 6-t (2019b). One-way schemes have a weaker impact: seven to 11 vehicles in the United States and three in France per each shared car. In the United States, this is mostly from single households becoming carless, but also from two-car households becoming one-car households (Cohen and Shaheen, 2016).

In terms of modal choice, reductions in car ownership occurring for individuals opting for carsharing are commonly associated with increased public transit ridership, walking, and bicycling (6-t, 2014, 2019b; Cohen and Shaheen, 2016; Martin, Shaheen and Lidicker, 2010). This phenomenon is stronger in France and weaker in the United States for public transport (probably due to differences in the availability of public transport). As a result, carsharing has led to limited impact on public transport trips: a slight reduction of public transport use in the United States, and a slight increase in France.

Car sharing also tends to reduce vehicle km travelled by about 10% for its members (6-t, 2014; Cohen and Shaheen, 2016; Shaheen and Cohen, 2016).

Micromobility

Stated preferences surveys indicate that roughly 30% of dockless e-scooter sharing trips displace car trips in car-intensive cities of North America (Bird, 2019; PBOT, 2018), 40% in Brazil (Kwak, Alves and Greco, 2019) but only 8% to 10% of in France (6-t, 2019a and 2019b). In France and Portland, car trip displacement is roughly split 50/50 for personal cars and car-based ridesourcing (Bird, 2019 and 6-t, 2019b). In Brazil, the shares are 36/64 (Kwak et al., 2019).

E-scooter sharing also replaces some lower emission active mobility trips. In Portland and Paris, respectively, if scooter sharing had not been available 37% and 47% of respondents said they would have walked, 10% and 29% would have taken public transport, 9% and 12% ridden a bicycle (5% owned and 4% shared in Portland; 7% shared and 2% owned in France) and 8% or 3% would have not made the trip (PBOT, 2018; 6-t, 2019b). Walking is also the most replaced option in Brazil (58%), followed by car-based ridesourcing (25%), car travel (14%) and public transport (8% for buses, 6% for BRT and 6% for metro or train) (Kwak, Alves and Greco, 2019).

6-t (2019b) and Kwak, Alves and Greco (2019) also report that 15% and 26% of the trips taken on e-scooters in France and Brazil, respectively, were connected with public transport, a characteristic that is also common (and even stronger, in both cases) for bikesharing. Lime (2018) reports a share of 20% of trips to/from public transport.

Bikesharing (including both dockless and station-based solutions) is used for trips having similar distances to *shared e-moped/motorscooters* (5.25 km/trip, in France), replacing public transport in cities where it is widely available (France), and only marginally in more car-centric environments (United States), especially when it allows users to get to destinations more quickly and cheaply than alternative modes (Cohen and Shaheen, 2016; Shaheen and Cohen, 2016). Like e-scooters, shared bikes are also found to substitute walking and to be positively correlated with the high availability of bike lanes, population density and with mixed land use. Reduced car use has also been observed in cases of station-based bikesharing systems (Chen et al., 2020).

Like other micromobility options, bikesharing systems have been found to be relevant as a segment of longer intermodal trips, increasing the catchment area of public transit (Chen et al., 2020): in France, bikesharing is used in roughly one trip out of three to four in conjunction with other modes – mostly public transport (Cohen and Shaheen, 2016 and Shaheen and Cohen, 2016).

Effects of changes in technologies and business models on energy and greenhouse gas emissions

The evolution of energy and GHG emission impacts on urban passenger mobility options depends on several elements. Some are the choices regarding materials used for vehicle and infrastructure construction, technologies related to vehicle powertrains and energy vectors, and the characteristics of new mobility business models given the implications these may have on modal choice, vehicle lifetime and operational services.

A clear strategy to minimising energy and GHG emissions is favouring modes or modal combinations that have high average load factors. This means giving priority to high capacity public transport services and, where appropriate, seizing opportunities to integrate new mobility options in ways that enhance overall accessibility and catchment areas at the outset.

For the vehicle component, the minimisation of energy and GHG emissions impacts will be facilitated by:

- a greater reliance on recycled materials and on material extraction, processing and production processes that maximise energy efficiency and/or use low-carbon energy sources
- giving more thought during the design phase to the following:
    - solutions that minimise material needs for the manufacture and maintenance of vehicles and their components (in particular batteries, given their material intensity)
    - solutions that maximise recycling opportunities
    - solutions that can extend the lifetime of vehicles and components for shared modes
    - choices related to the combination of materials used for vehicle manufacturing that balance energy and carbon intensiveness of materials against vehicle weight
    - the thermodynamic efficiencies of vehicle powertrains and the energy losses and GHG emissions resulting from fuel production and use.

Solutions that minimise energy and GHG emission impacts in the vehicle component of the LCA are especially relevant for vehicle technologies that are more material intensive, such as BEVs and FCEVs, and for vehicles with short vehicle lifetimes, such as those used for micromobility.

For the fuel component, minimising energy and GHG emission impacts requires:

- The increased reliance on energy-efficient (and, therefore, GHG emission-efficient) powertrain technologies for all transport vehicles, accompanied by the increased reliance on low-carbon energy vectors. This includes, in particular, electric motors and batteries in the case of vehicles and low-carbon electricity in the case of energy vectors. It also includes low-carbon hydrogen and liquid fuels (e.g. advanced biofuels and/or electrofuels), especially in cases where electrification faces implementation barriers (e.g. vehicles with large range requirements).
- The integration of systems (ICEs, electric motors, fuel cells, batteries, liquid fuel storage and hydrogen storage tanks), helping strike the optimal balance between:
  - resource-intensive technologies with excellent energy efficiency characteristics and low-carbon energy vectors (such as large car batteries and electric motors, combined with electricity)
  - vehicle technologies that are much less thermodynamically efficient (such as combustion engines and, to a lower extent, fuel cells, as well as the technologies needed to produce hydrogen and electrofuels) but have better performances in terms of resource efficiency (since they come with lower material requirements).[29]

Greater reliance on recycled materials and on material extraction, processing and production processes that maximise energy efficiency and/or the reliance on low-carbon energy sources is also relevant to reducing energy and GHG emission impacts for transport infrastructure construction. Design solutions that maximise portions of infrastructure that are less material intensive (e.g. at grade railways vs. underground or elevated) are also important, as is optimising maintenance and extending infrastructure lifetime. Additionally, since energy and GHG emissions/pkm due to the infrastructure component decline with increasing frequency of use, solutions supporting the integration of new mobility modes in ways that enhance the accessibility and catchment capacity of public transport infrastructure also may contribute to net GHG emission reductions. This is especially relevant in the case of modes for which energy and GHG emission intensities per network km are highest, like underground metros.

A number of developments related to mobility service operations could reduce the energy- and GHG-intensity of new mobility options. For car-based services (in particular ridesourcing), the most relevant developments include:

- favouring a transition to vehicle and energy vectors with lower energy and GHG emission impacts (e.g. shifting early to BEVs using renewables)
- prioritising the integration with public transport
- prioritising high vehicle occupancy.

For micromobility, prioritising design choices (such as modular construction) that extend the lifetime of vehicles and/or their components and integration with public transport have the highest relevance.

All new mobility services would also benefit from the minimisation of travel and energy/GHG intensity of servicing operations.

Ensuring that new mobility improves energy and climate outcomes

The uptake of new mobility services underscores the value they provide to people. Self-owned bicycles, followed by mopeds, metros and buses significantly outperform cars with respect to energy and GHG emission impacts per kilometre when the assessment accounts for vehicles, fuels and infrastructure together. However, when the scope of the assessment broadens to include operations (under the assumptions regarding average operating conditions underlying Table 1 and Table 2), new mobility options display variable results in terms of energy and GHG emission impacts per passenger kilometre of travel.

Shared micromobility services using e-scooters, bikes, e-bikes and mopeds have energy and GHG emission impacts per pkm that are comparable in magnitude to those of metros and buses, even if there is room for improvement, especially for shared e-scooters. Shared mobility services have the highest energy and GHG emission impacts/pkm of all urban mobility options. To lessen this impact, their load factor would have to be effectively increased, their deadheading kilometres minimised and their powertrain technologies and energy vectors switched to solutions that significantly reduce energy use and GHG emissions. Further improvements are possible if new mobility services are integrated in multimodal movements complementing public transport, ridesourcing and taxi trips, even under their typical operating conditions.

New mobility options are also characterised by significant impacts due to the operational component, a contribution that is generally excluded from conventional LCAs and should be duly taken into account for shared services. Figure 15 illustrates this, showing GHG emissions/pkm shares (based on the central estimate of Figure 2) for a selection of vehicles that can be used for private or shared purposes.

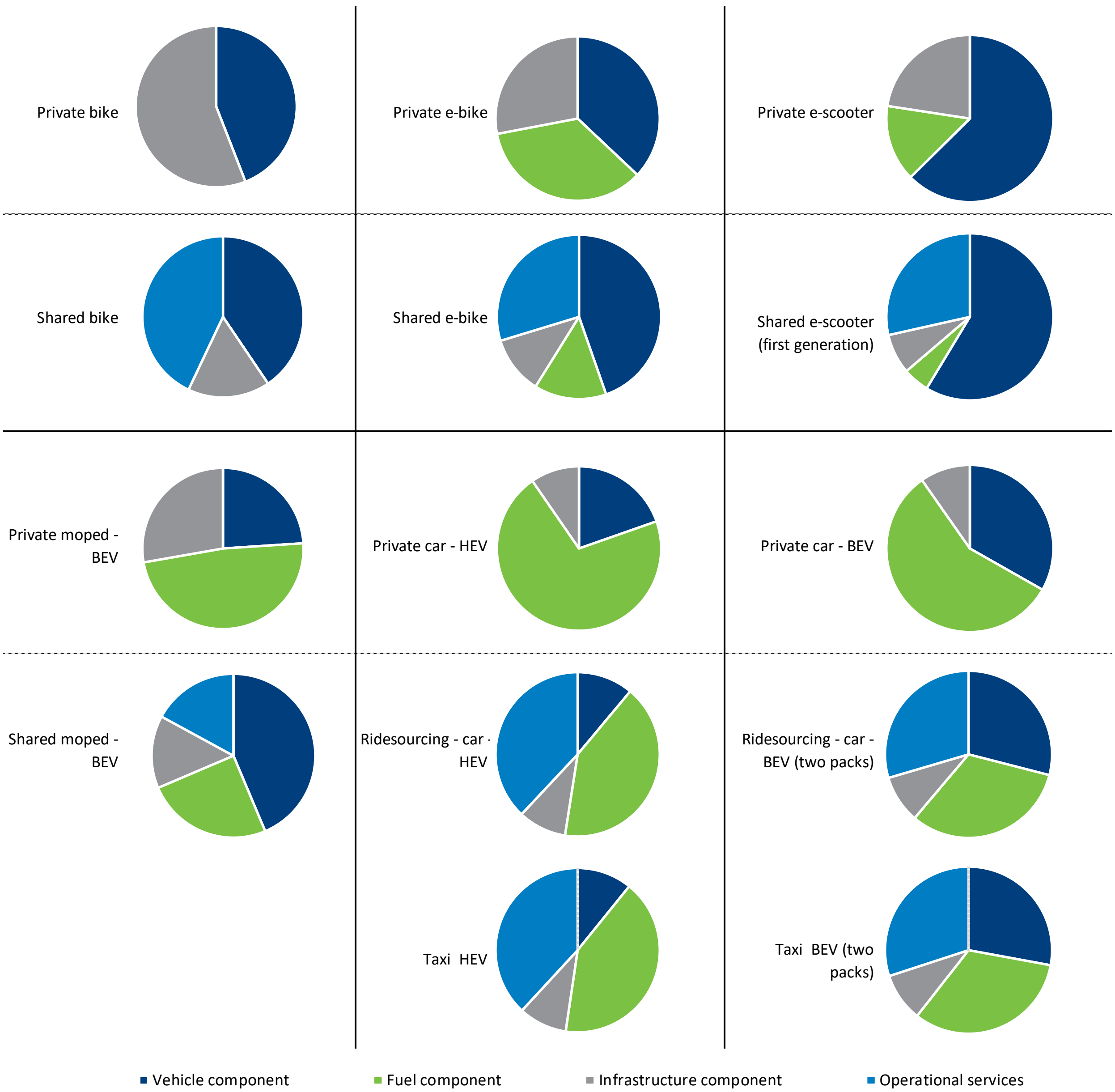
When people use new mobility services for travel they do not do so exclusively, nor even primarily in many cases, at the expense of personal car travel. Data that predate the shock of the Covid-19 pandemic indicate that these trips often replaced trips taken by less polluting means such as walking, public transport and cycling. In the same conditions, new mobility options also induce new trips.

Overall energy use and GHG emission impacts are sensitive to changes in a number of parameters. Among those, the following matter most:

- technology choice for vehicle propulsion and related energy vectors
- vehicle occupancy and lifetime
- vehicle size/mass
- frequency of infrastructure use
- characteristics of operational practices.

The adoption of good or best practice in each of these areas can lead to significant improvements in terms of energy and GHG emissions per passenger kilometre. Conversely, poor practices can have significant adverse effects, and should therefore be addressed through policy measures or other means.

Figure 15. Shares of emissions from different life cycle assessment components for selected modes



Notes: BEV = battery electric vehicle; HEV = hybrid electric vehicle. These estimates have been developed inputs (such as average number of passengers, the electricity mix and the ratio of operational km per active km) defined by global averages (see Annex A for further details and source used) observed prior to the Covid-19 pandemic. Specific circumstances occurring in different world regions, changes in operational practices and the Covid-19 pandemic should therefore be modelled as individual specific cases, modifying input data accordingly. Sensitivity results are presented in the following sections of this report.

ITF analysis is based on an assessment tool developed for this project and available at https://www.itf-oecd.org/good-to-go-environmental-performance-new-mobility. See Annex A for methodological details and data sources.

Strategies to reduce energy use and GHG emissions for new mobility

The following actions will improve direct energy consumption and GHG emission outcomes from new mobility services:

- Where possible, increase the number of passengers transported per vehicle. This is most relevant for ridesourcing services (since micromobility services are inherently focused on single-occupant vehicles) but also important for private cars and public transport. That said, current health imperatives requiring physical spacing due to Covid-19 is openly challenging such initiatives for public transport.
- Move towards vehicle powertrains and energy vectors that, as in the case of private cars and public transport, reduce energy use and cut emissions (such as electric vehicles). This is relevant for ridesourcing given the energy use and emissions of typical cars and vans, as well as for the vans that service micromobility operations.
- Extend vehicle lifetimes. This is especially relevant for micromobility vehicles and components that have relatively short lifetimes and rapid turnover.
- Favour smaller and lighter cars. These changes in supply and consumer preferences are especially relevant for carsharing.
- Decrease the ratio of service kilometres driven per kilometre of revenue travel. For ridesourcing services, this would entail reducing deadheading kilometres driven per passenger ride. For shared micromobility services, this would entail operational improvements that reduce travel for repositioning and charging services.
- Integrate new mobility services with public transport so they displace trips that would otherwise occur by car (including trips that would have been made exclusively by unshared ridesourcing).

The following sections draw from these insights to identify policy interventions that can help mitigate the environmental (in particular energy and climate) impacts of new mobility, taking into account the importance to conjugate these goals with the sustainability of economic and social systems to build resilient societies (Gurria, 2020).

The structure of the discussion that follows involves two main parts.

- The first considers the need for accurate information with regards to all life-cycle components to guide policy action by public authorities (where required) and the opportunity for new mobility operators to increase credibility and build consensus on the genuine benefits that new mobility options can offer (and under which circumstances). It elaborates on policies allowing to monitor the characteristics and environmental performance of vehicles and vehicle fleets, focusing on solutions that can improve data quality and enable greater transparency in new mobility.
- The second reviews key regulatory, economic and voluntary measures that can incentivise better life-cycle performance in terms of energy use and GHG emission impacts. Starting from considerations on measures with a general nature (i.e. not applied to specific services), it looks at situations where there is scope for targeted action on new mobility. To do so, it takes into account the presence of high impacts and the relevance of vehicles with elevated levels of lifetime vehicle travel as key discriminants for targeted interventions, combining it with other considerations on different types of new mobility services. The discussion is structured in three sub-sections. The first focuses on measures that seek to minimise life-cycle energy and GHG

emissions per vkm. The second covers measures seeking to incentivise higher vehicle occupancy rates. The third looks at measures to better co-ordinate new mobility with public transport.

Policies to improve data quality and enable greater transparency

Public authorities must be properly informed in order to guide policy action, where required. To reduce the overall environmental burden of vehicle travel, they must monitor the characteristics and environmental performance of vehicles and vehicle fleets. The analysis developed in the present report confirms that this evaluation should be based on broad and transparent LCA methodologies.

This information may be used, as it is in other domains, to set conditional market entry requirements, to incentivise better performance or to penalise adverse performance. More broadly, greater transparency with regards to full life-cycle impacts would also allow new mobility operators to increase credibility and build consensus on under which circumstances new mobility options deliver societal benefits.

