eHUBS - Smart Shared Green Mobility Hubs

Deliverable 1.1

State-of-the-art related to eHUBS

Prepared by:

- Fanchao Liao – TU Delft
- Gonçalo Correia – TU Delft

Contributors:

- Gustav Bösehans – Newcastle University
- Paul Goodman – Newcastle University
- Jaap Vleugel – TU Delft
- Bart van Arem – TU Delft
- Dilum Dissanayake – Newcastle University
- Neil Thorpe – Newcastle University
- Margaret Bell – Newcastle University

Table of contents

Executive summary

Shared mobility including e-mobility is expected to gradually replace car use and reduce the negative externalities of current road transport that is dominated by private fossil-fuel powered car trips. However, the further development and promotion of these services require knowledge regarding people's preference for these services and their impacts on multiple aspects of society. In order to better inform policy makers and indicate directions for further research, we conduct a comprehensive review of existing literature on shared e-mobility focusing on three themes: system performance, demand estimation and impact assessment.

First, we introduce the three themes both regarding the research question they aim to answer and the methodologies they apply. System performance studies mostly provide descriptive statistics and visualization of service usage patterns; demand estimation studies apply several different statistical models to analyze transaction records or stated preference data; while impact assessment studies (especially those on environmental impacts) use simulation. This survey of methodology provides solid foundation for the methodological approach used in our project.

We briefly review the findings on current performance of existing shared e-mobility systems, including their user profile, trip characteristics and usage pattern. As shared e-mobility services are still in their initial stage of development, their current users generally fit the characteristics of typical early adopters of new mobility modes: they are mostly male, middle age (typically between 25-45), with high education and higher than average income. In general users are concerned with environmental issues and are environmentally friendly, usually have limited access to a car, travel less by car and are frequent public transport and bike users; in addition, many of them are multimodal being flexible and open-minded regarding transport modes.

A categorization of the factors that influence the demand of several shared e-mobility modes is made and the impact of all factors has been elaborated. A wide range of factors which have influence on shared mobility demand have been identified by previous studies, including attributes of shared mobility service operation, individual socio-demographics, household characteristics, psychological variables, transport connectivity, land use variables, travel patterns and time and trip varying factors. We also summarize the evaluated and simulated impacts of shared e-mobility services on various aspects. Apart from the most commonly mentioned environmental impacts and direct influences on transportation system, it also has social, health and land use impacts.

We surveyed existing electric mobility policy incentives and propose a typology based on the following dimensions: vehicle type, business model, focus of incentive and addressed stakeholder. So far most policy incentives aim towards incentivizing consumers to buy EVs. More attention shall be devoted towards electric micro-mobility and usage of shared mobility services.

Finally, we discuss several possible trends of shared e-mobility development including service organization, the relation between different shared mobility modes, integration of different modes and operators and its relation with automation.

1. Introduction

Shared mobility and electrification are two main trends of transport systems because they can potentially deliver positive impacts in many different aspects: reduce traffic congestion by cutting single occupancy private car trips, reduce greenhouse gas emissions, improve accessibility and flexibility of mobility (Rycerski et al. 2016). Shared e-mobility refers to services which combine the two trends and may achieve synergy regarding the envisioned positive impacts. Several companies and governments have been operating pilot or full-scale shared e-mobility systems and are quickly expanding available services. In order to better facilitate the market penetration of shared e-mobility, more knowledge regarding its current system performance, consumer demand and potential impacts can be helpful with the decision making process of government bodies and shared mobility companies.

Our literature review on shared e-mobility service aims to provide a comprehensive synthesis of findings from existing relevant studies. The review aims to answer the following questions: 1) What are the main themes of shared e-mobility research? What methodologies are applied for each theme? 2) What are the main findings under each theme? 3) What are the possible future trends of shared e-mobility development? What recommendations can be given for future research?

When we refer to shared e-mobility, this respects to a diverse set of transport modes beyond the automobile. We include a wide range of modes of transport that involve vehicles powered by an electric motor (at least partially). We briefly introduce the main modes we include in this review in the following:

Electric carsharing: this is the most commonly considered mode in shared e-mobility. Electric carsharing is expected to speed up the replacement of fossil-fuel powered cars by EVs, since using shared EVs is not supposed to meet as much resistance as adopting private EVs due to the high purchase costs and multiple risks and uncertainties. Apart from the positive environmental impacts achieved by combining sharing and EV, deploying EVs in the shared car fleet can also be beneficial for operators as it can theoretically reduce operating cost as its energy cost is lower than CV. However, in reality electric carsharing faces higher operational complexity since EVs need a long charging time, which can increase the overall costs (Perboli et al. 2018).

*Electric shared micro-mobility***:** the term micro-mobility first appeared in 2017 and denotes those vehicles which are light (less than 500 kg) and designed for short distances (less than 15 km). It mainly consists of (conventional) bikes and scooters, while also includes other less common modes such as skateboard, gyroboard, hoverboard and unicycle. Like a full-size automobile, these small vehicles can also be electrified and deployed in a shared service. Currently there has been two types of electric shared micro-mobility systems which gain popularity, namely e-bike sharing and e-scooter sharing.

E-bike sharing: E-bike sharing systems are mostly found in Europe, which is likely due to its better biking infrastructure and culture. Depending on whether pedal assistance is necessary, e-bikes can be categorized into pedelecs (with pedal-assist) and e-mopeds: most e-bike sharing uses pedelecs, the top speed of which ranges from 25-45 km/h.

E-scooter sharing: E-scooter refers to kick scooters which can go up to 20km/h. The proliferation of e-scooter is unprecedented, it has largely replaced dockless bike-sharing and quickly gained popularity in many US cities (Populus 2018).

This literature review includes studies regarding shared e-mobility services with EV, e-bike (also e-cargo bike) and e-scooter. We used Google Scholar for starting collecting scientific articles and reports for the literature review. The keywords used were *sharing* combined with type of modes (electric vehicle, e-bike, e-scooter, e-cargo bike). Afterwards backward snowballing was applied on the initial article base. Almost all studies were conducted rather recently (within the past five years) so we did not apply any time filter and only chose articles based on their relevance. We also only consider passenger transport and exclude freight transport studies (mostly on e-cargo bikes).

This article is organized as follows: section 2 briefly introduces the content and methodologies of the three main categories of studies. Section 3 presents and synthesizes the findings in previous articles under the three categories. Section 4 identifies the types of incentives for electric mobility in general with a focus on electric shared mobility. Section 5 discusses several trends of shared e-mobility's future development. The final section concludes the article with main findings and recommendations for future research.

2. Main topics and methodology

In this section we extract several main topics from existing studies on shared e-mobility and briefly introduce their content and methodology.

Nowadays, there is a rapidly growing body of research investigating the development and uptake of shared mobility options, mostly cycle and car sharing (Burkhardt & Millard-Ball, 2006; Fishman, 2016; Shaheen et al, 1998, 2010), as well as the purchase of electric vehicles (e.g., Morton et al 2011; Rezvani et al 2015), including electric cycles and cars.

However, there remains a significant gap with regard to quantifying the uptake of shared mobility options available at physical mobility hubs or eHUBS, which differ from the more traditional shared mobility options in providing a choice from diverse shared (electric) mode options (e-bikes, e-cargo bikes, e-scooters or e-cars) to meet the user's specific needs at any one point in time. Therefore, an immediate concern is how to approach the study of shared mobility uptake.

Table 1 below lists common approaches to the study of EV uptake (adapted from Morton et al, 2011), which has been slightly modified to apply to the study of shared mobility uptake. These approaches can be variously applied to evaluate existing system performance (Section 2.1), potential demand estimation (Section 2.2) or impact evaluation (Section 2.3).

Table 1. Common methodological approaches to the study of (shared) electric mobility uptake (adapted from Morton et al, 2011)

Approach	Description
Agent-based modelling	• Capture some dynamic effects including the causal interactions between users and service provider's decisions and government policy (including infrastructure provision) • Investigate co-dependent user attributes, product attributes and market offerings, as well as other exogenous factors
Geo-demographic modelling and market segmentation	• Concerned with discussing group attitudes, behaviour and preferences of early adopters and mainstream users
Pre/post trials	• Before and after interviews of participants in shared (electric) mobility trials lasting between a few minutes to a few weeks or even months • Provide potential users with real word experience of shared mobility use • Offer the most comprehensive evidence on use habits, range anxiety (in the case of EVs), travel behaviour and overall user response
Qualitative surveys	• Can be used to explore symbolic meanings through the use of in-depth and ethnographic interviews • A possible caveat is that new symbolic meanings take time to surface among consumers
Questionnaire/attitude surveys	• Often largely confined to how consumers rank or rate certain attribute sets by importance • Other studies use batteries of attitude questions to elicit views on affective and symbolic motives, values and personality (or mobility styles). Usually based on theoretical underpinnings, although many studies are not
Stated Preference/Revealed Preference	• Combined with discrete choice (DC) analysis to infer user's evaluation of shared mobility attributes, infrastructure and policy incentives • Provides valuable insight into topics including market penetration, substitution effects, market dynamics and attribute valuation

2.1 Existing system performance

In the past few years there have been many new pilot projects and companies setting up shared e-mobility services worldwide. Many studies investigated the performance of these systems in order to derive insights for operations of similar systems in the future. Common topics include profiling system users, describing usage behavior, characterizing and visualizing the spatiotemporal patterns of trips generated by the users of the systems. These studies either collect survey data from system users or directly obtain transaction data from system operators. Data analysis usually remains at the level of description (descriptive statistics) and visualization.

2.2 Potential demand estimation

A strand of studies focuses on exploring factors which influence consumer preferences for shared e-mobility services which can be used in predicting potential demand for these services. Depending on their specific perspectives, studies can be further divided into the following two groups:

- *Disaggregate approach*: this group of studies take each individual as unit and investigates their choice of using the service. Commonly used dependent variables include portfolio choice regarding whether to become member of a shared mobility system, extent of intention of using the shared mobility system and mode choice for a specific trip. Given this focus on individuals, the data source of these studies is usually survey responses from general population or potential users.
- *Aggregate approach*: these studies usually directly analyze transaction data of an existing system and take geographic zone as unit. Therefore, the dependent variable can be number of members or usage frequency of a certain zone during a certain period.

The factors which influence demand identified by these two groups of studies are largely overlapping albeit in different forms: for example, "age of individual" in disaggregate approach would be "average age of a certain zone" in the aggregate approach. There are also some factors which only apply to one of the approaches, such as the built environment variables of a geographical zone. The main categories of influential factors include system operational attributes, individual-specific variables, built environment, travel pattern, trip characteristics and time-varying variables. More detailed description of factors can be found in section 3.2. Two points are worth noticing: first, different demand variables (such as membership choice and frequency of use) may be governed by different factors (Becker et al. 2017); second, some variables which are commonly used as proxy for actual demand such as intention to use expressed before implementation are not necessarily related to final decision of becoming a user (Munkácsy and Monzón 2017a).

Depending on the dependent variable and theoretical underpinning, demand studies applied a wide array of methodologies in collecting and analyzing data. Since shared e-mobility systems are still in its infancy period in most places, the most often used data collection method is stated choice experiment, while in cities and countries where such systems are already in place, revealed preference data can be collected via transaction records or surveys inquiring respondents' actual behavior. Multiple statistical models are applied to analyze the data depending on the dependent variable: when the research question is investigating people's preference for shared mobility service among other modes, the most often used model is discrete choice model; when studies aim to directly find out what influence the number of booking requests or profit, regression is used. A small fraction of studies asked for people's intention of using shared e-mobility service and focused on soft attitudinal constructs which may influence behavior, with structural equation models being the models used for the analysis in these cases. See Table for a detailed list of methodologies used in demand studies. The results of these studies are usually a statistical model consisting of a series of factors influencing demand with corresponding coefficients which are estimated; the model can be used as an input for demand forecast and demand-based location selection.

2.3 Impact evaluation

The main potential impacts of shared e-mobility systems can be roughly categorized into transportation, environmental, land use and social effects (Shaheen and Cohen 2013). There have been a small number of studies aiming to evaluate the impact of existing systems or forecast potential impact of prospective systems.