Which data and information to gather

There are several ways to gather energy use and GHG emission profiles of new mobility services. First, it is important to understand if existing reporting requirements can provide useful information to identify if and when additional, sector-specific reporting makes sense. New reporting requirements that are put into place should also differentiate between aggregate benchmarking data and operator-specific data that may reveal commercially sensitive information or impact the privacy of drivers or travellers. The former should be used to report on overall performance and the latter used internally by public authorities for audit and enforcement purposes in accordance with specific safeguards.

Energy use and GHG emission reporting frameworks can be broken down into three broad categories.

First is the reporting framework for ***vehicle-specific*** or ***fleet average*** fuel economy and GHG emission profiles for cars and vans, already in place in many countries and regions: this reporting framework can be extended to ridesourcing vehicles and to operational support vehicles for micromobility.

Second are reporting elements that generally do not exist for all vehicles but, if required for new mobility options (essentially ridesourcing), would enable authorities to better monitor the energy use and GHG emission impacts of new mobility ***services***. The most relevant among these is vehicle occupancy per revenue kilometre of travel. However, the question of fairness and proportionality arises: is it just to require ridesourcing and public transport operators to report such information when self-owned cars face no such obligation?

Third, reporting frameworks relating to new mobility ***operations*****,** since they are unlikely to exist already: Some cities, like San Francisco[30], are starting to require these. Reporting frameworks on operational parameters are viable options where they have potential to guide proportionate policy interventions. Ideally, such frameworks should cover:

- deadheading travel shares, in order to better assess energy use and GHG emission impacts of ridesourcing services
- information on average vehicle lifetime, the ratio of service vehicle travel per unit of revenue travel[31] and the energy and GHG intensity of service vehicles, to assess the life cycle impacts of shared micromobility.

How to gather missing data and information

Public authorities need data in order to make informed decisions on the deployment of services most aligned with public policy objectives. Today, access to information relating to the energy and GHG emission performance of new mobility services is often dependent on voluntary disclosure of information. To minimise regulatory burden, mechanisms should be put in place that allow for the use of existing reporting frameworks to gather the necessary data and information, to the extent possible. Additional requirements should only be introduced for information that is not already available.

Mechanisms currently exist for reporting information that will be used for monitoring the performance of new mobility services. Those mechanisms include: 1) direct reporting; and 2) the reliance on a trusted third-party or a shared-data platform.

Direct reporting of data to a regulatory agency is not uncommon and could certainly serve as a model. This approach requires that regulatory authorities have sufficient capacity to process the data and put in place the appropriate safeguards to prevent the misuse of this data or its accidental or malicious release.

Requiring operators to report performance data to a trusted third-party or shared-data platform addresses the issue of capacity limitations for data processing, but still requires the appropriate safeguards and verifications necessary in direct reporting.

In both cases, regulators should be able to audit the data they receive to verify its accuracy. The latter can be strengthened by legislation that makes public-sector and publicly funded data accessible and reusable more broadly, as the Freedom of Information Act does in the United States and the Open Data and Public Sector Information Directive (2019/1024) does in Europe.

Some jurisdictions have already rolled out mandatory reporting under existing regulatory frameworks. For example, the California Air Resources Board required the establishment of a baseline for GHG emissions of ridesourcing vehicles per unit distance travelled by passengers (California Senate, 2018) for ridesourcing companies operating in the state. This accompanied the approval of the Clean Miles Standard and Incentive Program. The baseline was finalised in late 2019 (CARB, 2019). Data requirements for the state now include the following: 1) distances completed by drivers; 2) shares taking place on zero-emission means (including walking, biking, other modes of active transport and zero-emission vehicles); 3) an estimation of the distance-weighted average of GHG emissions/km; and 4) accounting for the amount of passengers-per-trip and, in cases where exact passenger head count data was not captured, for an estimated average value. Mandatory reporting can also be integrated with licensing frameworks developed at the local level (California Senate, 2018).

Steps should also be taken to avoid unnecessary burdens on operators. Authorities should minimise the amount and scope of the data they request to only that which is necessary to carry out their regulatory mandates. They should minimise administrative requirements by seeking, where possible, synergies with other public bodies that require access to similar information.

Reporting should be made on a common basis and shared definition of terms. To align the definitions on what is to be reported, issues would have to be resolved related to a number of unique features of new mobility services. These include adjusting double counting of vehicle distances travelled across different platforms, offline (off-platform) travel to and from areas of activity where drivers estimate that there is a higher likelihood of getting a ride request, or, conversely, excluding on-line (on-platform) driving for a driver’s personal purposes and, in the case of pooled rides, incremental travel due to detours to pick up and drop off additional passengers (Wang, 2019).

Standardisation organisations can help establish common terms and accounting methods. For instance, the Society of Automotive Engineers (SAE) currently leads the Mobility Data Collaborative (SAE, 2019), which addresses micromobility terms. Were this or other such initiatives to expand to cover ridesourcing services and environmental aspects of transport (moving beyond the current focus on safety aspects), operators and authorities could improve the efficiency of reporting and monitoring efforts.

More broadly, requirements for reporting performance characteristics must recognise that the object of reporting – new mobility services and the vehicles they use – are diverse, rapidly iterating and changeable. Reporting and monitoring efforts should be adaptable to the diversity and dynamism in business models and vehicle types.

Regulatory, economic and voluntary measures

Improving energy and climate outcomes of new mobility requires a policy framework that acknowledges the growing interest of governments and businesses to develop strategies that bring together environmental policy priorities and economic growth. The recently announced European Green Deal is the most iconic representation of this.

Policies that support the deployment of clean mobility technologies are crucial in this respect. This is especially so where they can have significant effects on energy and resource savings: net reductions in costs and increased economic productivity (due to increased energy efficiency), greater resilience (from energy diversification) and a stimulus for growth through innovation.

E-mobility is especially relevant in the discussion, given the central role of transport vehicles for the scale-up of battery manufacturing. Scale increases and technology developments have the capacity of setting in motion a self-reinforcing virtuous cycle: they enlarge the scope of economic viability of batteries for transport vehicles (and beyond) for a broader range of usage profiles, thereby further facilitating scale increases and cost reductions and, as a result, an even broader scope for large-scale adoption.

National, sub- and supra-national governments have been and are increasingly using regulatory instruments (briefly reviewed in Box 3) and economic incentives to encourage a shift to clean mobility options in transport. A particular example of this is differentiated taxes (including feebates and bonus/malus schemes pegged to vehicle performance in terms of life-cycle energy use and GHG emissions per vkm, as well as pollutant emissions). Such taxes can be used to stimulate the adoption of energy-efficient and environmentally friendly vehicles by imposing penalties on the registrations of vehicles with poor performance and providing competitive advantages for vehicles with the best performances.[32]

Box 3. Regulatory incentives for better environmental performances of transport vehicles and fuels

Due to the historical predominance of internal combustion engines (ICE) and petroleum-based fuels (i.e. technologies that have similar characteristics in terms of energy requirements and GHG emission for vehicle manufacturing and fuel production), regulatory developments to date focused on tank-to-wheel energy use per kilometre or gram of CO_2 per vkm.

The first regulations on the energy efficiency of vehicles were enacted in the 1970s in the United States, with the development of the Corporate Average Fuel Economy (CAFE) standards. These were last updated in 2019 and 2020, with the finalisation of the Safer Affordable Fuel Efficient (SAFE) rule setting tank-to-wheel GHG emission limits for new vehicles sold between 2021 and 2026 (EPA, 2019, 2020).[33] Similar regulations are currently in place in all major car markets, including Canada, China, the European Union, India, Japan, Korea and Mexico (IEA, 2020b; IEA, 2019).

In recent years, these regulations have increasingly been accompanied by low- and zero-emission vehicle mandates (i.e. minimum thresholds in terms of market shares) and/or other regulatory mechanisms (e.g. targeted multipliers) providing incentives for the deployment of low- and zero-emission vehicle. Mandates are applied in the provinces of Québec and British Columbia in Canada (Banks, 2020); China; and ten states in the United States, including California (which initiated the application of the policy), Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont (C2ES, 2019). Incentive mechanisms are integrated in the New Energy Vehicle mandates in China and in the European regulations on g CO_2/km of cars, van and heavy duty vehicles (IEA, 2020b; ICCT, 2019a).

The emergence of technologies allowing a greater diversification of transport fuels, such as plug-in hybrids, battery electric and fuel cell electric vehicles, is increasing the relevance of the use of life-cycle approaches to guide these policy instruments. For this reason, regulations on energy efficiency and GHG emissions per vkm have been recently accompanied by regulations related to the carbon intensity of the production of energy vectors (i.e. well-to-tank energy and GHG emissions). Key examples of these measures are Low Carbon Fuel Standards (LCFS) and Renewable Fuel Standards (RFS) in North America and the Fuel Quality Directive (FQD) and the Renewable Energy Directives (RED, I and II) in Europe.

Maximum regulatory requirements on the energy and GHG emissions resulting from vehicle manufacturing (i.e. on the energy and carbon embedded in vehicles) have not yet been the subject of policy action. However, the development of electric vehicles[34] has recently sparked a growing interest in the regulatory frameworks for energy and GHG emissions resulting from vehicle manufacturing.

Local authorities have also taken proactive steps to contribute to the development of clean mobility. Key drivers that spurred this development include: 1) the reduction of energy use and GHG emission impacts; 2) the desire to foster industrial development and enhance economic productivity, 3) the need to abate local air pollution to reduce health impacts, 4) the importance to manage traffic congestion (allowing time and energy savings, and facilitating economic development); and 5) the relevance of an equitable urban space allocation for different modes of transport to improve the liveability of cities. In this context, many cities – predominantly in Europe – have established low, ultra-low or zero-emission zones and hybrid approaches that combine the regulatory instrument of urban vehicle access restrictions (UVARs) with economic measures, such as congestion and urban access charges, differentiating them for vehicles meeting specific energy-efficiency, pollutant and GHG emission/vkm thresholds.[35]

To meet green growth objectives, national, supra-national and local administrations are also developing public procurement programmes that privilege or require minimum thresholds for the adoption of low- and zero-emission vehicles in public fleets. These measures have been complemented by a number of voluntary actions by forward-looking businesses committed to accelerating the transition to clean mobility in their own fleets and logistical operations. Key examples include the EV100 and RE100 initiatives of The Climate Group, intended to accelerate the transition to electric vehicles (EVs) and the scale-up of renewable power (The Climate Group, 2020a, 2020b).

The importance of ensuring fair and proportionate measures

The LCA analysis in this report confirms the importance of using the life-cycle approach to develop policies capable of managing energy and GHG emission impacts of transport. But the analysis also indicates that some of the life cycle energy use and GHG emission impacts of urban mobility are specific to new mobility services. Key examples are the operational impacts of providing shared micromobility and the deadheading travel associated with ridesourcing. Other impacts – such as those linked to vehicle technologies and energy vectors or with low-vehicle load factors – are also found elsewhere within the urban mobility ecosystem.

Both general and specific policy responses will be needed to integrate new mobility services in policy frameworks that manage the environmental performances of transport while also accounting for other objectives related to industrial development, innovation and enhanced economic productivity. Achieving the right balance will be important to ensure that the clear benefits of these services are retained while their potential impacts are managed.[36] Policy interventions generally should conform to the objectives of the OECD Guiding Principles for Regulatory Quality (OECD, 2005), which serve as a durable and guiding framework for ensuring that balance. They state that good interventions should:

- serve clearly identified and motivated policy goals, and be effective in achieving them
- have a sound legal and empirical basis
- produce benefits that justify costs, considering the distribution of effects across society and taking economic, environmental and social effects into account
- minimise costs and market distortions
- promote innovation through market incentives and goal-based approaches
- be clear, simple, and practical for users
- be consistent with other regulations and policies
- be compatible as far as possible with competition, trade and investment-facilitating principles at domestic and international levels.

Measures to minimise life-cycle energy and greenhouse gas emissions per vkm

The principles outlined in the previous section form the basis of sound policy developments in the case of new mobility services such that final societal outcomes are maximised.[37] They also serve to frame the rollout of policy interventions moving from the more general application of rules (i.e. cross-sectoral and cross-mode) to, where it is justified, the use of measures specifically targeting new mobility services.

Ridesourcing and carsharing

Vehicles with elevated levels of lifetime travel (a characteristic of vehicles used for ridesourcing, taxi services, private-hire vehicle services and public transport) deserve special attention in the development of targeted measures aiming to minimise life-cycle energy and GHG emissions per vkm. The main reasons for this are that: 1) they account for a disproportionately high share of energy and GHG impacts (as compared to the average vehicle); and 2) as reductions in energy use and GHG emissions are likely to have the greatest net economic savings for vehicles travelling a lot (due to the higher share of energy costs), the limited adoption of energy-and GHG-saving technologies for vehicles with high lifetime mileage reflects market failure.[38] Unsurprisingly, public procurement programmes target clean vehicles for high-mileage public transport vehicles like urban buses.

The high energy and GHG emission impacts per pkm of taxis and ridesharing, combined with the relevance of fuel costs as an element impacting driver earnings[39], make taxis and vehicles used intensively for ridesourcing or carsharing a reasonable target for specific measures aiming to improve their energy efficiency and mitigate their environmental impacts. Covid-19 and ensuing mitigation measures will impact a number of factors that will condition these types of policies. These include near-term impacts such as the reduction of oil prices following the worldwide introduction of mobility restrictions (aggravated by a supply shock) and the likely increasing constraints for drivers and fleet owners to borrow capital. They also include longer-term considerations, such as:

- the progressive increase of oil prices as the global economy recovers, even if they could remain lower than before the pandemic, at least in the medium term (Tagliapietra, 2020)
- the importance of the development of stimulus packages that support sectors affected by Covid-19 (including new mobility) in a way that contributes to a low carbon economy while integrating environmental and equity considerations (Gurria, 2020; IEA, 2020c)
- the long-lasting benefits of energy efficiency improvements coming with net savings over the vehicle lifetime due to the resulting increase in economic productivity[40], focusing even more the need to prioritise clean mobility for vehicles with elevated lifetime mileages.

In the case of ridesourcing fleets, policies aiming to increase the ambition of energy and/or GHG emissions reductions also need to take into account of a number of specific characteristics.[41] The first is the uneven distribution of vehicles with elevated levels of lifetime travel. This is due to the diverse nature of drivers contributing to the service (Box 4). For non-professional drivers, the economic case for purchasing or leasing a low- or zero-emission vehicle is lower (and closer to conventional drivers of private cars) since they do not travel as much as fulltime drivers and they do so on their own vehicles (and thus the provision of ridesourcing services is not the only, nor even the principal, factor in its acquisition).

Box 4. Driver profiles in the case of ridesourcing and market size of highly used ridesourcing vehicles

Large shares of all ridesourcing vehicle kilometres are carried out by a small core group of full- or near full-time drivers, even in regulatory contexts where non-professional drivers are allowed to use their existing personal vehicles to provide ridesourcing services (i.e. in contexts that facilitate the provision of ridesourcing services by part-time drivers, a core feature of many ridesourcing business models, allowing the supply of drivers to rapidly scale in response to demand).

Estimates for the United States indicate that ridesourcing drivers work, on average, 17 hours a week, that approximately 20% of all drivers are full time (suggesting that part time drivers work, on average, less than one day per week) and that full time drivers also account for about half of all trips (Mishel, 2018).

One estimate of global the current ridesourcing fleet points to 18 million vehicles in operation worldwide in 2020 (Briggs, 2018). Assuming that approximately 20% of the total ridesourcing fleet would be used full time, approximately 3.6 million of these could be considered vehicles with high lifetime mileage that would be likely candidates for the adoption of energy-saving technologies. This represents a potential market of 1.4% of the global car fleet (Briggs, 2018).

Driver turnover is also high and drivers tend to leave ridesourcing platforms after a short period of time – on average after three months in the United States (IGAS and CGEDD, 2018; Mishel, 2018). Other specificities of the ridesourcing market relate to vehicle age (given that some local authorities place age restrictions on vehicles operating ridesourcing services)[42] and size (since ridesourcing vehicles may also be subject to minimum vehicle length and/or power)[43].

For vehicles providing ridesourcing services, one pathway to consider when taking these characteristics into account is the replacement of maximum vehicle age limits by maximum energy use, GHG and pollutant emission limits. This makes sense especially where overall activity levels pose specific and elevated risks, such as those linked to air pollution in dense urban cores.