The environmental impact of shared e-mobility schemes may be evaluated in a number of ways, e.g. by utilisation of outputs from a simulation of the scheme, or by inference and extrapolation from survey data. Typically such information can be coupled with suitable emission rate data to give an indication of the 'tailpipe' (direct atmospheric) emissions changes associated with the scheme, or the additional emissions associated with electricity generation upstream. Estimation of these changes is driven by two factors: The change in vehicle kilometres travelled (VKT) by mode, through the introduction of the scheme, and the nature of the vehicles being affected by the scheme, in terms of their original fuel source, engine (i.e. CV vs. EV), on-board technology and operational, kinematic characteristics.

The former factor, change in vehicle kilometres travelled by mode, will be driven by:

- Substitution or reduction of trips by one mode (i.e. by conventional vehicle, either private car, fleet vehicle or public transport), in favour of another (i.e. the electric vehicle, be it bicycle, scooter, cargo-bike or car), and:
- Induced or lengthened trips, whereby a trip is made by the EV that wouldn't have been made previously (e.g. because of lack of access to a suitable vehicle) or the trip is lengthened by the characteristics of the vehicle (e.g. an e-bike may allow a longer distance to be travelled for the same effort as a normal bicycle).

The latter factor determines the emissions characteristics of the vehicle, and allows appropriate emissions factors or rates to be applied to the by-mode VKT values. Influencing characteristics include:

- The type, size, weight and loading of the vehicle chassis, which may/will determine the engine size, rated power, and fuel used by the vehicle, and;
- The age of the vehicle, which may determine what emissions control technologies are present (e.g. catalytic converters, diesel oxidation catalysts, diesel particulate filters, selective catalytic reduction systems, exhaust gas recirculation systems etc.). For conventional vehicles the age may be used as a proxy for what 'EURO class' the vehicle falls into, and hence what emissions factors (i.e. emissions per km travelled) may be applied. Note that public transport emissions may be expressed in terms of 'per passenger kilometre', which requires additional information on base patronage levels and changes due to scheme implementation, to be evaluated fully.
- For electric vehicles, the primary influences on upstream emissions are the electricity generation mix of the region or country in question (i.e. affecting emissions per kWh), the precise nature of vehicle's electric drive (i.e. hybrid vs. full electric), and, potentially, climatic conditions when in operation (e.g. 'Hotel' loading required to keep vehicle occupants comfortable).
- Both CV's and EV's emissions will be influenced by the topography (i.e. flat vs. hilly or mountainous) of the region in operation.
- Both CVs and EVs generate tyre, brake and road surface wear particulate emissions and cause resuspension of road dust.

Suitable emissions factors or rates, applicable to the UK and Europe may be found in the Emissions Factors Toolkit (UK) (DEFRA, 2019), COPERT (Computer Program for Emissions from Road Transport) software (EU) (Emisia, 2018), and the Handbook of Emissions Factors for Road Transport (HBEFA) (Notter *et al.*, 2019). These software cover not only Greenhouse Gas Emissions (i.e. equivalent CO_2), but also local air pollutants (e.g. Oxides of Nitrogen, Particulate matter, Carbon Monoxide etc.). The carbon intensity of electricity generation for individual EU countries may be found in the indicators presented by the European Environment Agency (EEA, 2019).

The potential noise reduction impacts of e-mobility schemes are difficult to assess using many of the 'interim methods' used by EU member states to calculate traffic-related noise maps. However, newer methodologies, such as CNOSSOS-EU (Kephalopoulos, Pavotti and Anfosso-Lédée, 2012), that allow separation of vehicle source noise components, could be utilised to estimate on-road changes in noise levels. However, given the small number of vehicles likely to be affected in shared e-mobility trials, compared to remaining conventional traffic, any reductions are likely to be fairly negligible and undiscernible from prevailing ambient levels.

It is unlikely that fully detailed information regarding the number of trips displaced or substituted, the operational characteristics of vehicles etc. will be known, so there will be associated uncertainties arising from the use of default or assumed data that may need to be addressed in the course of the eHUBS project. Likewise extrapolation of large scale operational values estimated using scaling factors inferred from the questionnaire survey will need appropriate statistical analysis.

Also, it is prudent to note that the application of emissions factors to user travel data only (e.g. *before* and *after* scenarios generated from survey results) does not give a complete picture of the emissions potentially arising from a shared e-mobility scheme. Additional 'on-road' emissions and congestion would be associated with the 'rebalancing' of vehicles required across scheme locations to maintain functionality of the system (i.e. to prevent vehicles being unavailable at one location, or overabundant at another). If this rebalancing is carried out in an inefficient manner (e.g. frequent trips being made by 'dirty' conventional vehicles such as vans or small trucks carrying bikes and scooters) this may partly cancel out scheme benefits (Chiarlotti *et al.*, 2018). A full analysis of the 'on-road' environmental impacts of a scheme therefore may require operational data on rebalancing movements (e.g. directly from operational logs of rebalancing vehicles or from collective spatiotemporal analysis of positional (GPS) data of shared vehicles (e.g. multiple e-bikes moving collectively together could indicate a rebalance trip). The associated emissions will be estimated if data is forthcoming.

Likewise, a more holistic 'life cycle assessment' (LCA) approach would include analysis of the energy and materials embedded and consumed in both the production and end-of-life scrappage and recycling of vehicles. Electric vehicles are typically more 'resource heavy' in terms of embedded carbon in their production, than conventional vehicles, but far more advantageous in terms of their 'in-use' emissions per km (depending on electricity generation – see above). This, in turn, means that there is a 'cross-over' point (in terms of kilometres travelled, or, by proxy if usage is known, age of vehicle), before which the operation of EV may actually result in a net carbon gain for the system. If the operational lifetime of a shared vehicle is likely to be short, as may be the case for an e-bike or e-scooter, then LCA may paint a less favourable picture of e-mobility schemes (Hollingsworth et al., 2019).

Finally, whilst larger electric vehicles are mostly based on lithium-Ion battery technologies, smaller e-bikes and e-scooters may still utilise older nickel-cadmium, nickel-metal-hydride or even lead-acid batteries. A life cycle assessment incorporating analysis of the fate of vehicles also may need to consider the recycling potential, or the environmental pollution risk of battery packs. The former is uncertain in the case of lithium-ion packs (Dewulf *et al.*, 2010), whilst the latter may be quite high, with issues with lead-acid technology reported in China (Campbell *et al.*, 2016). Compared to private vehicles, it should be easier to control the pollution caused by batteries of shared electric modes since they are centrally managed by the service operator and can be processed and recycled in batch.

A key question for the eHUBS project is therefore in the definition of scope for any environmental evaluation (i.e. limited to on-road emissions related to user's trip changes, or broader in scope). This, in turn, influences the data that would need to be collected for the evaluation, and the amount of work required 'in-field' as opposed to being desk-based of appropriate literature reviews).

3. A synthesis of findings

3.1 System performance

This section presents the findings regarding the performance of existing shared e-mobility systems. The main topics include user profile, usage behavior and the spatiotemporal distribution of trips. **Table** lists the papers in which system performance is studied.

Table 2. Overview of studies on current systems

Author year	Mode type	Location	Time of data collection	Data type	Topic	Scale	System
(Munkácsy and Monzón 2017a)(Munkácsy and Monzón 2017b)	E-bike	Madrid, Spain	3 waves May/June 2014 June 2015 June/July 2016	Survey	Perception, Trip substitution	1859 584 534	BiciMAD
(Becker and Rudolf 2018)	E-cargo bike	Germany	July to December 2016	Survey	User characteristics and behavior	40 E 94 non e 9750 users	Multiple
(Romanillos et al. 2018)	E-bike	Madrid, Spain	April 2017	GPS route data	Visualization of spatiotemporal pattern of cycling flow	230238 trips	BiciMAD
(Degele et al. 2018)	E-moped	Stuttgart, Germany	April 22 - Oct 20 2017	Transaction data	Clustering user segments	53000 trips	Stella
(NACTO 2018)	E-scooter	US	2018	Transaction data, survey	Usage behavior		
(PBOT 2019)	E-scooter	Portland, US	July 23, 2018 – November 20, 2018	Transaction data, survey	Usage behavior		Bird Lime and Skip
(McKenzie 2019)	E-scooter	Washington DC, US	June 13 through October 23, 2018	GPS route data	Contrast of spatiotemporal pattern between scooter and bike	937,590trips	Lime
(Kramer et al. 2014)	EV	Berlin, Germany	November 2010 Sep 2011 Three waves	Survey	User characteristics and usage behavior	311 160 178	BeMobility/Berlin elektroMobil
(Wielinski et al. 2016)	EV	Montreal, Canada	June 2013 to April 2015	Transactional and GPS data	Probability of choosing EV and spatial distribution of trips	98923 transaction records	Auto-mobile, free-floating
(Boldrini et al. 2016)	EV	Paris, France	April 2015	Pickup and drop-off times at stations	Spatial and temporal patterns of station utilization	Every two minutes	Autolib
(Ampudia-Renuncio et al. 2018)	EV	Madrid, Spain	November 2016	Survey	Perception	186 students (25% user)	Car2go
(Sprei et al. 2019)	EV	Madrid, Spain and Amsterdam, Netherlands	Between 2014 and 2017	Vehicle availability data	Usage pattern		Car2go

User profile: the users of current systems are usually characterized based on their socio-demographics, attitude towards environmental issues and common travel patterns. **Table** lists the findings regarding typical user characteristics of various shared e-mobility systems.

The user profile for different modes of shared mobility services are different but share some traits: they are predominantly male, middle age (typically between 25-45), with high education and higher than average income (Campbell et al. 2016 provided contrasting evidence in China). In general users are concerned with environmental issues and are environmentally friendly. As for their previous travel behavior before the system became available, they usually have limited access to a car, travel less by car and are usually frequent public transport and bike users; in addition, many of them are multimodal being flexible and open-minded regarding transport modes. These results are largely intuitive and match with the image of a typical early adopter of new mobility modes. When shared e-mobility service is only used as a supplementary mode instead of the main mode, it can also appeal to people who have children and own cars (Burghard and Dütschke 2019).

Table 3. Profile of current shared e-mobility service users

	EV	E-scooter	E-bike	E-cargo bike
Gender	87% male	Greater gender parity (compared to bikesharing)	Males	63% male
Age	30-40 Few students and pensioners	Frequent users 34 Casual users 28	27-40	38 widely distributed
Education	High, university		Low education	
Income		Upper to middle	Low income	
Employment	High level of employment			
Attitude towards environment	Environmentally friendly and open- minded towards car sharing and mobility concepts			Environmentally friendly
Travel pattern	Multimodal; Dominated by PT Travel by bike more often Travel by car less than average			Main transport mode: 71% bike 13% PT 6% multimodal 6% car 3% walking
Reference	(Kramer et al. 2014)	(Degele et al. 2018; Populus 2018; Shaheen and Cohen 2019)	(Campbell et al. 2016; Romanillos et al. 2018)	(Becker and Rudolf 2018)

Table 4. Length and temporal distribution of shared mobility system trips

Mode	EV	E-moped	E-bike	E-scooter	E-cargo bike
Trip length	Mean length 28 km (Kramer et al. 2014) Free-floating: 27 min (actual driving time 15 min) (Sprei et al. 2019)	4-5 km 15-20 min (Howe 2018)	Most frequent trip 2km (Romanillos et al. 2018) 1 - 3.5 km (Guidon et al. 2019)	Mean length 1.85 km (PBOT 2019)	15.48km (Becker and Rudolf 2018)
Peak usage	Weekday: 3-8 PM Weekend: 2-8 PM Weekend higher than weekday (Hu et al. 2018)	Weekday: Early evening Weekend: Continuous increase in the afternoon and evening	Weekday: morning commute, afternoon and evening (Romanillos et al. 2018)	Weekday: 3 - 6 PM Weekend: 2 - 5 PM (PBOT 2019)	

Trip length: **Table** presents the typical length range and peak hour of shared mobility trips. The trip length is affected by the power mode: in case of electric carsharing, although the typical trip length is well below the driving range of shared EVs, BEVs are still chosen for shorter trips compared to conventional vehicles (CV) (Sprei et al. 2019); while for cargo bikes, the electric cargo bikes are used for longer trips compared to normal cargo bikes (Becker and Rudolf 2018). Apart from the special cases of e-cargo bikes, the typical trip length of all other electric micro-mobility modes are similar, falling below 5 km and mostly around 2 km. This range overlaps with that of public transport and taxi modes (Guidon et al. 2019), and is slightly higher than the typical trip length of shared bikes, which is about 1-1.6 km depending on country (Boor 2019; Shen et al. 2018). For trips within this range, shared micro-mobility can be a strong alternative to private cars since they are economically competitive (Smith and Schwieterman 2018); while for longer trips they tend to cost higher and also require more physical activity. However, if micro-mobility can be facilitated as a first-mile and last-mile connection mode to public transport, then these two modes combined may still enable substitution from private car use.