A stronger option is the adoption of regulatory requirements aiming to modulate energy efficiency and GHG emissions. This can be paired with targeted mandates on low- and zero-emission vehicles (the first fuelled by low-emission fuels) and eventually complemented by targeted economic incentives. A key example in this respect is a case of London, which announced in 2016 the requirement for all newly registered taxis to be zero-emission capable as of 2018 (TfL, 2016, 2020). This move was followed shortly afterwards by a voluntary commitment from Uber to aim for every car on the app in the capital to be fully electric in 2025 (Mayor of London, 2019; Uber, 2018). This is part of a comprehensive scheme that includes mandatory age limits for taxis, incentives for the early retirement of vehicles, investments for the deployment of publicly accessible electric vehicle chargers and the possibility to express preferences on their location, financial support for the installation of home chargers and discounted charging rates (LEVC, n.d.; TfL, 2020). A second important example is the California Clean Miles Standard and Incentive Program. The programme requires the establishment of annual targets and goals for ridesourcing by 2021 – to be effective in 2023 – to reduce greenhouse gases per passenger-mile driven by ridesourcing (California Senate, 2018).

Given the characteristics of ridesourcing business models, regulatory requirements on energy efficiency and GHG emissions and/or low- or zero-emission vehicle mandates are best conceived when they target vehicles with high lifetime travel. Energy and GHG emission performances of other vehicles can be addressed in the broader context of regulations on fuel economy or GHG emission per vkm applied to new vehicle registrations. Again, California’s Clean Miles Standard is an interesting example. It uses a compliance metric based on annual energy or GHG emissions per vehicle km and zero-emission km travelled, taking into account the average travel-distance-weighted performance of ridesourcing services, in order to account for the uneven distribution of high- versus low-distance drivers so not to impose undue constraints on occasional drivers (CARB, 2020).

To meet these standards, operators will need: 1) a diversity of usage profiles for independent drivers operating on ridesourcing platforms[44]; and 2) a method of incentivising their drivers to purchase or lease vehicles that meet the mandated standards. Financial support, assistance and discounts (e.g. bulk orders) could help ridesourcing drivers meet these requirements, as could timely information regarding payback periods for more energy-efficient vehicles at the time of purchase or lease. The future of the employment/independent contractor relationship between drivers and platforms may also have an incidence on how the use of lower-energy and GHG emission vehicles may be incentivised or required.

Uber’s voluntary commitment in London is an example of how platform-based incentives may contribute to better outcomes. Uber established a fund intended to help drivers to upgrade to an electric vehicle and financed it with a clean air fee of roughly USD 0.1/km (Uber, 2018). Public authorities can also provide complementary (or alternative) support. However, as the economic rationale for this is weaker for high-mileage vehicles than for privately owned cars (given the larger relevance of operational savings that occur on highly utilised vehicles), incentivised registration fee structures for ride service and operational support vehicles makes little sense beyond those imposed on the general vehicle population.[45]

Applying dedicated ridesourcing-fleet-specific regulations on energy use or GHG emissions per km, or low- or zero-emission vehicle mandates when these do not exist for the broader vehicle population, is more challenging. This is not only because such a decision should be shown to be fair and proportionate to the impacts that it imposes (something that may be justified by the disproportionate amount of travel, in case of highly utilised vehicles), but also because it should be practically feasible. In particular, this requires that the supply of low- and zero-emission capable vehicles be sufficiently vast and diverse, which is less likely where demand for these vehicles is not sufficiently strong.

Finally, urban vehicle access restrictions (UVARs) and road or access charges also have an incidence on the energy and GHG emission profiles of new mobility services, especially in cases where they target dense urban cores where a disproportionate number of ridesourcing and carsharing travel takes place.

Given the urban nature of new mobility services like ridesourcing and carsharing, their simple inclusion in the scope of application of these policy instruments is bound to contribute to an accelerated transition towards cleaner technologies without requiring targeted action.[46] However, their effects are different for ridesourcing in the way they impact high-volume rather than low-mileage drivers who wish to operate throughout the urban area.

Binary UVARs (e.g. vehicle access permitted/not permitted) have a strong impact on fleet composition. They incentivise drivers who wish to service lucrative trips in restricted zones and carsharing providers that want to serve these same zones to invest in vehicles that meet UVAR requirements. This is also relevant for ridesourcing drivers who are based (or typically operate) outside these zones. Cordon-based urban access charges that are differentiated by vehicle energy or GHG emission performance also result in similar incentives for drivers and carsharing schemes to invest in energy-efficient technologies. For ridesourcing, both impact not only high-volume drivers but also occasional and low-mileage drivers.

Charges based on travel distance and differentiated by energy and GHG emission performance may more effectively incentivise high-mileage drivers and carsharing schemes operating in the urban core to switch to more fuel efficient vehicles, as their higher mileage in the areas subject to these charges exposes these drivers and carsharing vehicles to proportionally higher costs if they do not switch.

Micromobility

Shared micromobility fleets are largely dominated by electric vehicles. As a result, their life-cycle and GHG emission impacts are due mostly to the vehicle and operational services component and much less to the fuel component of the LCA framework set out in this report. This is ultimately what leads to net benefits or penalties that occur in comparison with the alternative forms of transport that they replace.

To address life-cycle energy efficiency and GHG emissions for micromobility, policymakers should, therefore, primarily target the vehicle and operational services components of the LCA framework. This report highlights that proactive actions to extend lifetime mileage and minimise energy use and GHG emissions from operational services leads to LCA impacts of shared micromobility that are comparable in magnitude to those of bus travel on a per-passenger kilometre basis. However, they lead to more than twice that of non-shared micromobility, thus leaving scope for improvement. A common accounting framework and agreement on environmental performance standards would help in this respect.

For micromobility, technical requirements related largely to safety performance have been established in a number of European countries. However, no common European standard exists for safety performance (or environmental performance), with the exception of a very broad consumer product safety rule. In North America, SAE is developing a standard for vehicle classification and safety (SAE, 2019), but not yet for environmental performance.

The development of standardised methodologies for the evaluation of life-cycle emissions of shared micromobility is especially important since most of the energy- and GHG emission-related impacts are not imputable to vehicle use. Given the importance of energy use and GHG emissions due to vehicle manufacturing and operational services, performance requirements and incentives are also well suited for more specific parameters, beginning with lifetime mileages and the ratio between energy use and GHG emissions from service km and active km of micromobility vehicles.

A typical e-scooter or e-bicycle is made up of hundreds of individual parts. Their individual components are subject to different rates of wear, and age accordingly. The major component groups include the chassis/frame (including steerage), the wheels, embarked electronics and the battery for electric vehicles. Even if there is a natural pressure on shared micromobility operators to deploy vehicle models that maximise lifetimes with respect to technology costs, not all operators chose to deploy the same technology. Depending on individual firms' business strategies and supplier networks, some may favour more durable and more expensive vehicles whereas others may deploy less expensive, shorter-lived and more rapidly updated models.

The accounting methodologies developed in international standards for the life cycle assessment of energy use and emissions occurring during vehicle manufacturing need to be flexible enough to ensure proper accounting for different technical arrangements, but also capable of guaranteeing reliable indications. For example, standards or technical requirements targeting minimum lifetimes and durability should account for modular constructions and be designed in such a way as to favour the switching of these as needed to extend overall usage of the vehicle.

These methodologies are important prerequisites for developing minimum performance standards. The standards may target vehicle lifetime mileages to promote the use of anti-tampering features. Such features could help improve environmental performance by amortising the environmental impact of vehicle production over longer vehicle lifetimes and encouraging the development of strategies aimed at achieving higher per-vehicle travel volumes. Incentivising best practices in addition or as an alternative to minimum performance requirements may allow operators to be rewarded for taking early or significant action.

Operational services are the second-largest contributor to life cycle energy consumption and GHG emissions from a major micromobility mode like shared e-scooters. Agreed, standardised methodologies for the assessment of the energy use and GHG emissions from operational services could help minimise these life cycle impacts. Key parameters requiring accurate monitoring and verification include the amount of micromobility vehicles serviced by each service vehicles, distances covered by service vehicles, energy and GHG emissions per km, the number of micromobility vehicles serviced per trip, the frequency of servicing events and the travel completed by micromobility vehicles between servicing events.

Additional regulatory requirements imposed on micromobility operators also need to be developed, balancing the benefits that the micromobility services deliver with the energy- and environment-related implications they have. This is especially important for some of the existing local regulations for micromobility. In particular, mandatory daily scooter pick-ups or service-level obligations requiring very short (e.g. two-hour) response times for repositioning scooters can significantly increase the overall energy and GHG emissions for the fleet since they can lead to higher ratios of operational service km per active km of the micromobility vehicles.

The pathway for incentivising better energy and GHG emission performance for micromobility vehicles is not as straightforward as for cars and vans used for ridesourcing services. Part of the reason is that the absolute energy and GHG emission impacts are roughly on par with public transport and impacts depend on which trips are replaced by shared micromobility (e.g. car trips vs. walking trips) and the number of new trips that are generated by the availability of these services. Broad national legislation is unlikely to be a viable option, as it is for car-based services, because net energy and GHG impacts differ according to location. Municipal or regional authorities also in charge of road space allocation may, therefore, be better placed to require or incentivise improvements in energy and GHG emission performance from the shared micromobility fleets to which they grant licences or permits. On the other hand, the value of regulatory harmonisation is widely recognised in industry. It saves costs to the operators, which are no longer required to tailor specific vehicle and operational models to small, local markets. The combination of common requirements, regulations and standards at national and supra-national levels, complemented by a co-ordinated approach from different local administrations could be an effective solution to ensure that both public policy and private business goals are satisfied.

Docked micromobility schemes (primarily bikesharing) were established initially in partnership with municipal or regional governments, which often provided substantial subsidies. Since, private entities have introduced dockless schemes without direct public subsidy, taking advantage of an initially permissive regulatory environment. Cities in both the United States and Europe have rolled back from this approach and are in the process of implementing regulatory frameworks of variable stringency. Some of these set out market entry rules, others create operation licenses and, in some instances, authorities are putting in place concession-based frameworks limiting the market to one or several operators.

Market entry rules and licences allow authorities to set minimum technical and operating standards, and link market access to operators meeting and maintaining these standards. Concession-based market entry frameworks build on specific contractual arrangements that must be maintained under the threat of penalties or exclusion. Experience with concession-based models is recent and it is too early to assess their performance or identify potential lessons (ITF, 2019).

All of the above frameworks conceptually allow public authorities to set technical or operational standards. However, the concession-based model is perhaps more interesting in that it creates a flexible framework allowing authorities to set baseline performance and incentivise best-practice. Concessions can also specify minimum energy and GHG emission performance objectives or requirements for the micromobility operator (including requirements on energy and GHG emission impacts from the vehicle LCA component and operational services) and link performance above baseline thresholds to the provision of a public subsidy.

An additional option available to stimulate micromobility operators to deploy vehicle models that maximise lifetimes is to set minimum thresholds on vehicle life and use. These incentivise operators to deploy vehicle models that maximise lifetimes and can be developed in ways that integrate different flexibility mechanisms – for example, by targeting fleet averages with a single performance indicator (lifetime mileage). They may be integrated into contractual arrangements incorporating performance requirements and may be paired with other instruments, like with bonus/malus schemes (i.e. premiums and/or penalties for operators exceeding or not meeting the required/targeted performances).

Here again, co-ordinated action will reap the greatest benefits. Using standardised indicators to help define concession requirements can certainly help minimise regulatory burdens on authorities and cut compliance costs for micromobility services and operators.

Policies aiming to increase occupancy on new mobility services

The previous section discussed policy measures aimed at minimising life-cycle energy and GHG emissions per vkm. A second area of policy intervention targets higher occupancy levels for new mobility services since these deliver better energy efficiency and environmental performance for the same service (passenger movements in cities, i.e. pkm). Contrary to the former type of measure, which acts via vehicle replacement, policies aiming to increase occupancy on new mobility services have the important advantage of having an immediate impact, applying directly across the existing vehicle fleet.

Since micromobility is specifically designed for single-rider trips (in most cases) it has limited scope to increase occupancy. As such, measures related to higher occupancy are especially relevant for ridesourcing and, for coherence, can also apply to taxis and other private-hire vehicles (ITF, 2019).

Differentiated levies on ridesourcing

Levies on ridesourcing have been collected in various cities in Brazil, Canada, Mexico and the United States as a flat fee per ride or a percentage of the trip price. The intention is that at least part of the revenue goes towards funding the urban transport system. ITF (2019) reports on research backing these levies. It suggests that the development of ridesourcing has led to declines in public transport ridership in US cities. It also suggests that levies may be used to address the negative social and economic impacts of the disruption to the taxi industry.

In order to incentivise higher ridership, these levies could be differentiated based on vehicle occupancy (lower levies for pooled rides, higher for single-occupancy rides) and could also be part of a broader scheme that would provide subsides for high-occupancy rides. This scheme could be designed as budget-neutral or revenue-generating. The app-based nature of ridesourcing would likely make such designs feasible. On the other hand, it seems that pooled services have not gained much widespread public acceptance and uptake, so there may be natural limits to pooling, especially in cars. This is especially the case in light of the real and perceived risks linked to crowding due to the Covid-19 pandemic. These limits may matter less for pooled rides in larger vehicles such as minibuses or vans but such services are typically different in nature than car-based ridesourcing, providing pop-up routes instead of door-to-door service.

Even if levies applied to ridesourcing could narrow the ridership gap with private cars, charges targeting only ridesourcing have been less effective and more prone to disproportionately hampering the benefits of ridesourcing than charges that are applied more broadly (or even generally), including the ridership of other transport options as well, even private cars).[47] One way to avoid disproportionate interventions for occupancy-based levies for ridesourcing could be to calibrate the levies in a way that fills the occupancy gap between ridesourcing services (where deadheading has a detrimental effect to the pkm/vkm ratio) and movements taking place in private cars (taking into account their average loads).

Minimum occupancy incentives and standards

Differentiated levies could be part of a more complex policy framework consisting of minimum occupancy incentives. One way to incentivise high-occupancy is to ensure that driver remuneration rules, if they are implemented, are explicitly designed to favour higher vehicle occupancy. This is the case of the Driver Income Rule adopted in New York City, also bound to help reduce the energy and GHG impacts of ridesourcing, and not only because it incentivises increased occupancy (see Box 5).

Box 5. Implications labour policies on ridesourcing for its energy and environmental impacts

The Driver Income Rule is the first attempt to regulate the incomes of ridesourcing drivers. It has recently been adopted in New York City (New York Taxi and Limousine Commission, 2018) and took effect in February 2019. It sets a minimum per-trip payment to drivers, based on a formula that includes time and distance elements, modified by a utilisation rate. This is a parameter that takes into account: 1) the ridesourcing km with one or multiple passengers on board; and 2) the overall ridesourcing km (Parrott and Reich, 2018).

This formula will be determined for each ridesourcing company and creates an inverse relationship between the minimum per-trip driver payment and the utilisation rate, making it more expensive for ridesourcing companies to rely on occasional or part-time drivers. The rule also creates incentives for ridesourcing companies to increase utilisation rates, thus reducing the impact of ridesourcing vehicles on congestion, while at the same time ensuring that average driver incomes are constant, regardless of actual utilisation rates (ITF, 2019).

The effects of the Driver Income Rule for energy and environmental impacts are positive, for two reasons:

- First, the rule provides incentives for ridesourcing companies to reduce the share of deadheading travel and, therefore, increase the average occupancy of vehicles.
- Second, the cost structure promotes the adoption of energy efficient vehicles. This happens because the Rule provides economic incentives for ridesourcing providers to rely on drivers using ridesourcing vehicles for extensive periods of time (and, therefore, on vehicles with elevated lifetime mileage).

Minimum occupancy standards could also help increase the occupancy of ridesourcing trips while still allowing for different contributions from different trips. For example, trips with a single rider and long deadheading distances could be compensated by pooled services with low deadheading distances. They could be designed as flexible policy instruments, setting average requirements for the overall ridesourcing operations using trip distance shares (including deadheading) as the weighting parameter and occupancy rates as the regulated parameter. Differentiated levies based on occupancy could be roughly analogous for occupancy as low carbon fuel standards are for incentivising lower carbon fuel mixes.[48]

Minimum occupancy standards (eventually paired with economic incentives) offer significant theoretical advantages in terms of flexibility (in terms of compliance, degree of policy ambition and budgetary implications). However, they also face a number of theoretical and practical challenges. The first set of challenges is that, even if there are signs that occupancy is lower in shared services like ridesourcing and taxis, low vehicle occupancy is a widespread and durable feature of private car travel. The second set of challenges relates to implementation. Setting up occupancy standards requires monitoring and reporting. This is likely to be best addressed with the buy-in of the stakeholders involved.

Such measures should account for the specificities and flexibility of ridesourcing operators to deploy novel solutions. For instance, several operators provide a mix of services on their platforms, notably mixing shared micromobility and ridesourcing services. Many operators incentivise or make it easy for users to make short trips on shared micromobility so as to free ridesourcing capacity for more remunerative trips.