Time saving compared to other modes: Time saving can be one of the main reasons for mode switching. In case of carsharing, shared EVs do not have any strengths compared to their fossil-fuel powered counterparts. Free-floating carsharing rental times are generally longer than cycling but considerably shorter compared to public transport (Sprei et al. 2019). As for other micro-mobility modes, their compact size does not take much road space and enable travelers to save time compared to driving, which can make these modes attractive options especially for short trips during a congested period.

Trip purpose: Similar to bikesharing, a large proportion of shared e-bike trips are being used for commuting (Guidon et al. 2019; Romanillos et al. 2018). In contrast, e-scooter usage pattern is more similar to casual bike-share usage (McKenzie 2019) and more often used for social, shopping and recreational trips, although the percentage of people who say they use e-scooter for work and transit are around the same compared to those who use it for social and recreational purposes (NACTO 2018). Despite the suitability of transport mode for different trip purposes, another possible reason for this usage pattern is that scooter sharing systems have only started more recently: it is still expanding and the pattern may be subject to change.

Trip distribution: **Table 4** shows that the hours of peak usage of e-bike roughly match the commuting peak hours, which makes sense since e-bikes are often used for commuting. As for electric carsharing and e-scooter, the temporal distribution of their trips are similar: rides are more dispersed throughout the day compared with e-bike and usage is on a continuous high level starting from early afternoon to evening (NACTO 2018). As for spatial distribution, the pattern of shared e-scooter trips is found to be quite dissimilar to both frequent and casual bikesharing rides (McKenzie 2019). The benefits of e-scooters regarding accessibility improvement also vary greatly between different locations depending on their access to public transport (Smith and Schwieterman 2018) since it can be used as first-mile and last-mile trips for connecting transit (Romanillos et al. 2018).

3.2 Demand estimation

This section presents an overview of findings of demand estimation studies on shared e-mobility services. A list of studies can be found in **Table** . The vast majority of these studies aims to explore the factors that influence the demand of shared e-mobility services. We will discuss those factors which were found to have a significant impact on choice and demand regarding shared e-mobility. **Table** categorizes and lists the main influential factors identified in previous studies.

System operational attributes refer to the characteristics of the shared mobility system which are within the control of service operators. The most commonly investigated attributes include price level, availability of shared car, access distance, shared car type, etc. These attributes largely determine the quality of the entire service and have great influence on consumers' willingness to use the service. So far all studies focusing on system attributes are concerning carsharing systems and only a few considered electric shared cars (Hu et al. 2018; Jung and Koo 2018; Zoepf and Keith 2016). The service attributes which play a role in adopting conventional carsharing services are mostly found to be influential in case of electric carsharing as well. Previous studies provided mixed evidence regarding the preference for fuel type: compared to conventional shared car, EV is found to be preferred (Dieten 2015; Jung and Koo 2018; Liao et al. 2018), less preferred (Zoepf and Keith 2016) or the difference in preference is not significant (Yoon et al. 2017). Some possible reasons for these conflicting results can be the difference in study time (EV was less accepted earlier) or EV range. The preference for EV is lower if the user is male, the trip distance is longer and weather is cold (Wielinski et al. 2016; Zoepf and Keith 2016).

Individual and household characteristics include common socio-demographic and socio-economic variables, such as gender, age, education, income, size of household, etc. The impact of most variables on sharing e-mobility demand are found significant, although there are also cases in which they appear non-significant. The direction of estimated effects generally match the profile of early adopters in section 2, although there are sometimes conflicting results: such as the effect of income on e-bike demand which has been found to be positive (Guidon et al. 2019) but also negative (Campbell et al. 2016). A possible reason is that the e-bike sharing in (Guidon et al. 2019) is a premium service whose price is higher than public transport; it can also be due to the fact that the impact is actually non-linear and non-monotonous (Hu et al. 2018), as most early adopters of shared e-mobility also tend to be people with middle-upper level income. Across different shared mobility modes, the impact of variables can also vary, such as females are found to have higher intention of using e-bike sharing compared to males (Kaplan et al. 2018) which contradicts the typical early adopter of new mobility modes, at least those that are not electric.

Psychological variables are mostly investigated in studies which apply psychological frameworks to explain people's behavior in adopting shared e-mobility which usually include attitudes, perceptions, norms, etc. Depending on the different motivations, adopting and using shared e-mobility can be seen as a behavior which is environmentally friendly, risky or satisfying human needs, which can in turn be studied using different psychological theories and corresponding constructs. Overall, a broad distinction can be made between approaches that regard (travel) behaviour as a purely *rational* decision-making process weighing pros and cons or those that regard it as a process subjective to *non-rational* factors such as emotions, habits and personal norms.

Rational approaches

The most common approaches defining travel or purchase behaviour as a rational choice process are represented by the Theory of Planned Behaviour (TPB, Ajzen 1991) and Rational Choice Theory (RCT, e.g. Satz and Ferejohn 1994). These approaches depict the individual as a rational decision maker influenced by, in the case of TPB, the individual's *behavioural beliefs* (i.e., the weighting of possible positive and negative consequences of behaviour), *control beliefs* (i.e., the perceived behavioural control or feasibility of the target behaviour), and *subjective norms* (i.e., either personal norms or perceived expectations of important reference groups such as family, friends or colleagues). While behavioural beliefs in rational choice (RC) approaches tend to focus primarily on instrumental factors, including cost, contextual or technical factors (e.g., Jensen et al 2013; Lieven et al 2011; Zhang et al 2011) – they may also consider altruistic or, more commonly, environmental concerns, which have been included in various studies investigating electric vehicle (EV) uptake based on RC frameworks (e.g., Carley et al 2013; Egbue and Long 2012; Krupa et al 2014; Moons and De Pelsmacker 2012). Based on a careful consideration of these factors (i.e., attitudes, norms and control beliefs), the individual then forms behavioural intentions, which, in turn, are supposed to predict behaviour. One point worth mentioning is that seemingly similar modes may actually be vastly different: higher interest in bike technology, lower perception of cycling ease and lower subjective norms towards cycling are related to higher appeal of e-bike for tourists; while the direction of all these impacts are the opposite for normal bike sharing (Kaplan et al. 2015). (Diez 2017) also found that the attitude towards cycling is not significantly related to the intention of using e-bike sharing, which suggests that bike and e-bike usage behavior are distinct.