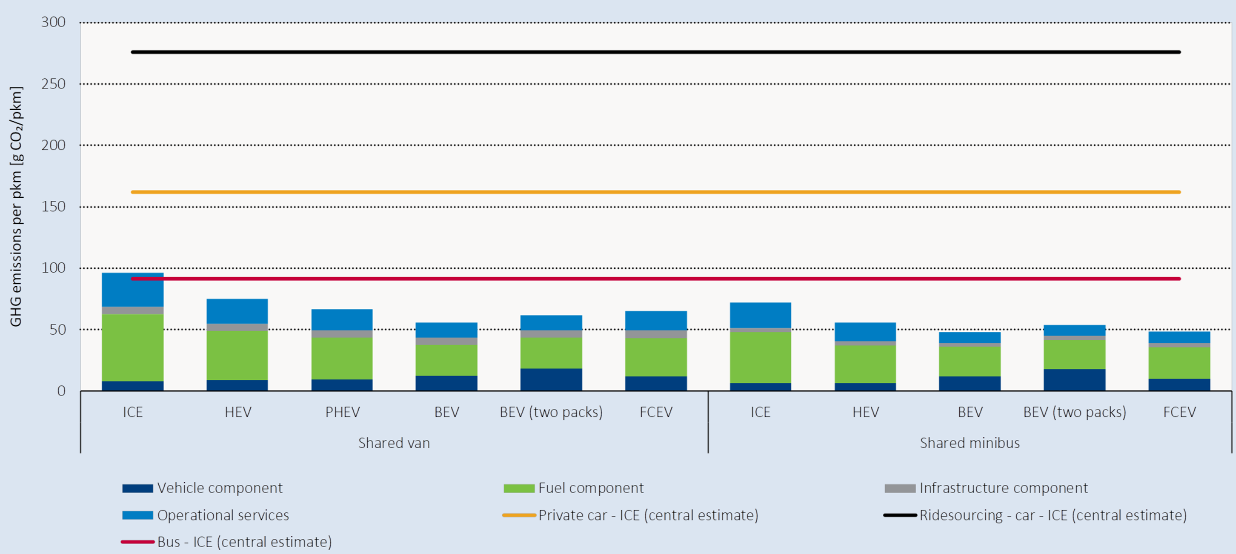
It is important to note that occupancy factors may have limits both in ridesourcing and public transport. The extent to which these services can scale depends significantly on consumer acceptance – which may be distributed unevenly among the different demographic groups and by location. Customer acceptance may also be impacted by external events, like a perceived lack of safety linked to crime or communicable diseases, as in the case of the Covid-19 pandemic).[49]

There may be an effective way to respond to the limited acceptance of sharing traditional cars for pooled services while raising occupancy to improve energy and environmental performances of ridesourcing: it requires rethinking vehicle design for ridesourcing services along the lines of larger-capacity vans and minibuses. Such vehicles exist already and currently provide pop-up routes that allow for lower deadheading distances and higher occupancies than conventional ridesourcing services (see Box 6). The International Transport Forum has issued a series of reports on shared mobility that further investigate 8- and 16-seater taxi-buses that provide such services (ITF, n.d.). While these types of services provide less flexibility and higher response times than traditional car-based ridesourcing, their integration in the offer of ridesourcing platforms may provide some of the consumer benefits of ridesourcing at a lower energy and GHG emission impact.

Box 6. Life cycle GHG emissions/pkm from ridesourcing services operated by vans and minibuses

Figure 16 illustrates that when ridesourcing is operated as on-demand shuttle services with lower deadheading distances and higher occupancies its life cycle GHG emissions per pkm are close to the ranges observed for public transport. They are even lower for shared minibuses. They are, therefore, significantly lower not only than the GHG impact per pkm of ridesourcing operated by passenger (as per the central estimate in Figure 2), but also than private cars using ICEs.

Figure 16. Life-cycle GHG emission impact of ridesourcing services operated by vans and minibuses



Note: For vans, these results are based on a utilisation rate of 70%, very close to the value reported by Parrott and Reich (2018) for Via in New York City. Combined with the travel needed to transfer the vans between the area of operation (downtown) and the depots – assumed to be the same as for buses – the total share of operational km in the total of all vehicle travel becomes 37.5%. Van capacity is assumed to be eight seats, with an average occupancy of 4.5 people (Via, 2020). Lifetime mileage is 400 000 km. For shared minibuses, these estimates are based on the same deadheading share of operational km in the total of all vehicle travel and lifetime mileage. The average capacity of a shared minibus is assumed to be 20 people (informed by Zeelo, 2020) and average occupancy is ten (resulting from a weighted average of the capacity factor of vans and buses).

ITF analysis is based on an assessment tool developed for this project and available at https://www.itf-oecd.org/good-to-go-environmental-performance-new-mobility. See Annex A for methodological details and data sources.

Another response that public authorities could adopt is setting differential curb access rules for pick-up and drop-off (PUDO) based on occupancy factors much as they do for roads when implementing high-occupancy vehicle (HOV) lanes. This approach recognises that public space is a valuable and constrained resource, especially in urban cores. Public authorities can establish a framework for curb access such that vehicles with high occupancy (e.g. buses, pooled minibuses and vans) have direct preferential access to high-volume destinations and curbside PUDO zones. This includes major streets, public transport nodes, essential services and educational facilities, and popular shopping areas. Low-occupancy ridesourcing vehicles and taxis would be incentivised (in the case of PUDO fees) or required to use PUDO zones slightly further away from these crowded areas (with the exception of those transporting passengers with mobility impairments). This measure requires, of course, a comprehensive curb management policy and effective monitoring – something few cities have yet in place.

Policies for better integration of new mobility services in public transport

A factor that cannot be captured by LCA alone is how the *full* deployment of new mobility options, in conjunction with facilitative policies, would impact the changes determining the structure of travel in the longer term. It has been argued that a much broader uptake of new mobility, in a way that would lead to a drop in the ownership and use of private cars for urban trips, would result in much more sustainable outcomes in terms of energy use and GHG emissions. It would also contribute to beneficial outcomes in terms of pollution, safety, noise and more balanced uses of public space.

However, available evidence shows that, in the current stage of deployment of new mobility options, new urban transport modes are not only replacing urban car trips but also public transport trips. It is also clear that determining whether or not a switch to new mobility delivers net improvements in energy and GHG emissions depends on: 1) the relative performance of those new mobility services and the options they replace; and 2) changes in the longer-term structure of the urban mobility demand.

In this context, policy interventions aiming to strengthen the passenger kilometre shares of modes with the lowest energy use and GHG emissions/pkm (all else being equal) appear to be an appropriate way forward. Given that both shared and owned micromobility tend to be associated with lower energy and GHG emissions than ridesourcing, policies aiming at the better integration of micromobility with public transport have the greatest chances of leading to net reductions in energy and GHG emission impacts.

Some of the measures that could help movement in this direction are: the application of tax rebates; differentiated fees; or the provision of subsidies for micromobility and ridesourcing operators that deploy and incentivise the use of their vehicles and services in areas that improve the catchment capacity of public transport. This could be most interesting in suburban areas where there is greater scope for relative increases in ridership due to the expansion of the catchment area around stations. Using ridesourcing or micromobility trips as feeder services to public transport in less dense areas would putatively increase the competitiveness of public transport with respect to car travel.

Mobility as a Service (MaaS), which provides multimodal mobility solutions that break the link between mobility and ownership of vehicles, is another development that could offer positive contributions towards the integration of micromobility with public transport. The potential benefits of a full-blown MaaS framework can already be induced by bilateral co-operation between micromobility operators and public transport authorities. One example includes the provision of data feeds by micromobility operators for inclusion in public transport operator's mobile apps, allowing users to see public transport information as well as micromobility vehicle availability. Another is the public incorporation of dedicated corrals and space to accommodate shared modes, including, for example, charging stations.

Additional policy action can also target structural interventions capable of reinforcing the integration of new mobility services with public transport. Policies that make micromobility and intermodal public transport trips more appealing for urban movements have the potential to kick-start a virtuous circle: raising the rates of utilisation of both public transport and shared devices; and driving down energy use and emissions per pkm as users shift from car travel to other modes. One way of doing this is by providing adequate and safe road space for shared and owned micromobility, e.g. through investments in bike lanes, e-scooter corrals, and, more generally, reclaiming public space from private automobiles. Continuous, comfortable, connected and safe infrastructure leads to a greater uptake of these modes beyond first-adopters and, in the case of active modes including pedal-assisted electric bicycles, delivers clear societal health benefits (ITF, 2013, 2018). Well-designed infrastructure strengthens public transport by extending catchment areas and facilitating longer-distance multimodal travel. These benefits are especially relevant in areas where public transport accessibility is lower, such as suburban areas (as opposed to central business districts). Such infrastructure also serves as a pressure valve for crowded public transport systems, providing people with alternative travel options at peak hours.

Notes

1 This issue is further exacerbated by the fact that economic insurance packages for new mobility businesses are subject to a lower degree of certitude compared with public transport, which is also often publicly subsidised. Yet, if new mobility services are disrupted, constituents are deprived of a service they may have relied on, with inevitable consequences for the reliability of an ecosystem that is important to break up the car dependence of urban movements.

2 Uber stated that in 2018, 24% of their ridesourcing gross bookings were realised from five metropolitan areas – Los Angeles, New York City, and the San Francisco Bay Area in the United States; London in the United Kingdom; and São Paulo in Brazil (United States Securities and Exchange Commission, 2019). Uber stated also that it "will continue to face challenges in penetrating lower-density suburban and rural areas, where our network is smaller and less liquid, the cost of personal vehicle ownership is lower, and personal vehicle ownership is more convenient" (United States Securities and Exchange Commission, 2019).

3 Rides totalled 9.2 billion according to Mittal (2019) for all ridesourcing providers but Didi, in 2018. Didi's rides were 7.5 billion in 2016 according to Chiu (2018). This is 1.8 times more than Uber, in the same year. Applying this ratio to the Uber rides for 2018 leads to an estimate of 5.2 billion rides for Didi in 2018. The ICCT (2019b) give a total estimate of 17.2 billion rides (based on trips per day figures) for the same year, slightly higher than the the sum of the 9.2 and 5.2 billion rides identified here.

4 For a more extensive definition of micromobility, see (ITF, 2020b).

5 In the United States, the National Household Travel Survey indicates that about 30% of all car trips are below 3.2 km (two miles), almost 50% below 4.8 km (three miles) and 60% below eight km (five miles) (ORNL, n.d.). This excludes walking, cycling and other modes of transport. Heineke et al. (2019) report that passenger trips of less than eight km (five miles), which account for as much as 50% to 60% of today's total passenger miles travelled in China, the European Union, and the United States.

6 Other players include Grow, Skip, Spin, Scoot, PopScoot, Beam, Tier Mobility, Wind Mobility, Voi Technology, Vogo, Dott, and Flash – all listed by Ajao, (2019) as having announced large capital raises in 2018-19.

7 In 2016, Asia accounted for 58% of worldwide membership (nine million) and 43% of global fleets deployed (70 000 vehicles). Europe was second with 29% of worldwide members (4.5 million) and 37% of vehicle fleets (60 000). North America followed with less than half of the members (1.8 million) and cars (25 thousand) of Europe, then Australia (100 000 members and 5 000 cars) and Latin America (7 000 members and 130 cars) (Shaheen, Cohen and Jaffee, 2018a). Europe had 3.7 million members and 47 000 cars in 2018 (Erich, 2018).

8 North America had almost three million members and 130 000 cars for peer-to-peer schemes at the beginning of 2017, according to Shaheen, Cohen and Jaffee (2018a). Erich (2018) estimated 7.9 million members and 326 000 cars in Europe for peer-to-peer carsharing. The lower availability of the cars in peer-to-peer schemes (where cars could be made available only occasionally, e.g. once a month or once every quarter) justifies a higher number of vehicles per member (see Erich (2018) for Europe and Shaheen, Cohen and Jaffee (2018a) and Shaheen, Cohen and Jaffee (2018b) for North America).

9 The term energy vector refers to a generic form of energy that can be stored and used on transport vehicles. Key examples include petroleum products, electricity and hydrogen.

10 Despite significant progress on LCA techniques and methodologies, LCAs remain limited by the fact that they represent the reality through a model (and the choices made to define the model, e.g. with respect to the granularity of the items embedded in a product) and cannot be decoupled from the methods selected to define different characteristics of the system that they aim to scrutinise.

11 Key and recent examples of these LCA applications include Kelly, Dai and Wang (2019), Jungmeier et al. (2019), Emilsson and Dahllöf (2019), Cazzola et al. (2019) [is this IEA 2019a or 2019d? Please modify as appropriate] and the reviews of Hausfather (2019) and Hall and Lutsey (2018).

12 GWPs give an indication of the contribution of the different gases to the possible global warming. They are expressed in form of an equivalent amount of CO_2 and aim to allow the measurement the impact of different gases to global warming with a single metric by introducing multiplicative factors to GWPs give an indication of the contribution of the different gases to the possible global warming. They are expressed in form of an equivalent amount of CO_2 and aim to allow the measurement the impact of different gases to global warming with a single metric by introducing multiplicative factors to apply to emissions of each specific gas, taking into account of the extent to which a unit of mass of emissions contributes to global warming with respect to the same mass of CO_2. According to the Intergovernmental Panel on Climate Change (IPCC), GWPs for CO_2, CH_4 and N_2O are equal to, respectively, 1, 34 and 298 (see Table 8.7 in Stocker et al., 2013).

13 The use of average values is interesting to evaluate average impacts that have relevance over long time periods, but there may be cases requiring to focus on indicators that are targeting more specific time periods (e.g. peak hours vs. non-peak when evaluating public transport

systems, since occupancy rates vary). In the analysis carried out here, the focus on energy and GHG emissions is relevant mainly for long time periods. Additionally, peak and off-peak variability is seen here as a necessary element allowing the operation of different types of transport services, given that continuous off-peak operation (which typically comes with higher impacts) would likely limit the economic viability of the services.

14 For example, the energy use per km of a battery-operated electric vehicle using electricity as energy vector depends on the energy efficiency of electric motors, and it is typically significantly higher than the energy use per km of an internal combustion engine using a liquid or gaseous fuel as energy vector.

15 As in the case of vehicle occupancy rates, network utilisation can vary at different points in time (e.g. peak vs. off-peak hours, day and night, winter and summer). Additionally, they can also vary by location (urban centre, suburban area, rural area). For energy inputs and GHG emission impacts, which have long-term implications, the use of average values (or the ratios of cumulative impacts and total usage parameter across the vehicle life) is the most relevant. Regarding spatial differences, the urban focus of this work suggests that the relevant values to take into account are once more average indicators characterising a metropolitan area, and not location-specific ones, given that the very nature of urban mobility intends to look at movements that take place across different parts of the metropolitan area.

16 Despite differences in accounting of primary energy between nuclear energy and modern electricity renewables like solar and wind (with greater weight given to nuclear electricity, since nuclear heat is assumed to be the primary form of energy for nuclear, while electricity itself is assumed to be the primary form of energy for solar and wind, as in the case of hydro), the share of fossil fuels in the energy mix remained prominent over the past decades (IEA, n.a.).

17 The California Ari Resources Board estimated that almost 11% of vehicle travel during this time overlaps between at least two companies (CARB, 2019).

18 This value reflects average values for well-to-refinery and refinery-to-tank emissions. Well-to-refinery emissions, in particular, may be subject to significant variations, depending on resource characteristics and extraction technologies and practices, as pointed out in Masnadi et al. (2018a), Masnadi et al. (2018b) and Malins et al., (2014).

19 For comparison, Kelly, Dai and Wang (2019) give values of 65 kg CO_2/kWh for a European-dominant supply chain and 100 kg CO_2/kWh a Chinese-dominant supply chain. They also identify the electricity mix used for aluminium smelting as a key driver of changes in the carbon intensity of current practices of automotive battery manufacturing.

20 Note that changes in the annual mileage and lifetime alter these results. Bikes that are underutilised and/or scrapped early are subject to increases in the amount of energy and GHG emissions per vkm and pkm due to the lower lifetime mileages implied by these practices.

21 A recent study on e-scooters (Hollingsworth, Copeland and Johnson, 2019) points at GHG emissions per pkm that, in a central assessment, are about 10% higher than those estimated here for the first generation of shared e-scooters, despite some differences in key assumptions. First, there is a difference in the amount of GHG emissions due to vehicle manufacturing (200 kg CO_2/vehicle in Hollingsworth, Copeland and Johnson (2019), and 163 kg CO_2/vehicle with the estimation method used here). Second, the ratio of travel of service vehicles per unit of e-scooter travel is higher in Hollingsworth, Copeland and Johnson (2019) than the 0.13 service vkm/e-scooter km retained in the analysis developed here. The latter is based on information from Chester (2018) and Domonoske (2019), representing established practices based on third-party service providers, complemented by Dickey (2020) and Perch Mobility (n.d.), representing new or emerging practices and information obtained from the authors' personal communications with different micromobility operators. The basis for the first difference is the decision to adopt a consistent approach across different modes used in this study, combined with the choice to rely on information derived from GREET2. The difference in the ratio of travel of service vehicles per unit of e-scooter travel stems from the focus on a city that required night-time removal of the e-scooters, irrespective of their state of charge, used in Hollingsworth, Copeland and Johnson (2019) and resulting in higher service vehicle travel requirements (and higher servicing costs). This reflects a desire to focus on servicing and repositioning practices that are more closely consistent not only with global practices (not including this specific obligation), but also with a business model that is more likely to be economically viable (an approach that is consistent with the choices made in this analysis for all other urban transport options). Daily travel distances are also different in the central case of Hollingsworth, Copeland and Johnson (2019), which use ten km/day/e-scooter and in this analysis, using 7.9 km/day/e-scooter to account for partial e-scooter availability (83%) due to the need for maintenance and time losses for repositioning and charging.