Non-rational approaches

Non-rational approaches complement traditional rational choice approaches by devoting more importance to the individual and social aspects of decision-making, such as affective and symbolic aspects (e.g., Gatersleben 2007; Steg 2005; Steg et al 2001). The latter have been devoted particular attention in relation to car use, as car use reduction lies at the core of the sustainable mobility agenda. More specifically, it is now widely acknowledged that car use not only satisfies instrumental motives (Jakobsson 2007), such as convenience, comfort and (reduced) travel time, but also addresses people's affective motives, such as the joy derived from driving a car, as well as symbolic motives, primarily by offering individuals a way to express their identity (Steg 2005). In fact, affective motives have been found to override instrumental motives in the prediction of car use (Lois and López-Sáez 2009).

With regard to EV uptake, affective (or 'hedonic') and symbolic attributes were found to mediate any influence of instrumental factors on EV adoption (Schuitema et al 2013). Likewise, research with potential buyers of EVs showed that a positive emotional (affective) response to driving an EV was positively associated with EV attitudes and purchase intention (Moons and De Pelsmacker 2012), suggesting that emotional factors play an essential role in electric mobility uptake. There is less clarity, however, on how these factors relate to the uptake of shared (electric) mobility. There is thus a need to better understand how shared mobility options can not only address people's mobility needs, but also their affective and symbolic motives.

Market segmentation

Apart from traditional theory-based rational or non-rational approaches to the study of shared (electric) mobility, another popular approach worth mentioning is the segmentation of a sample of the population based on factual trip data and/or people's individual beliefs and preferences. While not bound to any particular theoretical framework, Hinkeldein et al (2015) contest in their research that attitudinal market segmentation is a much-needed tool for the successful implementation of integrated e-mobility services and offer their own mobility typologies. The authors distinguish five different kinds of segmentation approaches including:

i. distinction by homogenous behaviour based on socio-demographics
ii. distinction by life stages
iii. distinction by lifestyle
iv. distinction by mobility style and
v. attitude-based mobility typologies

With regard to integrated sustainable mobility services, the authors propose that an up-to-date market segmentation should a) cover a representative sample; b) be up-to-date (i.e., not older than 5 years); c) include items on openness to mobility services; d) include items on openness to information and communication technology; and also e) include items on openness to innovation. For further details on Hinkeldein et al's (2015) study, see **Table 5**.

Transport connectivity denotes the accessibility and transport service level of a carsharing station or potential user's home. In general, all indicators of connectivity including transit proximity, public transport service level and bike infrastructure are all found to have a significantly positive impact on the demand of electric carsharing and e-bikeshare. Several possible reasons can explain this fact: first, shared mobility services are used as the first-mile and last-mile tips for connecting to transit stations; second, public transport provides the necessary backup when shared vehicle is not available, which implies that public transport and shared mobility can be complementary (Guidon et al. 2019). However, in contrast to the above findings regarding shared e-mobility, a study on conventional carsharing (Becker et al. 2017) found that proximity to public transport is a negative predictor for demand, which calls for further examination. Moreover, the increased demand of different locations varies in their temporal distribution: for example, the impact of a main train station is only significant during weekends, while the impact of urban rail is significant at all other times (Guidon et al. 2019)

Land use variables consists of the use purpose and the number of different types of POIs (point of interest) of an area. Obviously, these variables only apply when the study takes an aggregate approach and the dependent variable is the demand on a specific geographical area. Studies found that residential and office areas increase electric carsharing demand, as well as places with mixed land use purpose, although the opposite impact is also found in case of conventional carsharing (Hu et al. 2018). As for the impact of POIs, Table shows that most types of POIs have positive impact on EV carsharing and e-bikeshare demand, while some recreational POI such as sport facilities and cinemas do not have a significant impact on e-bike sharing, probably because e-bike is more suitable for transporting single individuals while people usually visit these places in groups (Guidon et al. 2019). Similar to transit stations, the demand increase of different types of POI also varies in its temporal distribution (Boldrini et al. 2016; Guidon et al. 2019).

Table 5. Overview of demand studies

Author, year	Type of mode	Country	Time of data collection	Population	Number of respondents	Dependent variable	Modelling approach
(Kaplan et al. 2015)	E-bike	Copenhagen, Denmark	November 2013	Tourists	655	Intention to use during holiday	Theory of planned behavior. SEM
(Campbell et al. 2016)	E-bike	Beijing, China	July and August of 2012, SP survey	General population (stratified transport users)	496	Mode choice	MNL mode switching (bikeshare, e-bikeshare, original mode)
(Diez 2017)	E-bike	Curitiba, Brazil		University students	511	Intention to use	Regression
(Kaplan et al. 2018)	E-bike	Poznan, Szczecin, Gorzow, Poland	March and April 2016	General population	717	Intention to use	Hybrid bivariate ordered model
(Guidon et al. 2019)	E-bike	Zurich, Switzerland	April to November 2017	Users transaction data of Smide	72648 trips	Number of daily bookings Number of rentals per zone	Negative binomial regression Linear regression (box-cox transformation)
(He et al. 2019)	E-bike	Park city, Utah, US	July 20 to November 3, 2017, 107 days	Users transaction data of Summit	7921 trips	Number of daily rides on station level	Poisson Regression
(Hess and Schubert 2019)	E-cargo bike	Basel, Switzerland	2017 summer	Members of Carvelo2go and nonmembers	202 m Active member 153 128 non	Membership to user segment	Multilevel regression
(Zoepf and Keith 2016)	EV	US mostly big cities	October 2013	Zipcar members	1605	Mode choice for trip	MNL, mixed logit
(Wang and Yan 2016)	EV	Shanghai	May 2014–November 2014	General population	394	Intention to use	MNL
(Wielinski et al. 2016)	EV	Montreal	June 2013 to April 2015	Transactional and GPS data		Probability of choosing Electric car in a CS service Mode choice	DCM
(Yoon et al. 2017)	EV	Beijing	2013 Summer	General population	1010 2023 trips	Mode choice for trip	DCM
(Wang et al. 2017)	EV	China	June 2015 to November 2015	General population	826	Mode choice for trip of different purpose and distance	Hierarchical tree based regression
(Liao et al. 2018)	EV	Netherlands	June 2015	Potential car buyer	1003	Intention of replacement	Latent class model
(Jung and Koo 2018)	EV	Korea	April 2017	General population	807	Choice of carsharing service (mode choice)	DCM, linear regression
(Hu et al. 2018)	EV	Shanghai	January 1, 2017, to December 31, 2017	Transaction data of EVCARD	5,790,000 transactions made by 242,600 members	Number of booking requests and turnover rate	generalized additive mixed model (GAMM)