22 Note that emissions due to the vehicle cycle may also be larger than estimated here, given that their smaller production scale when compared with cars, mopeds and scooters, likely to be coupled with higher energy and GHG emission requirements for the assembly processes than those assumed in this analysis (relying on data that refer to cars).

23 Note that high loads (pkm/vkm) are a requirement that limits the scope of effective (both economically and environmentally) use of these modes to cases that require high capacity of passenger movements.

24 What works poorly from an economic perspective is also likely to work poorly from an environmental perspective.

25 Smaller increments in energy and GHG emissions/pkm due to the vehicle size also take place in the vehicle component. These are larger for BEVs and FCEVs, given the higher material intensity of these powertrains with respect to ICEs.

26 Results related to the energy balance are affected by methodological choices related to the way different forms of energy are defined. In the case of solar, wind and hydroelectricity, the electricity itself is considered as the primary form of energy. This implies that there are no losses upstream of the electrolysis process, which requires electricity to produce hydrogen. In the case of fossil fuels, the primary energy is the heat generated by their combustion. This adds losses taking place in the conversion of this heat into electricity, upstream of the electrolysis process.

27 The RED II sets an overall 14% target of renewable fuels in transport in 2030. To be eligible for financial support by public authorities and be counted toward this target, the RED II requires that low-carbon transport fuels produced in any installations starting operation from 1 January 2021 deliver at least 65% GHG emission savings (amongst other sustainability criteria). These requirements apply to biofuels, biogas and bioliquids (EC, 2020b).

28 A wide range of low-carbon fuel pathways are among the options thoroughly discussed in the well-to-wheel analyses of the JEC (JEC, n.d.2). Due to the wide spectrum of possible options and a scope that is focused on new mobility rather than alternative fuels, these are not discussed in detail in this analysis.

29 The balance between battery electric and ICE/FCEV driving is likely to depend on a number of different factors related to costs (of batteries, fuel cells, electricity, hydrogen, liquid fuels), the policies influencing them, the extent to which EV charging and hydrogen refuelling infrastructure will become available, and other aspects resulting from policies, political decisions (e.g. deliberate oil production cuts and/or increases) and market developments (e.g. related with the balance between oil supply and demand). Developing scenarios on potential levels of adoption for different solutions is beyond the scope of this report.

30 This is based on personal communication of the authors with an operator.

31 For micromobility, the determination of the ratio of service vehicle travel per km with passengers on board may be difficult, especially in cases where it is not directly controlled by the micromobility service provider. This can be the case, for example, when charging operations are delegated to third parties: as with “juicers”, contracted people or companies that pick up micromobility vehicles – namely e-scooters – off the streets and charge them. Given the importance of energy and GHG emission impacts due to operational services, addressing this is likely to require the adoption of different (more transparent and accountable) practices by operators, allowing them to have a better capacity to track information about the nature of the operational services.

32 From a budget perspective, these instruments are also well suited to align the balance of expenditures and revenues that they generate, not only because taxes on poorly performing vehicles can finance subsides on the best performing ones, but also because the emissions thresholds that defines which vehicles contribute and/or benefit from the scheme (and the extent to which this happens) can be adjusted over time.

33 The second part of the SAFE rule, finalised in April 2020, amends earlier standards for vehicle model years 2021-2026 (EPA, 2020), reducing the stringency of standards that were established earlier for model years 2021-2025. The first part of the SAFE rule, released in September 2019, also revokes the requirement of state and local authorities to develop GHG emissions standards as well as zero emission vehicle (ZEV) mandates for road transport vehicles (EPA, 2019). In November 2019 the US state of California and 22 other US states filed a lawsuit contesting the amendment (Shepardson, 2019a).

34 The availability of technical standards and/or regulations defining technical specifications of the vehicles and sustainability characteristics of the fuels are key prerequisites for this sort of regulation. For most road vehicles, technical standards and/or regulations on the measurement of energy use and tailpipe GHG emissions/km have been developed in the context of the World Forum for the harmonisation of vehicle regulations (WP.29) of the United Nations. In the case of fuels, the most relevant examples currently existing related with the sustainability criteria developed in the framework of the Low Carbon and Fuel Standards (LCFS) and Renewable Fuel Standards (RFS) in North America, the Fuel Quality and Directive (FQD) Renewable Energy Directives (RED, I and II) in Europe and the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) in the case of international aviation. The assessment of embedded energy and carbon in vehicle manufacturing is a subject where technical regulations and standards are still at an early phase of developments. The European Union is one of the global regions currently spearheading this development, as this sort of issue has relevance for the ongoing discussion on carbon border taxes.

35 See Sadler Consultants, Ltd. (n.d.) for an overview of such measures in Europe.

36 A recent ITF Roundtable on the regulation of app-based services (ITF, 2019) indicates that policies aiming to minimise the environmental impacts of transport are most effective when they are applied proportionately, consistently and broadly to all vehicles and services that contribute to increased energy use and GHG emissions. The same report also acknowledges that there may be cases where specific (or targeted) interventions may be relevant and appropriate.

37 Policies also come with costs. The latter may result from the budgetary requirements needed for economic incentives, the compliance burden on regulated entities, the monitoring and enforcement burden borne by regulators and the general costs that policy development engenders. Policies will need to ensure that these costs are minimised and certainly exceeded by the benefits that the policies generate.

38 Starting from the cases with the highest usage profiles, drivers or fleet owners should have a clear economic case to switch to energy-efficient technologies that fit desired (or required) vehicle size, comfort and power classes. This is due to the lower operational costs these technologies entail and the relevant share of costs that fuel consumption represents for drivers. However, technologies that have the best energy-efficiency and GHG-emissions/km performances are not widely adopted on these vehicles. There can be a wide range of reasons for this. The first is imperfect information regarding the energy performance and costs of technologies (see for example Andor, 2020). Other reasons include technology-specific limitations (e.g. in terms of availability or technical characteristics) since some of the vehicle categories are calibrated to the needs of average drivers.

39 Fuel consumption accounted for 11% of post-platform commission earnings in France, according to Uber (2019).

40 If the net savings are delivered through e-mobility, benefits also include opportunities for positive spillovers for industrial and economic development, given the centrality of e-mobility for cost reductions in battery storage, growing competitiveness of electric vehicles once battery costs decline (with a self-reinforcing effect) and the importance of battery storage for the broader context of the clean energy transition, generating other opportunities for increased scale, technology progress and further cost cuts.

41 ITF (2019) suggests that a clear understanding of the dynamics of the relevant market is a key requirement for the development of targeted measures related with the regulation of app-based services.

42 The imposition of age limits results in lower average emissions for the ridesourcing fleet as compared to the average emissions for all vehicles (where these impacts have been measured as in California) (CARB, 2019).

43 For example, France requires a minimum vehicle length (4.2 metres) and minimum power (84 kW) for ridesourcing vehicles, skewing per vehicle energy use and GHG emissions upwards (IGAS and CGEDD, 2018).

44 Usage profiles refer to different characteristics of driver behaviour with respect to their vehicle travel per year and, therefore, also the importance of energy consumption in their expenses. It can also identify different drivers directly, since different magnitudes of annual vehicle travel is likely paired with different drivers (and can also depend heavily on the frequency of their work on ridesourcing platforms).

45 However, given that ridesourcing drivers are not always aware of their full operating costs, the targeted provision of the impact of differentiated registration fees at the moment of purchase, set in the broader context of overall operating costs and potential earnings, could reinforce the shift towards more fuel-efficient vehicles.

46 This consideration is aligned with the recent ITF Roundtable Regulating App-based Mobility Services. The Roundtable's Summary and Conclusions (ITF, 2019) finds that generally applicable congestion charges or low-emission zones are more effective than measures only targeting ridesourcing (since they have a broader basis of application and avoid the risk of effects having only a temporary nature). It also warns that measures that specifically target ridesourcing in cities on the subject of congestion and urban pollution shall be weighted against the welfare benefits generated by the sector (ITF, 2019). The same report also flags some factors that could justify charges that apply specifically to ridesourcing and taxi services. In particular: i) the possibility for ridesourcing-specific charges designed to achieve the same policy objectives (including those related with the promotion of technology shifts) as parking fees (which do not apply to ridesourcing); and ii) congestion (and therefore energy use, pollutant and GHG emission) impacts due to the near constant movement of ridesourcing vehicles and their tendency to block traffic during pick-up and drop-off activity, especially in dense inner-urban environments.

47 This is because broader measures avoid the risk of inducing effects of a temporary nature (e.g. if they induce switches to single passenger car travel and/or away from rides that have been transitioned to low- or zero-emission vehicles). They also mitigate impacts that would otherwise disproportionately affect the benefits generated by the availability of ridesourcing as an additional transport option for urban mobility (see ITF (2019) for a more extensive discussion on the subject).

48 This policy design would be similar to the one used for low carbon fuel standards, aimed at regulating the maximum overall carbon intensity of fuels through the provision of a mix of fuels with different carbon intensities, weighting their relevance on the basis of their share in the total fuel mix. Another analogy can also be made with policies regulating fuel economies or GHG emissions per vkm, also based on averages for all new vehicles sold, with new vehicle registrations as weighting parameter.

49 For public transport (not in the focus of the main text), calls to increase occupancy on lightly used feeder routes may also run into people's objections to constrain travel to rigid and infrequent services.

References

6-t (2019a), *Enquête auprès des utilisateurs de trottinettes en free-floating Dott à Paris*, Study for Dott, 6-t Bureau, full report available here: https://6-t.co/etudes/utilisateurs-trottinettes-dott/.

6-t (2019b), *Enquête nationale sur l'autopartage – Edition 2019*, Study for Agence de l'Evironnement et de la Maîtrise de l'Energie, 6-t Bureau, full report accessible here: https://6-t.co/etudes/enquete-autopartage-2019/.

6-t (2019c), *Enquête sur les utilisateurs, l'utilisation et les impacts de Cityscoot à Paris et en banlieue parisienne*, Study for Cityscoot, 6-t Bureau, full report accessible here: https://6-t.co/etudes/enquete-cityscoot/.

6-t (2019d), *Usages et usagers de services de trottinettes électriques en free-floating en France*, Study for Study for Agence de l'Evironnement et de la Maîtrise de l'Energie, 6-t Bureau, full report accessible here: https://6-t.co/etudes/usages-usagers-trottinettes-ff/.

6-t (2016), *Etude sur les différentes formes de voitures de transport avec chauffeur (VTC)*, Study for Agence de l'Evironnement et de la Maîtrise de l'Energie, contract n° 1566C0030, 6-t Bureau, full report accessible here: https://www.uberisation.org/sites/default/files/etude-differentes-formes-voitures-transport-avec-chauffeur-vtc_rapport.pdf.

6-t (2014), "One-way carsharing: which alternative to private cars?", 6-t Bureau, full report accessible here: https://6-t.co/wp-content/uploads/2014/05/AD_ExecutiveSummary_140708-copie-2.pdf.

Adra, N., J.-L. Michaux and M. André (2004), *Analysis of the load factor and the empty running rate for road transport. Artemis - assessment and reliability of transport emission models and inventory systems*, 31p., hal-00546125, HAL archives-ouvertes, https://hal.archives-ouvertes.fr/hal-00546125/document.

Ajao, A. (2019), "Electric Scooters and Micro-Mobility: Here's Everything You Need to Know", Forbes https://www.forbes.com/sites/adeyemiajao/2019/02/01/everything-you-want-to-know-about-scooters-and-micro-mobility/#4e99f8b25de6 (accessed 07 August 2020).

Alstom and Bombardier (2015), "Azur - Environmnetal Product Declaration", Consortium Alstom-Bobardier, https://www.bombardier.com/content/dam/Websites/bombardiercom/supporting-documents/Sustainability/Reports/BT/Bombardier-Transportation-EPD-AZUR-2015-en.pdf.

Anair, D. et al. (2020), "Ride-Hailing's Climate Risks: Steering a Growing Industry Toward a Clean Transportation Future", Union of Concerned Scientists, https://www.ucsusa.org/sites/default/files/2020-02/Ride-Hailing%27s-Climate-Risks.pdf.

Andor, M. (2020), "Running a car costs much more than people think — stalling the uptake of green travel", *Nature*, https://doi.org/10.1038/d41586-020-01118-w (accessed 07 August 2020).

Ansaldo Breda (2011), "Metropolitana di Roma Linea C", Environmental Product Declaration, Registration N. S-P-00276, UN CPC Code 495, http://www.avnir.org/documentation/bdd/epd/epd276en.pdf.

ANL (2020a), "GREET® Model: The Greenhouse Gases, Regulated Emissions and Energy Use in Transportation Model", Argonne National Laboratory, https://greet.es.anl.gov/index.php (accessed 07 August 2020).

ANL (2020b), *GREET Publications*. https://greet.es.anl.gov/publications.

Athena Institute (2006), *A Life Cycle Perspective on Concrete and Asphalet Roadways: Embodied Primary Energy and Global Warming Potential*, http://www.athenasmi.org/wp-content/uploads/2012/01/Athena_Update_Report_LCA_PCCP_vs_HMA_Final_Document_Sept_2006.pdf.

Balding, M. et al. (2018), "Estimated TNC Share of VMT in Six US Metropolitan Regions (Revision 1)", Memorandum, Fehr & Peers, https://drive.google.com/file/d/1FIUskVkj9lsAnWJQ6kLhAhNoVLjfFdx3/view (accessed 07 August 2020).

Banks, K. (2020), "Industry stakeholders are divided on the merits of a national ZEV mandate as federal budget nears", *Electric Autonomy*, https://electricautonomy.ca/2020/02/04/industry-divided-on-the-merits-of-a-national-zev-mandate-as-federal-budget-nears/ (accessed 07 August 2020).

Base10 (2019), "It's all about e-scooters...Or is it?", Base10 Venture Capital, https://base10.vc/insights/last-mile-transportation/ (accessed 07 August 2020).

Bird (2019), "A Look at e-Scooter Safety: Examining risks, reviewing responsibilities, and prioritizing prevention", https://cleanairpartnership.org/cac/wp-content/uploads/2020/01/Bird-Safety-Report-April-2019-3-min.pdf (accessed 07 August 2020).

Briggs, M. (2018), "Will the car have a future?", Presentation for the MaaS Market – Concept to Delivery Conferernce, London, United Kingdom, 20 February 2018, Bank of America Merrill Lynch, www.maas-market.com/sites/default/files/MARTYN_BRIGGS_0.pdf.

BYD (2019), "The BYD K9", Technical statistics pamphlet, Build Your Dreams®, https://en.byd.com/wp-content/uploads/2019/07/4504-byd-transit-cut-sheets_k9-40_lr.pdf.

C2ES (2019), "U.S. State Clean Vehicle Policies and Incentives", map, Center for Climate and Energy Solutions, https://www.c2es.org/document/us-state-clean-vehicle-policies-and-incentives/ (accessed 07 August 2020).

California Senate (2018), "SB-1014 California Clean Miles Standard and Incentive Program: zero-emission vehicles", Bill No. 1014, Chapter 369, https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB1014.

CARB (2020), "Clean miles standard", webpage, California Air Resources Board, https://ww2.arb.ca.gov/our-work/programs/clean-miles-standard/about (accessed 07 August 2020).

CARB (2019), *SB 1014 - Clean Miles Standard: 2018 Base-year Emissions Inventory Report*, California Air Resources Board, https://ww2.arb.ca.gov/sites/default/files/2019-12/SB 1014 - Base year Emissions Inventory_December_2019.pdf.

Chang, A. et al. (2019), *Trend or fad? Deciphering the enablers of micromobility in the U.S.*, SAE International, https://www.sae.org/binaries/content/assets/cm/content/topics/micromobility/sae-micromobility-trend-or-fad-report.pdf.

Chen, Z., D. van Lierop and D. Ettema (2020), "Dockless bike-sharing systems: what are the implications?", *Transport Reviews*, Vol. 40, pp. 333-353, https://doi.org/10.1080/01441647.2019.1710306.

Cherry, C., J. Weinert and Y. Xinmiao (2009), "Comparative environmental impacts of electric bikes in China", *Transportation Research Part D: Transport and Environment*, Vol. 14/5, pp. 281-290, https://doi.org/10.1016/j.trd.2008.11.003.

Chester, M. (2008), "Life-cycle Environmental Inventory of Passenger Transportation in the United States", In *Institute of Transportation Studies: Dissertations*, University of California, Berkley, https://escholarship.org/content/qt7n29n303/qt7n29n303.pdf.

Chester, M. (2018), "It's a Bird…It's a Lime…It's Dockless Scooters! But Can These Electric-Powered Mobility Options Be Considered Sustainable Using Life-Cycle Analysis?", Chester energy and policy blog, https://chesterenergyandpolicy.com/2019/01/28/its-a-bird-its-a-lime-its-dockless-scooters-but-can-these-electric-powered-mobility-options-be-considered-sustainable-using-life-cycle-analysis/ (accessed 07 August 2020).

Chester, M. and A. Horvath (2009), "Environmental assessment of passenger transportation should include infrastructure and supply chains", *Environmental Research Letters*, Vol. 4/2, https://doi.org/10.1088/1748-9326/4/2/024008.

Chester, M., A. Horvath and S. Madanat (2010), "Comparison of life-cycle energy and emissions footprints of passenger transportation in metropolitan regions", *Atmospheric Environment,* Vol. 44/8, pp. 1071-1079, https://doi.org/10.1016/j.atmosenv.2009.12.012.

Chiu, K. (2018), "Didi Chuxing taking competition with nemesis Uber abroad", *Abacus*, South China Morning Post, https://www.abacusnews.com/who-what/didi-chuxing-taking-competition-nemesis-uber-abroad/article/2161545 (accessed 07 August 2020).

Clewlow, R. and G. Mishra (2017), *Disruptive Transportation: The Adoption, Utilization, and Impacts of Ride-Hailing in the United States*, Institute of Transportation Studies, University of California, Davis, https://merritt.cdlib.org/d/ark:%2F13030%2Fm5sj6gbk/1/producer%2FUCD-ITS-RR-17-07.pdf.

The Climate Group (2020a), EV 100, webpage, https://www.theclimategroup.org/project/ev100 (accessed 17 August 2020).

The Climate Group (2020b), RE 100, webpage, https://www.theclimategroup.org/RE100, (accessed 17 August 2020).

Cohen, A. and S. Shaheen (2016), *Planning for shared mobility*, APA Planning Advisory Service Reports, American Planning Association, Chicago, https://escholarship.org/content/qt0dk3h89p/qt0dk3h89p.pdf.

Cramer, J. and A. Krueger (2016). "Disruptive change in the taxi business: The case of Uber", *NBER Working Paper*, No. 22083, *American Economic Review*, Vol. 106/5, pp. 177-182, https://www.nber.org/papers/w22083.

DfT (2020), "Road traffic statistics – London", webpage, Department for Transport https://roadtraffic.dft.gov.uk/regions/6 (accessed 07 August 2020).

DfT (2019), *Road lengths in Great Britain: 2018*, Statistical release, Department for Transport, https://www.gov.uk/government/statistics/road-lengths-in-great-britain-2018.

Dickey, M. (2020), "How scooter charging startups want to make the industry more profitable", TechCrunch, https://techcrunch.com/2020/01/17/how-scooter-charging-startups-want-to-make-the-industry-more-profitable/?guccounter=1 (accessed 07 August 2020).

Dillet, R. (2019), "Lime stops working with freelancers in Paris", TechCrunch, https://techcrunch.com/2019/09/05/lime-stops-working-with-freelancers-in-paris/ (accessed 07 August 2020).

Domonoske, C. (2019), "Who Charges All Those Electric Scooters? Follow A Nocturnal 'Juicer'", National Public Radio, https://www.npr.org/2019/03/13/701130673/who-charges-all-those-electric-scooters-follow-a-nocturnal-juicer?t=1583502215112&t=1584954792847 (accessed 07 August 2020).

EC (2020a), *Clean transport, Urban transport: European Clean Bus deployment Initiative*, European Commission, https://ec.europa.eu/transport/themes/urban/cleanbus_en (accessed 07 August 2020).

EC (2020b), *Renewable Energy – Recast to 2030 (RED II)*, webpage, European Commission, https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii (accessed 07 August 2020).

EC (2019), "A European Green Deal: Striving to be the first climate-neutral continent", webpage, European Commission, https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en (accessed 07 August 2020).

EC (2018), *A Clean Planet for all: A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy*, Report No. COM/2018/773 final, European Commision, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0773.

Emilsson, E. and L. Dahllöf (2019), *Lithium-Ion Vehicle Battery Production. Status 2019 on Energy Use, CO_2 Emissions, Use of Metals, Products Environmental Footprint, and Recycling*, Report No. C 444, IVL Swedish Environmental Research Institute, https://www.ivl.se/download/18.14d7b12e16e3c5c36271070/1574923989017/C444.pdf.

EPA (2019), "Final Rule: One National Program on Federal Preemption of State Fuel Economy Standards", *Regulations for Emissions from Vehicles and Engines*, United States Environmental Protection Agency, https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-one-national-program-federal-preemption-state (accessed 17 August 2020).

EPA (2020), "The Safer Affordable Fuel Efficient (SAFE) Vehicles Final Rule for Model Years 2021-2026", *Regulations for Emissions from Vehicles and Engines*, United States Environmental Protection Agency, https://www.epa.gov/regulations-emissions-vehicles-and-engines/safer-affordable-fuel-efficient-safe-vehicles-final-rule (accessed 17 August 2020).

Erich, M. (2018), *Car sharing unlocked: How to get a 7.5 million shared car fleet in Europe by 2035*, ING, https://think.ing.com/uploads/reports/ING_-_Car_sharing_unlocked.pdf.

European Cyclists' Federation (2011), *Cycle more often 2 cool down the planet! Quantifying CO_2 savings of cycling*, https://ecf.com/sites/ecf.com/files/ECF_CO2_WEB.pdf (accessed 07 August 2020).

Fink, L. (2020), "A Fundamental Reshaping of Finance", Letter to CEO, BlackRock, https://www.blackrock.com/us/individual/larry-fink-ceo-letter (accessed 07 August 2020).

Fishman, E., S. Washington and N. Haworth (2014), "Bike share's impact on car use: Evidence from the United States, Great Britain, and Australia", *Transportation Research Part D: Transport and Environment*, Vol. 31, pp. 13-20, https://doi.org/10.1016/j.trd.2014.05.013.

Franckx, L., and I. Mayeres (2016), *Future trends in mobility: the rise of the sharing economy and automated transport*, Deliverable 3.3 of the MIND-SETS project, funding came from the European Union's Horizon 2020 reseach and innovation programme, http://www.mind-sets.eu/wordpress/wp-content/uploads/2017/05/D3.3_ANNEXA.pdf.

Friedel, A. (2020), Free Floating Micro Mobility Map Europe, https://maphub.net/Augustin/micro (accessed 07 August 2020).

Frost and Sullivan (2016), *Future of Carsharing Market to 2025: Technology Advancements, Market Consolidation and Government Initiatives to Influence Market Growth Over the Next Decade*, Frost and Sullivan, available for purchase at https://store.frost.com/future-of-carsharing-market-to-2025.html.

Furth, P. (1985), Alternating Deadheading in Bus Route Operations. *Transportation Science*, INFORMS, Vol. 19/1, pp. 13-28, https://doi.org/10.1287/trsc.19.1.13.

Gauquelin, A. (2020), "Jump: the next battery-swap technology?", *Shared MicroMobility*, https://shared-micromobility.com/jump-the-next-battery-swap-technology/ (accessed on 14 August 2020).

Gogoro (2020), The Gogoro Battery Pack, http://gogoro-website.s3-website-ap-northeast-1.amazonaws.com/battery-pack/ (accessed 14 August 2020).

Gurria, A. (2020), "An inclusive, green recovery is possible: The time to act is now", https://ccacoalition.org/en/blog/inclusive-green-recovery-possible-time-act-now.

Hall, D., and N. Lutsey (2018), "Effects of battery manufacturing on electric vehicle life-cycle greenhouse gas emissions", *ICCT Briefing*, International Council on Clean Transportation, https://theicct.org/publications/EV-battery-manufacturing-emissions (accessed 14 August 2020).

Hausfather, Z. (2019), "Factcheck: How electric vehicles help to tackle climate change", *Carbon Brief*, https://www.carbonbrief.org/factcheck-how-electric-vehicles-help-to-tackle-climate-change (accessed 14 August 2020).

Hawkins, A. (2020), "Skip pulls back the curtain on the high costs of electric scooter maintenance", *The Verge*, https://www.theverge.com/2020/1/21/21072785/skip-electric-scooter-life-cycle-maintenance-costs (accessed 14 August 2020).

Heineke, K. et al. (2019), "Micromobility's 15,000-Mile Checkup", McKinsey and Company, https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/micromobilitys-15000-mile-checkup (accessed 14 August 2020).

Henao, A., W. Marshall and B. Janson (2019), *Impacts of Ridesourcing on VMT, Parking Demand, Transportation Equity, and Travel Behavior*, Report No. MPC-514, Mountain-Plains Consortium, Fargo, https://www.ugpti.org/resources/reports/downloads/mpc19-379.pdf.

Hildebrand, P. and T. Donilon (2020), "Davos brief", Lit. No. DAVOS-BREIF-0120, BlackRock, Inc., https://www.blackrock.com/us/individual/literature/whitepaper/bii-davos-brief-2020.pdf.

Hollingsworth, J., B. Copeland and J. Johnson (2019), "Are e-scooters polluters? The environmental impacts of shared dockless electric scooters", *Environmental Research Letters*, Vol. 14/8, https://doi.org/10.1088/1748-9326/ab2da8.

Honda (2019), "Scooters", company catalogue, Honda Motor Europe, Ltd., https://moto.honda.fr/content/dam/local/france/motorcycles/brochures/Honda-catalogue-scooters.pdf.

Hug, V. (2015), "Copenhagen trial with 12 m B.Y.D K9 electric buses", Presentation, Movia Trafik, https://www.nordicenergy.org/wp-content/uploads/2018/02/3.-Test-of-large-charged-electric-buses-in-Copenhagen-Victor-Hug.pdf.

ICCT (2019a), "Overview of global zero-emission vehicle mandate programs", Briefing, International Council on Clean Transportation, https://theicct.org/sites/default/files/publications/Zero Emission Vehicle Mandate Briefing v2.pdf.

ICCT (2019b), "Assessing ride-hailing company commitments to electrification", Briefing, International Council on Clean Transportation, https://theicct.org/sites/default/files/publications/EV_Ridehailing_Commitment_20190220.pdf.

IGAS and CGEDD (2018), *La régulation du secteur des voitures de transport avec chauffeur et des taxis*, Report, IGAS No. 2018-050R and CGEDD No. 012070-01, Inspection générale des Affaires Sociales and

Conseil Général de l'Environnement et du Développement Durable, https://www.ecologique-solidaire.gouv.fr/sites/default/files/2019.01.31_rapport_regulation_vtc_igas.PDF.

Impact World+ (n.d.), "IMPACT World+ Framework", Website, IMPACT World+, www.impactworldplus.org/en/methodology.php (accessed 14 August 2020).

International Association of Public Transport (2015), *Extending Life of Rolling Stock*.

International Association of Public Transport (2019), *Development of System Design Authority for Alterations/Modifications to rolling stock*.

IEA (2020), Tracking Transport 2020, International Energy Agency, Paris, https://www.iea.org/reports/tracking-transport-2020.

IEA (2020b), *Global EV Outlook 2019: Entering the decade of electric drive?*, OECD Publishing, Paris, https://doi.org/10.1787/d394399e-en.

IEA (2020c), *How clean energy transitions can help kick-start economies*, Commentary, International Energy Agency, Paris, https://www.iea.org/commentaries/how-clean-energy-transitions-can-help-kick-start-economies.

IEA (2019), *Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017*, Licence: Creative Commons Attribution CC BY-NC-ND 3.0 IGO for all parts of the work except chapters 4 and Annex B, and International Energy Agency (IEA)/International Council on Clean Transportation (ICCT), 2019, (Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017). Licence: Creative Commons Attribution CC BY-NC-ND 3.0 IGO for chapters 4 and Annex B of the work. https://www.globalfueleconomy.org/media/708177/gfei-wp19.pdf.

IEA (n.d.), Data and statistics, https://www.iea.org/data-and-statistics (accessed 14 August 2020).

IPCC (2018), "Chapter 2: Mitigation pathways compatible with 1.5°C in the context of sustainable development", in *Global Warming of 1.5°C*, An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, https://www.ipcc.ch/sr15/ (accessed 14 August 2020).

ISO (2015). *ISO/TC 207/SC 1 - Environmental management systems*, International Organization for Standardization, https://committee.iso.org/sites/tc207sc1/home/projects/published/iso-14001---environmental-manage/life-cycle.html (accessed 14 August 2020).

ITF (2020a), "Electric Mobility: Taking the Pulse in Times of Coronavirus", *Covid-19 Transport Brief*, International Transport Forum, Paris, https://www.itf-oecd.org/sites/default/files/electric-vehicles-covid-19.pdf.

ITF (2020b), *Safe Micromobility*, International Transport Forum, Paris, https://www.itfoecd.org/sites/default/files/docs/safe-micromobility_1.pdf.

ITF (2019), *Regulating App-Based Mobility Services: Summary and Conclusions*, ITF Roundtable Reports, No. 175, OECD Publishing, Paris, https://doi.org/https://doi.org/10.1787/94d27a3a-en.

ITF (2018), *Cycling Safety: Summary and Conclusions*, ITF Roundtable Reports, No. 168, OECD Publishing, Paris, https://doi.org/10.1787/7f4da6f4-en.

ITF (2013), *Cycling, Health and Safety*, ITF Research Reports, OECD Publishing, Paris, https://doi.org/10.1787/9789282105955-en.

ITF (n.d.), ITF Work on Shared Mobility, https://www.itf-oecd.org/itf-work-shared-mobility (accessed 14 August 2020).

ITP (2017), *Understanding and Managing Congestion*, Report for Transport for London on behalf of Greater London Authority, Integrated Transport Planning, Ltd., http://content.tfl.gov.uk/understanding-and-managing-congestion-in-london.pdf.

JEC (2019), *Decarbonising transport by 2030: the EC-industry JEC analysis*, European Commission's Joint Research Centre, EUCAR and Concawe, Presentation at the EU Sustainable Energy Week, Brussels, https://www.eusew.eu/sites/default/files/programme-additional-docs/EUSW_JEC_all_v1306_final.pdf.

JEC (n.d.1), JEC website, European Commission's Joint Research Centre, EUCAR and Concawe, https://ec.europa.eu/jrc/en/jec (accessed 14 August 2020).

JEC (n.d.2), Well-to-Wheels Analyses, webpage, European Commission's Joint Research Centre, EUCAR and Concawe, https://ec.europa.eu/jrc/en/jec/activities/wtw (accessed 14 August 2020).

Jullien, A., M. Dauvergne and V. Cerezo (2014), Environmental assessment of road construction and maintenance policies using LCA, *Transportation Research Part D: Transport and Environment*, Vol. 29, pp. 56-65, https://doi.org/https://doi.org/10.1016/j.trd.2014.03.006.

Jungmeier, G. et al. (2019), *Estimated Greenhouse Gas Emissions and Primary Energy Consumption in the Life Cycle Assessment of Transportation Systems with Passenger Vehicles*, Joanneum Research, Graz, https://circabc.europa.eu/d/d/workspace/SpacesStore/26e009dc-49c3-4d7b-be1e-e3c5ed871855/Report_LCA_Tool_20191029_FINAL_1.2.pdf.

Kelly, J., Q. Dai and M. Wang (2019), "Globally regional life cycle analysis of automotive lithium-ion nickel manganese cobalt batteries" *Mitigation and Adaptation Strategies for Global Change*, Vol. 25, pp. 371-396, https://doi.org/10.1007/s11027-019-09869-2.

Kwak, A., L. Alves and R. Greco (2019), "Pesquisa de perfil dos usuários de patinetes e bicicleta Yellow em São Paulo" ("Profile search of Yellow scooters and bicycle users in São Paulo"), *Medium*, https://medium.com/@growmobility/pesquisa-de-perfil-dos-usuários-de-patinetes-e-bicicleta-yellow-em-são-paulo-55728861ac57 (accessed 14 August 2020).

Lagadic, M. (2019), "Emerging mobility solutions and their impact on practices", Presentation made at the International Transport Forum's Corporate Partnership Board workshop on 1 October 2019, https://www.itf-oecd.org/sites/default/files/docs/emerging-mobility-solutions-impact.pdf.

LEVC (n.d.), Grants and incentives for electric taxi drivers: Programme funding available to support electric, low emission taxis, webpage, https://www.levc.com/finance/ev-taxi-grants-incentives/ (accessed 14 August 2020).