(Burghard and Dütschke 2019)	EV	Germany pilot regions for electric mobility		Pedelec/EV sharing participants	947	Early adopter profile	Clustering analysis
(Lan et al. 2019)	EV	Shanghai	Dec 2017	Users or potential users of the shared EV EVCARD online community	602	Intention of use	SEM
Schaefers (2013)	Car sharing	Germany		Car sharing users	14	Motivational patterns	(Qualitative) Hierarchical means-end chain analysis
Mattia, Mugion & Principato (2019)	Car sharing	Rome, Milan, and Palermo, Italy	February 2018	Service users coming from different parts of Italy / General population	15 / 300	Intention to re-use free-floating car sharing.	Theory of planned behavior. SEM
Paundra, Rook, Van Dalen & Ketter (2017)	Car sharing	Netherlands		University students	493	Intention to select a shared car	Theory of planned behaviour. Psychological ownership. Regression.
Hinkeldein, Schoenduwe, Graff & Hoffmann (2015)	Integrated e-mobility services (IeMS)	Berlin, Hamburg, Frankfurt, Munich, Germany	August 2012	General population	2400	Intention to use integrated e-mobility services (IeMS)	Attitudinal market segmentation

Table 6. Overview of factors which influence shared e-mobility demand

Attribute type	Attribute	Operationalization	Mode type	Studies which find it has significant positive effect	Studies which find it has significant negative effect
System operation	Price level	Cost per hour	EV		(Jung and Koo 2018; Zoepf and Keith 2016)
	Charging infrastructure	Charging station supply rate	EV	(Jung and Koo 2018)	
	Accessibility	Distance of station	EV		(Hu et al. 2018; Zoepf and Keith 2016)
		Delivery to door service	EV	(Jung and Koo 2018)	
	Availability	Time slot difference from ideal	EV		(Zoepf and Keith 2016)
	One-way		EV	(Jung and Koo 2018)	
	Car type	SUV	EV	(Jung and Koo 2018)	
Individual socio-demographics	Gender	Female	EV		(Hu et al. 2018; Wang and Yan 2016)
			E-bike	(Kaplan et al. 2018)	(Campbell et al. 2016)
			E-cargo bike		(Hess and Schubert 2019)
	Age		EV	(Yoon et al. 2017) 18-30 years old (Wang and Yan 2016) Adult (Hu et al. 2018)	
			E-bike	Peak at 36 (Campbell et al. 2016)	Age higher than 35 years old (Kaplan et al. 2018)
			E-cargo bike		(Hess and Schubert 2019)
	Education		E-bike		(Campbell et al. 2016)
			E-cargo bike		For inactive member (Hess and Schubert 2019)
	Population size	Population in each zone	EV	(Hu et al. 2018)	
			E-bike	(Guidon et al. 2019; He et al. 2019)	
Household characteristics	Income	Household income	E-bike	(Guidon et al. 2019)	(Campbell et al. 2016)
			E-cargo bike	Inactive member (Hess and Schubert 2019)	
	Household size	Single	EV		(Wang and Yan 2016)
		Number of household members	E-cargo bike	Inactive member (Hess and Schubert 2019)	
Psychological variables	Environmental attitude		E-bike	(Campbell et al. 2016)	
	Theory of planned behavior		E-bike	(Kaplan et al. 2015) (Diez 2017)	
	ERG theory of needs		E-bike	(Kaplan et al. 2018)	
	Perceived scarcity risk of the EV-sharing		EV		(Lan et al. 2019)
Transport connectivity	Transit proximity	Close to tram and train stations	E-bike	(Guidon et al. 2019)	
		Bus and metro route number	EV	(Hu et al. 2018)	
		Transit center	EV	(Hu et al. 2018)	
			E-bike	(He et al. 2019)	

	Public transport level	Public transport service level high	E bike	(Guidon et al. 2019)	
	Bike infrastructure	Proximity to bike trail	E-bike	(He et al. 2019)	
		Length of bicycle infrastructure	E bike	(Diez 2017; Guidon et al. 2019)	
Land use variables	Mixed land use	Entropy of land use	EV	(Hu et al. 2018)	
	Residential area	Percentage of residential land	EV	(Hu et al. 2018)	
	Office area	Percentage of office land	EV	(Hu et al. 2018)	
	Working POI	Number of workplaces per zone	E bike	(Guidon et al. 2019)	
	Dining POI	Number of bars and restaurants	E-bike	(Guidon et al. 2019)	
	Shopping POI	Shopping center	EV	(Hu et al. 2018)	
	Recreational POI	Recreational center	E-bike	(He et al. 2019)	
	Educational POI	University	EV	(Hu et al. 2018)	
Travel patterns	Use of transport modes	Bus	E-bike	(Campbell et al. 2016)	
		Subway	EV	(Wang and Yan 2016)	
		Bike	EV	(Wang and Yan 2016)	
			E-bike	Cycle long (Kaplan et al. 2018)	
		Public transport	EV	(Wang and Yan 2016) (Yoon et al. 2017)	
		Sheltered	EV	(Yoon et al. 2017)	
	Car ownership		EV	One-way (Yoon et al. 2017)	Roundtrip (Yoon et al. 2017)
			E-cargo bike		Inactive member (Hess and Schubert 2019)
	Driver license		E-cargo bike	Inactive member(Hess and Schubert 2019)	
Time and trip varying factors	Weather	Precipitation	E-bike		(Campbell et al. 2016; Guidon et al. 2019)
		Temperature	EV	Not too cold (Yoon et al. 2017)	
			E-bike	(Guidon et al. 2019; He et al. 2019)	
		Wind speed	E-bike		(He et al. 2019)
	Season	Summer	E-bike	(He et al. 2019)	
	Day of week	Weekend	E-bike	(He et al. 2019)	(Guidon et al. 2019)
	Trip distance		E-bike		(Campbell et al. 2016)