Li, Y. et al. (2018), "Calculation of life-cycle greenhouse gas emissions of urban rail transit systems: A case study of Shanghai Metro", *Resources, Conservation and Recycling*, Vol. 128, pp. 451-457, https://doi.org/10.1016/j.resconrec.2016.03.007.

Lime (2018), *Year-End Report*, https://www.li.me/hubfs/Lime_Year-End Report_2018.pdf.

Loijos, A., N. Santero and J. Ochsendorf (2013), "Life cycle climate impacts of the US concrete pavement network", *Resources, Conservation and Recycling*, Vol. 72, pp. 76-83, https://doi.org/10.1016/j.resconrec.2012.12.014.

Mahadikar, J., R. Mulangi and T. Sitharam (2015), "Optimization of bus allocation to depots by minimizing dead kilometers", *Journal of Advanced Transportation*, Vol. 49/8, https://doi.org/10.1002/atr.1312.

Malins, C. et al. (2014), *Upstream Emissions of Fossil Fuel Feedstocks for Transport Fuels Consumed in the European Union*, International Coucil on Clean Transporation, Washington, D.C., https://circabc.europa.eu/sd/a/0eef6ba6-280f-4bcd-a804-3a6bd7794d78/ICCT_Upstream-emissions-of-EU-crude_Feb2014.pdf.

Martin, E., S. Shaheen and J. Lidicker (2010), "Impact of carsharing on household vehicle holdings: Results from North American Shared-Use Vehicle Survey", *Transportation Research Record*, Issue 2143, pp. 150-158, https://doi.org/10.3141/2143-19.

Masnadi, M. et al. (2018a), Global carbon intensity of crude oil production, *Science*, Vol. 361/6405, pp. 851-853, AAAS, Washington, D.C., https://doi.org/10.1126/science.aar6859.

Masnadi, M. et al. (2018b), "Well-to-refinery emissions and net-energy analysis of China's crude-oil supply" *Nature Energy*, Vol. 3, pp. 220-226, https://doi.org/10.1038/s41560-018-0090-7.

Mayor of London (2019), "Mayor sets out plans for London's electric vehicle future", https://www.london.gov.uk/press-releases/mayoral/mayor-sets-out-londons-electric-vehicle-future (accessed on 14 August 2020).

Meddin, R. et al. (n.d.), "The Meddin Bike-sharing World Map", http://bikesharingworldmap.com/ (accessed 17 August 2020).

Miatto, A. et al. (2017), "Modeling material flows and stocks of the road network in the United States 1905-2015", *Resources, Conservation and Recycling*, Vol. 127, pp. 168-178, https://doi.org/10.1016/j.resconrec.2017.08.024.

Mishel, L. (2018), *Uber and the labor market: Uber drivers' compensation, wages, and the scale of Uber and the gig economy*, Economic Policy Institute, Washington, D.C., https://www.epi.org/files/pdf/145552.pdf.

Mittal, S. (2019), "Ride-sharing: Profitable or not?", *Sector Briefing*, No. 75, DBS Group Research, DBS Bank Ltd., https://www.dbs.id/id/sme/aics/pdfController.page?pdfpath=/content/article/pdf/AIO/052019/190527_insights_ride_sharing.pdf.

Motor Scooter Guide (n.d.), Honda Elite S / SR / LX (SA50), webpage, http://www.motorscooterguide.net/Honda/EliteSA50/EliteSA50.html (accessed 14 August 2020).

Nasibov, E. et al. (2013), "Deadhead trip minimization in city bus transportation: A real life application", *Traffic and Transportation*, Vol. 25/2, pp. 137-145, https://pdfs.semanticscholar.org/94ea/eed1e234c5a228bf948a25fdab7d60c4405b.pdf.

New York Taxi and Limousine Commission (2018), "Driver income rules", https://www1.nyc.gov/assets/tlc/downloads/pdf/driver_income_rules_12_04_2018.pdf.

Nikitas, A. (2019), "How to save bike-sharing: An evidence-based survival toolkit for policy-makers and mobility providers", *Sustainability*, Vol. 11, https://doi.org/10.3390/su11113206.

Nylund, N. O., K. Erkkilä and T. Hartikka (2007), "Fuel consumption and exhaust emissions of urban buses: Performance of the new diesel technology", VTT Technical Research Centre of Finland, https://www.vttresearch.com/sites/default/files/pdf/tiedotteet/2007/T2373.pdf.

ORNL (n.d.), Popular Vehicle Trips Statistics, webpage, Oak Ridge National Laboratory, https://nhts.ornl.gov/vehicle-trips (accessed 17 August 2020).

OECD (2005), *OECD guiding principles for regulatory quality and performance*, OECD Publishing, Paris, https://www.oecd.org/fr/reformereg/34976533.pdf.

Parrott, J. and M. Reich (2018), *An Earnings Standard for New York City's App-Based Drivers: Economic Analysis and Policy Assessment*, Report for the New York City Taxi and Limousine Commission, The New School, New York and Univeristy of California, Berkley, http://www.centernyc.org/an-earnings-standard.

PBOT (2018), "2018 E-Scooter Pilot User Survey Results: Live or Work in Portland, Portland Bureau of Transportation, https://www.portlandoregon.gov/transportation/article/700916.

Perch Mobility (n.d.), Scooter charging pods and suites, website, https://www.perchmobility.com/ (accessed 17 August 2020).

RATP (2018), *Rapport d'activité et de développement durable 2018*, Groupe RATP, https://ratpgroup.com/ratpgroupe-content/uploads/2019/06/ratp_radd18.pdf.

Rayle, L. et al. (2014), "App-based, on-demand ride services: Comparing taxi and ridesourcing trips and user characteristics in San Francisco", Working Paper, University of California Transportation Center, Berkley, https://www.its.dot.gov/itspac/Dec2014/RidesourcingWhitePaper_Nov2014.pdf.

Sadler Consultants, Ltd. (n.d.), Urban access regulations in Europe, website, https://urbanaccessregulations.eu/ (accessed 17 August 2020).

SAE (2019), "SAE International Publishes Industry's First Standard for Classification and Definition of Powered Micromobility Vehicles", Press release, Society of Automotive Engineers, https://www.sae.org/news/press-room/2019/11/sae-international-publishes-industry's-first-standard-for-classification-and-definition-of-powered-micromobility-vehicles (accessed 17 August 2020).

Santero, N., A. Loijos and J. Ochsendorf (2013), "Greenhouse gas emissions reduction opportunities for concrete pavements", *Journal of Industrial Ecology*, Vol. 7/6, pp. 859-868, https://doi.org/10.1111/jiec.12053.

Saxe, S., E. Miller and P. Guthrie (2017), "The net greenhouse gas impact of the Sheppard Subway Line", *Transportation Research Part D: Transport and Environment*, Vol. 51, pp. 261-275, https://doi.org/10.1016/j.trd.2017.01.007.

Schaller Consulting (2017), *Unsustainable? The Growth of App-Based Ride Services and Traffic, Travel and the Future of New York City*, http://www.schallerconsult.com/rideservices/unsustainable.pdf.

Schönberg, T., A. Dyskin and K. Ewer (2018), "Bike sharing 5.0.: Market insights and outlook", Presentation, Roland Berger, https://www.rolandberger.com/publications/publication_pdf/roland_berger_study_bike_sharing_5_0.pdf.

Schuller, A. and M. Aboukrat (2019) "White paper: The Role of e-scooters and Light Electric Vehicles in Decarbonizing Cities", Study report for Bird, Carbone 4, Paris, http://www.carbone4.com/wp-content/uploads/2019/09/Carbone-4-for-Bird-E-Scooter-and-Cities-decarbonization.pdf.

Severengiz, S. et al. (2020), "Life Cycle Assessment on the Mobility Service E-Scooter Sharing", in *2020 IEEE European Technology and Engineering Management Summit (E-TEMS)*, pp. 1-6, Dortmund, https://doi.org/10.1109/E-TEMS46250.2020.9111817.

Shaheen, S. and A. Cohen (2019), "Shared Micromoblity Policy Toolkit: Docked and Dockless Bike and Scooter Sharing", Transportation Sustainability Research Center, University of California, Berkeley, https://doi.org/10.7922/G2TH8JW7.

Shaheen, S., and A. Cohen (2016), *Shared Mobility: Current Practices and Guiding Principles*, United States Department of Transporation, Washington, DC, https://ops.fhwa.dot.gov/publications/fhwahop16022/fhwahop16022.pdf.

Shaheen, S., A. Cohen and M. Jaffee (2018a), *Innovative Mobility: Carsharing Outlook – Peer-to-peer carsharing market trends in North America*, Transportation Sustainability Research Center, University of California, Berkeley, https://doi.org/10.7922/G2ZC811P.

Shaheen, S., A. Cohen and M. Jaffee (2018b), *Innovative Mobility: Carsharing Outlook - Worldwide carsharing growth*, Transportation Sustainability Research Center, University of California, Berkeley, https://doi.org/10.7922/G2CC0XVW.

Sharma, N., B. Smeets and C. Tryggestad (2019), "The decoupling of GDP and energy growth: A CEO guide", *McKinsey Quarterly*, McKinsey and Company, https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/the-decoupling-of-gdp-and-energy-growth-a-ceo-guide (accessed 17 August 2020).

Shepardson, D. (2019a), "California, other U.S. states sue to block EPA from revoking state emissions authority", Reuters, https://www.reuters.com/article/us-autos-emissions-california/california-other-u-s-states-sue-to-block-epa-from-revoking-state-emissions-authority-idUSKBN1XP25Q (accessed 17 August 2020).

Shepardson, D. (2019b), "Daimler, BMW exiting North American car-sharing market, cutting in Europe", Reuters, https://www.reuters.com/article/us-autos-carsharing/daimler-bmw-exiting-north-american-car-sharing-market-cutting-in-europe-idUSKBN1YM2BI (accessed 17 August 2020).

Shoup, D. (2007), "Cruising for parking", *Access*, No. 30, Spring 2007, http://shoup.luskin.ucla.edu/wp-content/uploads/sites/2/2015/02/CruisingForParkingAccess.pdf.

Siemens (2005), "Metro Oslo: Environmental product declaration according to ISO 14021", Brochure, https://www.ecodesign-company.com/download/Siemens-EPD_metro_oslo.pdf?m=1473168020.

Stocker, T. F. et al.(2013), *Climate Change 2013: The Physical Science Basis*, Working Group, Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, https://doi.org/10.1017/CBO9781107415324.

Sustainable Bus (2018), "Solaris unveils the mild hybrid low entry. Curb weight under 9 tonnes", https://www.sustainable-bus.com/hybrid/solaris-unveils-the-mild-hybrid-low-entry-curb-weight-under-9-tonnes (accessed 17 August 2020).

Tagliapietra, S. (2020), "COVID-19 is causing the collapse of oil markets: When will they recover?", Bruegel blog, https://www.bruegel.org/2020/04/covid-19-is-causing-the-collapse-of-oil-markets-when-will-they-recover/ (accessed 17 August 2020).

TIER Mobility (2019), "TIER mobility launches operations with swappable batteries as the first e-scooter provider worldwide", Press release, TIER Mobility, https://www.tier.app/tier-mobility-launches-operations-with-swappable-batteries-as-the-first-e-scooter-provider-worldwide/ (accessed 17 August 2020).

Toll, M. (2019), "It's finally happening: Americans are switching to electric mopeds as rental programs expand", Electrek, https://electrek.co/2019/08/16/electric-mopeds-americans-revel-scoot-muving/ (accessed 17 August 2020).

TfL (2020), "Emissions standards for taxis, TfL webpage, Transport for London, https://tfl.gov.uk/info-for/taxis-and-private-hire/emissions-standards-for-taxis (accessed 17 August 2020).

TfL (2019), "Tube trivia and facts", Transport for London, https://madeby.tfl.gov.uk/2019/07/29/tube-trivia-and-facts/ (accessed 17 August 2020).

TfL (2018), *Travel in London: Report 11*, Transport for London, http://content.tfl.gov.uk/travel-in-london-report-11.pdf.

TfL (2016), "Taxi and Private Hire Action Plan 2016", Transport for London, http://content.tfl.gov.uk/taxi-and-private-hire-action-plan-2016.pdf.

Transportation life-cycle assessment. (2020). *Publications, Reports, and Media,* www.transportationlca.org/publications.php (accessed 17 August 2020).

Uber (2018), "Uber's Clean Air Plan to help London go electric", https://www.uber.com/en-GB/newsroom/uber-helps-london-go-electric/ (accessed 17 August 2020).

Uber (2019), "Étude sur les revenus des chauffeurs en 2018" ("Study of driver revenus in 2018"), https://s3.amazonaws.com/uber-static/France/Uber+-+étude+sur+les+revenus+des+chauffeurs+en+2018.pdf.

USGS (2006), "Materials in Use in U.S. Interstate Highways", Fact Sheet 2006-3127, United States Geological Survey, United States Department of the Interior, https://pubs.usgs.gov/fs/2006/3127/2006-3127.pdf.

United States Securities and Exchange Commission (2019), *Form S-1 Registration statement under the Securities Act of 1933 - UBER Technologies, Inc.*, https://www.sec.gov/Archives/edgar/data/1543151/000119312519103850/d647752ds1.htm (accessed 17 August 2020).

Via (n.d.), "How many people will I share a ride with?, Customer support webpage, https://support.ridewithvia.com/hc/en-us/articles/360003374231-How-many-people-will-I-share-a-ride-with- (accessed 17 August 2020).

Wang, J. (2019), "Sharing the Road — Travel Efficiency", Medium, https://medium.com/uber-under-the-hood/sharing-the-road-travel-efficiency-2c70b6119618 (accessed 17 August 2020).

Williams, R. (2019), "Three Early Takeaways from the 2017 National Household Travel Survey", Medium, https://medium.com/uber-under-the-hood/three-early-takeaways-from-the-2017-national-household-travel-survey-b23506efe8ad (accessed 17 August 2020).

Xiaomi (n.d.), Mi Electric Scooter, webpage, https://www.mi.com/global/mi-electric-scooter/specs (accessed 14 August 2020).

Zeelo (n.d.), Zeelo is making hiring a coach super simple, Zeelo webpage, https://travel.zeelo.co/great-value-coach-hire/ (accessed 17 August 2020).

Annex A. Methodological details backing the results of the analysis

This Annex provides details on the methodology and key sources of information and assumptions used in the LCA tool developed for this report. The focus of this description is on the parameters used for the elaboration of the central estimates shown in Figure 2 to Figure 5.[1]

A key aspect and a unique feature of this work is the application of a consistent set of assumptions on the carbon intensity of materials and energy sources used by all the forms of urban mobility assessed. The objective behind this choice is the possibility of developing a comparative assessment of life-cycle emissions of different urban transport options where results are not positively or negatively affected by technical aspects that apply exclusively to one option or another.

Methods and assumptions used in this analysis are outlined below, looking at each life cycle assessment component: vehicles, fuels/energy vectors, infrastructures and operational services.

Vehicles

The evaluation of energy and GHG emission impacts related to the vehicle component were developed at the vehicle level, then attributed to vkm based on lifetime and mileage, and to pkm based on loads evaluated as the weighted average of distances covered and the number of passengers associated with each distance portion (including deadheading, where relevant).

More specifically, energy and GHG emissions impacts related to the vehicle component were estimated, taking into account:

- The energy and GHG emission intensities of material production (including assumptions of the shares of recycled materials) available from the GREET2 model of the Argonne National Laboratory, combined with a range of other data sources allowing to develop estimates on vehicle weights and material composition.

  Vehicle weights (summarised in Table 1) and material composition assumptions have been informed by Hollingsworth, Copeland and Johnson (2019) and personal communications with operators for e-scooters; Cherry, Weinert and Xinmiao (2009) for bikes, e-bikes, mopeds (complemented by Motor Scooter Guide (n.d.) for details on engine weight, as well as GREET2 for the weight and composition of electric motors), Chester (2008), Sustainable Bus (2018) and BYD (2019) for buses, as well as GREET2 for fuel cell vehicles (scaled based on differences in energy and power requirements between buses and cars); GREET2 in combination with IEA (2019) for cars, and; 5) Ansaldo Breda (2011), Alstom and Bombardier (2015) and Siemens (2005) for metros/urban trains.

1 The information included here also have relevance for the sensitivity results illustrated in the main analysis. This is because, unless otherwise specified, sensitivity results have been developed in a framework where all input values except the sensitivity parameters themselves have been kept unchanged.

- The energy and GHG emission intensities of vehicle assembly and disposal, available in GREET2 for the case of cars, generalised to other modes.
- The energy and GHG emission intensities of battery manufacturing, based on specific battery chemistries, also available in GREET2[2] , as well as the estimates on battery capacities summarised in Table 1.

  Battery capacity assumptions have been informed by Hollingsworth, Copeland and Johnson (2019) and communications with operators for e-scooters; Cherry, Weinert and Xinmiao (2009) for e-bikes and e-mopeds (complemented by Gogoro, 2020); IEA (2019a) and GREET2 for cars, and; BYD (2019) and Hug (2015) for electric buses.

The assessment also used the assumption that the energy and GHG emission intensities of battery disposal are comparable to those of the disposal of materials used in cars.[3]

The assumptions related to vehicle mileages and lifetimes, as well as loads (pkm/vkm), are summarised in Table 2.

Mileage assumptions for shared e-scooters have been informed by Chester (2018), Hawkins (2020), Lagadic, (2019) and Chang et al., (2019), and Severengiz et al., (2020) for shared e-scooters, in addition to specific communications with operators. Schuller and Aboukrat (2019) and personal communications with operators informed assumptions on e-scooter lifetimes. Mileages and lifetimes of bikes are informed by the European Cyclists' Federation (2011) and conservative assumptions to reflect the effect of theft, tampering and vandalising. Fishman, Washington and Haworth, (2014) is the main source for shared bike and e-bike usage, RATP (2018) and 6-t (2019c) for shared mopeds. Typical urban speeds and travel times of 1.5 hours per weekday, resulting in 12 100 km/year, informed mileage assumptions for cars. Car lifetimes (15 years) reflect averages observed in developed countries. Data from the CARB (2019), Schaller Consulting (2017), Cramer and Krueger (2016), Henao, Marshall and Janson (2019) and Balding et al. (2018) inform the assumptions retained for the average daily travel of ridesourcing and taxis. In particular, they inform the choice to use an annual mileage (deadheading included, but excluding the commute to/from the driver's residence) of 48 000 km/year. Lifetimes are calculated considering a lifetime mileage of 400 000 km, including travel needed for commutes and assuming a dedicated use of vehicles for ridesourcing. Urban bus mileages consider an average speed of 18.5 km/h for eight hours a day, six days a week and 50 weeks per year. Bus lifetimes (nine years) reflect European averages (EC, 2020a). Annual travel assumptions for urban trains/metros account for an average speed of 27.5 km/h, for eight hours/day and six days/week for 50 weeks/year for urban trains/metros. Their lifetimes are based on inputs derived from International Association of Public Transport (2015 and 2019).[4]

Fuels/energy vectors

For the fuel component, energy and GHG emission impacts were developed per each unit of final energy needed in the vehicles (final energy use). These results were then converted to energy and GHG emissions per vkm multiplying by specific energy consumption, i.e. the ratio of final energy use per km, also

2 These refer to manufacturing facilities running at 75% capacity for a plant size of 2 GWh and relying mostly on natural gas for the supply of heat.

3 Energy and emissions needed to transport the vehicle from the area of production to the point of commercialisation, based on simplified assumptions related to the selection of modes used to move the products across different parts of the globe (and having minor impacts on the results) have also been included in the vehicle cycle.

4 This information was obtained following personal communications of the authors with members of the ITF with Nicolas Erb (Alstom).

accounting for the shares of driving attributed to each relevant form of final energy. Lifetime mileages allow the conversion of these results to data related with each vehicle, and loads (evaluated as the weighted average of distances covered and the number of passengers associated with each distance portion, including deadheading) allow their conversion into energy and GHG emissions per pkm.

More specifically, energy and GHG emissions impacts related with the fuel component were estimated taking into account:

- energy and GHG emission intensities of fuel production and (where relevant) combustion available in the GREET1 model of the Argonne National Laboratory[5]
- estimates of energy use per km for each urban transport option, summarised in Table 1 derived from a range of different sources, including technical assessments, technical specifications, modelling tools and scientific literature.

  For cars, the energy use/km is consistent with the assumptions used by the International Energy Agency in the Global EV Outlook 2019 in the case of mid-size cars (IEA, 2019a), informed by the assessment developed in IEA (2019), as well as the default values available in the GREET1 tool. The resulting values are consistent with the results of energy consumption test developed with the Worldwide Harmonised Light Duty Test Procedure (WLTP). E-scooter estimates are informed by Xiaomi (n.d.) and personal communications with operators (especially for new generation e-scooters); e-bikes estimated from Cherry, Weinert and Xinmiao (2009); e-mopeds from IEA (2019a); mopeds from average value of small vehicles (less than 125 cc, the most widespread globally), e.g. available in Honda (2019); buses from Nylund, Erkkilä and Hartikka, 2007; e-buses from Hug (2015); metros/urban trains from Ansaldo Breda (2011), Alstom and Bombardier (2015) and Siemens (2005), among others.

A limit in the assessment of energy and GHG emission impacts related with the fuel component relates to the nature of the system boundary that, given the methodological choices outlined above, excludes the construction and roll out of dedicated infrastructure for the provision of electricity to plug EVs (PHEVs and BEVs) and the distribution of hydrogen to FCEVs.[6]

5 The GREET1 values have been adjusted to account for a 33% efficiency in the case of nuclear electricity in order to align the methodology to that used by the International Energy Agency for the elaboration of its energy balances. More broadly, the results available in GREET1 for the fuels considered in this assessment are similar in magnitude to those found in other well-to-wheel assessment tools, in particular the analyses developed in the case of Europe by the JEC (JEC, n.d.1).

6 In the case of plug EVs, additional energy and GHG emissions would be imputable to the construction and installation of private and publicly accessible chargers (accounting also for the chargers to vehicle ratios), as well as eventual modifications that may be required to the power system to deal with structural changes in the electricity demand (something that is subject to different interpretations), that may reasonably not only be imputable to plug EVs (e.g. net additions to the electricity generation capacity, including emissions due to the construction and installation of new power generation facilities and eventual upgrades to the electricity transport and distribution network) and may even lead to net savings (e.g. in cases where EVs are integrated as an element allowing for greater flexibility in the power system). In the case of FCEVs, additional energy and GHG emissions would need to account for the construction and installation of hydrogen charging stations and hydrogen transport and distribution systems. As in the case of modifications that may be required to the power system, some of these impacts (especially those related to hydrogen transport) would need an allocation based on the relevance of different hydrogen end-uses, and others (e.g. those related with improvements in the power system flexibility enabled by the FCEV integration in the electricity grid) may come with net benefits (e.g. due to the possibility of increasing the share of renewable energy in power generation). The frequency of use of the refuelling station is also relevant for the assessment of life-cycle impacts of FCEVs, as it is for plug EVs. Given the characteristics of FCEVs, and in particular their reliance on refuelling practices similar to ICE vehicles (and, therefore, less decentralised than in the case of plug EVs), ensuring high frequency of use of the refuelling infrastructure is especially important to limit the life-cycle impacts of the construction and installation of hydrogen charging stations and hydrogen transport and distribution systems.

Infrastructures

Energy and GHG emission impacts for the infrastructure component were first evaluated for each km of infrastructure (based on material contents and, for road, excluding earthworks) and then converted into impacts per vkm through information on the frequencies of use of different infrastructures. The latter are specific to each vehicle. Impacts expressed per vkm are then converted into impacts per vehicle or pkm using lifetime mileages and loads, as already outlined in the case of the fuel component.

More specifically, energy and GHG emissions impacts related with the infrastructure component were estimated taking into account:

- Energy and GHG emission intensities of the production of cement and steel from the GREET2 model of the Argonne National Laboratory.
- Material intensities of different types of infrastructures (bike lanes, urban roads, bus lanes and metro tracks) available in scientific literature. In particular, material intensities (asphalt, cement, concrete and steel) of roads have been informed by Miatto et al., (2017), Athena Institute (2006), Loijos, Santero and Ochsendort (2013), Santero, Loijos and Ochsendort (2013) and USGS (2006). For urban rail, material intensities are informed by Saxe, Miller and Guthrie (2017), Li et al. (2018), Chester, Horvath and Madanat (2010) and Chester and Horvath, (2009).
- Corrective factors aiming to include energy and GHG emissions imputable to infrastructure maintenance. These are evaluated assuming that the emissions due to infrastructure construction account for 67% of the total of construction and maintenance (based on Jullien, Dauvergne and Cerezo, 2014) and 58% for rail (based on Saxe, Miller and Guthrie, 2017).
- Corrective factors for the share of energy and emissions due to road maintenance that allocate the values resulting from the assumptions just described to cars and modulate them based on vehicle weight (doubling emissions from maintenance for vehicles with a weight that is double the weight for cars, for example).
- Assumptions on infrastructure lifetimes (30 years for roads and bike lanes, 50 for metro tracks).
- Frequencies of use of different infrastructure types based on the generalisation of values found in the case of London, thanks to the availability of detailed data on infrastructure extension and usage profiles. Road traffic statistics for London are extracted from DfT (2020) and the road network extension from DfT (2019). Bus lanes are available in ITP (2017). Cycle lanes in TfL (2018). Metro activity and network extension are available in (TfL, 2019).

In addition to the simplifications just described, an additional limit in the assessment of energy and GHG emission impacts related with the infrastructure component is the exclusion from the system boundaries of stationary docking systems, relevant for some of the new mobility modes (especially e-bikes). Considering that docking infrastructure for e-bikes has material requirements that are comparable in magnitude to those of manufacturing the bikes themselves, that the docking infrastructure is likely to have a longer lifetime of the shared bikes, but also that there are impacts associated with construction work needed to install the docks and that there is more than a single dock per shared bike, it is conceivable that adding docking stations and their construction could lead to energy and GHG emission impacts from the infrastructure component that have a similar magnitude of those related with the manufacture of the shared bikes themselves. In addition, differences in vehicle lifetimes, likely lower in the case of dockless bikes than for station-based ones, also influence energy and GHG impacts when measured per vkm or pkm (the higher the lifetime mileage, the lower these impacts are, all else being equal).

Operational services

Energy and GHG emission impacts related to operational services were assessed accounting for amount of travel by service vehicles to enable the operation of new mobility services.

They were calculated first per each km of service vehicle travel and then multiplied by the ratio of service vehicle travel per unit of final travel to get estimates of energy and GHG emissions per vkm. This ratio depends on the average daily distance of service vehicle trips required, the average number of vehicles handled by each service vehicle trip and the average daily distance actually travelled by the vehicles when they are in operation (final travel). Impacts expressed per vkm are then converted into impacts per vehicle or pkm using lifetime mileages and loads, as already outlined in the case of the fuel component.

More specifically, energy and GHG emissions impacts related with operational services were estimated as follows:

- For micromobility, taking into account: i) the type of vehicles needed for the operational services[7] (shown in Table 2); ii) the average daily distance of the service vehicle trips; iii) the average number of vehicles (or batteries) handled in each trip;[8] and iv) their well-to-wheel energy use and GHG emissions per km. In the last case, the use of well-to-wheel figures reflects the fact that only emissions due to the fuel component are accounted. This is based on the consideration that vehicles are not built on purpose for this use, but also used for other purposes (the same assumption was retained in Hollingsworth, Copeland and Johnson, [2019]).

  For e-scooters, the daily distance of service vehicle trips and the number of vehicles handled in each trip are informed by information shared (through personal communications) with the authors by a number of operators, and they are complemented by data available from Chester (2018), Domonoske (2019) representing established practices based on third-party service providers, complemented by Dickey, (2020) and Perch Mobility (n.d.), representing new or emerging practices. These lead to assumptions of 11.25 km of service vehicle round trip/day/e-scooter. This value is compatible with 45 km of service vehicle travel per round trip per day (or 90 km of service vehicle travel per day, with each vehicle completing two round trips per day) and a frequency of e-scooter servicing trips of one every four days).

  A key difference between first-generation and new shared e-scooters is the number of vehicles handled in each service trip. These are assumed to be limited to ten for first-generation, and increase to 14 (on average) for the new generation (leaving, therefore, good margins for improvement since the capacity of the servicing vans can attain 60 units per trip).

  For e-bikes and e-mopeds, the daily distance of service vehicle trips and the number of vehicles handled in each trip are assumed to be the same as for the latest e-scooter generation.

- For ridesourcing and bus services, taking into account of deadheading km and the commuting travel from/to the driver residence.

  Assumptions related with deadheading km have been informed by the sources outlined in Box 1 for buses, taxis and ridesourcing, retaining the value of 38.5% of deadheading (excluding multi-apping) in the total of deadheading km and km with passenger on board in the specific case of

7 Operational services for shared micromobility service include travel needed for charging and repositioning. The latter is neglected for e-mopeds and not considered for ICE powered shared mopeds.

8 For e-scooters, these are informed by Chester (2018) and Domonoske (2019), representing established practices based on third-party service providers, complemented by Dickey, (2020) and Perch Mobility (n.d.), representing new or emerging practices.

ridesourcing (CARB, 2019) and adding to it 0.29 km per km with a passenger on board to account for commuting (Henao, Marshall and Jansen, 2019). For taxis, deadheading km were based on the ridesourcing estimate multiplied by the ratio available in the analysis of Cramer and Krueger (2016). For buses, the deadheading share considered in the central estimate is 10%.

For taxis and ridesourcing, energy and GHG emissions/vkm related with operational services include distances related with overheading, cruising and commuting travel to and from the driver residence. Impacts due to overheading and cruising on the average loads are reflected in all results expressed using pkm as the functional unit.

Annex B. Workshop participants

Sarah BADOUX, Public Policy Associate, VOI, Sweden

Björn BRÖSKAMP, International Marketing Manager, Tier Mobility GmbH, Germany

Jean-Baptiste BURTSCHER, Group External Affairs and Sustainable Development Manager, Valeo, France

Pierpaolo CAZZOLA, Advisor, Energy, Technology and Environmental Sustainability, International Transport Forum (ITF)

Adam COHEN, Survey Researcher, University of California Berkeley - Institute of Transportation Studies, United States

Philippe CRIST, Advisor - Innovation and Foresight, ITF

Anne DE BORTOLI, Postdoctoral Associate Visiting Researcher, University of Patras, ENPC/IFSTTAR/UPEM, Greece

Simone EHRENBERGER, Researcher, Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR) German Aerospace Center, Germany

Steffen EPPLER, Mobility Solutions Strategy Team, Bosch, Germany

Lina FEDIRKO, Senior Program Associate, Transportation and Advisory and Research Teams, ClimateWorks, United States

Patrick GAILLARD, Senior Lab Scientist, Aramco, France

Victor GORDILLO ZAVALETA, Senior Lab Scientist, Aramco, France

Marine GORNER, Analyst, International Energy Agency (IEA)

Ali GUIROUS, Business development Executive, Private Equity, Financial and Business Services, Frost & Sullivan, United States

Melinda HANSON, Senior Manager, Sustainability Policy, Bird, Netherlands

Agnès JULLIEN, Director, European and International Affairs, IFSSTAR, France

Gerorge KAMIYA, Analyst, IEA

Marion LAGADIC, Project Manager, 6t, France

Hadrien LEMAIRE, Business Development Executive, Mobility, Frost & Sullivan, United States

Luis MARTINEZ, Lead Modeller / Transport Analyst, ITF

Sharon MASTERSON, Manager, Corporate Partnership Board, ITF

Lucien MATHIEU, Transport and Emobility Analyst, T&E, Belgium

Julie MORIN, Responsable des Études d'Économie des Transports (ÉMET/ EDT), RATP Group, France

Romain MUGGEO, R&D LCA Expert, Michelin, France

Alison MURPHY, Director, Sustainability and Impact, Lime, United States

Alian ROUSSEAU, Directeur des Relations Extérieures France, CIRC, France

Camille ROZANES, Sustainability Manager, Alstom Group, France

Alexandre SANTACREU, Policy Analyst, Road Safety, ITF

Eddy VAN BOUWEL, Policy Planning Senior Advisor, ExxonMobil, Belgium

Philippe VENTEJOL, Senior Advisor RATP Group, RATP Group, France

Michael WANG, Manager, Systems Assessments, Argonne National Laboratory, United States

Laurence WILSE SAMSON, Senior Manager, Policy Research, Bird, Netherlands

Marta YUGO, Science Executive, Economics and Modelling (CO_2 and Energy), Concawe, Belgium

International Transport Forum

Good to Go?

Assessing the Environmental Performance of New Mobility

This report examines the climate impact of personal and shared electric kick-scooters, bicycles, e-bikes, electric mopeds, as well as car-based ride-sharing services. Users in cities across the globe are rapidly adopting new mobility forms, helped by digital connectivity and electrification technologies. New urban mobility services are often sold as “green” solutions. But what is their real impact on energy demand and greenhouse gas emissions? This study analyses the life-cycle performance of a range of new vehicles and services based on their technical characteristics, operation and maintenance, and compares it with that of privately owned cars and public transport. Finally, the report identifies solutions to make new mobility a useful part of the urban transport mix while helping to reduce energy use and limit climate change.

International Transport Forum
2 rue André Pascal
F-75775 Paris Cedex 16
+33 (0)1 73 31 25 00
contact@itf-oecd.org
www.itf-oecd.org

OECD

Published: 09/2020 | Photo credit: Ana Cuzovic