Travel patterns refer to individuals' use of different transport modes and availability of modes such as car and bike ownership. Several studies found that people who use public transport and bike more often are more inclined to use shared e-mobility, which fits the early adopter profile. As for the impact of car ownership, car owners are more likely to conduct one-way carsharing trips but less likely to choose roundtrip carsharing (Yoon et al. 2017), which indicates that the influence of car ownership is not unidirectional and depends on other characteristics of the shared mobility service.

Time varying factors include variables specific to each trip such as weather, time of day, day of week and season etc. Compared to sheltered modes, e-bike sharing is more strongly affected by bad weather; only when the temperature is too low electric carsharing demand reduces probably because the driving range of EVs is lower when it is cold.

To sum it up, shared e-mobility demand is under the influence of a wide range of factors: the direction of most factors is intuitive and supported by evidence apart from a few factors which have conflicting results. We hereby provide some discussion on the findings:

- The impact of factors varies for different dependent variable: although all groups of variables have a significant influence on almost every mode and there are many overlapping predictors among different modes, there are still many distinct factors specific to each mode. When the demand being studied concerns different modes (e-bike sharing and normal bikesharing), different ways of organization (one-way carsharing versus roundtrip carsharing) or different demand type (membership choice and frequency of use), the estimated impact of factors can differ.
- Correlation between factors: many demand studies investigated the impact of land use variables and travel patterns. However, these variables can be closely correlated with each other (such as car ownership density and transit service level); furthermore, these variables are also correlated with socio-demographic and psychological variables. Therefore, these possible correlations shall either be handled during the analysis using statistical techniques and or be considered when interpreting results.
- More modes and factors: so far there have been no study on exploring influential factors for e-scooters by statistical analysis, probably because it only appeared recently. Some factors which are found to play a role in other transport related decision have not been investigated yet, such as experience with the mode and social influence (Ampudia-Renuncio et al. 2018).
- Difference between ownership and sharing: the usage of private cars and carsharing service are considered to be vastly different behaviors: carsharing (especially free-floating) is seen as a "new mode", and the characteristics of current carsharing users also roughly match the early adopter profile of other new mobility modes. When the transport vehicle itself is also innovative (such as e-scooter and e-bike), it is even more interesting to explore the difference between ownership and using the corresponding shared service: whether they are influenced by the same group of factors, whether their adopters overlap, etc.
- Barriers in adoption: beyond the factors mentioned above, there are many factors which can appear as barriers for adoption in the actual implementation of the systems which can be difficult to include in quantitative studies, such as familiarity with sharing procedure (Hess and Schubert 2019), legislations, enforcement of regulations, etc.

3.3 Impact estimation

This section summarizes studies on evaluating the impact of existing shared e-mobility systems or forecasting the potential impact of such a system. **Table** lists the studies focusing on impact estimation. The most often investigated impacts include transportation, environmental, health and social impacts. An overview of impacts can be found in **Table** .

Table 7. Overview of studies on shared e-mobility impacts

Author, year	Mode type	Location	Time of data collection	Type of effect	System	
(Firnkorn and Müller 2015)	EV	Ulm Germany	9 February 2013	Transportation (Car ownership)	Car2go	
(Martin and Shaheen 2016)	EV	San Diego, US	Sep 2014	Transportation (VMT, car ownership, modal shift) Environment (GHG emission)	Car2go	
(Vasconcelos et al. 2017)	EV	Lisbon, Portugal		Environmental (GHG and pollutants emission)		
(Otero et al. 2018)	E-bike	Europe (Madrid with full e-bike)		Safety	BiciMAD	
(PBOT 2019)	E-scooter	Portland, US		Transportation Environmental		
(Hollingsworth et al. 2019)	E-scooter	Raleigh, US		Environmental		
(Hayden et al. 2019)	E-scooter	Austin, US	Sep-Nov 2018	Safety		
(Trivedi et al. 2019)	E-scooter	US	September 1, 2017, and August 31, 2018	Safety		

Table 8. List of findings on shared e-mobility impacts

Category of impact	Type of effect	Specific effect	Mode type	Description
Transportation	Mode substitution	Driving	EV	11% increased distance, 27 % decreased (Martin and Shaheen 2016)
			E-bike	17% would have used car (Campbell et al. 2016) 4-6% (Munkácsy and Monzón 2017a)
			E-cargo bike	46% (Becker and Rudolf 2018)
			E-scooter	34% (Hollingsworth et al. 2019; PBOT 2019)
		Public Transport	EV	8% increased frequency, 26% decreased (Martin and Shaheen 2016)
			E-bike	30% would have taken PT (Campbell et al. 2016)
			E-scooter	11% (Hollingsworth et al. 2019)
		Walking	EV	7% increased frequency, 6% decreased (Martin and Shaheen 2016)
			E-bike	27% would have walked (Campbell et al. 2016)
			E-scooter	7% (Hollingsworth et al. 2019) 37% (PBOT 2019)
		Cycling	EV	34% increased frequency, 9% decreased (Martin and Shaheen 2016)
			E-bike	11% would have biked (Campbell et al. 2016)
			E-cargo bike	15% (Becker and Rudolf 2018)
			E-scooter	41% (Hollingsworth et al. 2019) 5% (PBOT 2019)
	Trip creation	Enabling trips which would not have been taken	E-cargo bike	13% (Becker and Rudolf 2018)
			E-scooter	7% (Hollingsworth et al. 2019)
	Car ownership	Sold car	EV	1 per shared vehicle (Martin and Shaheen 2016)
			E-scooter	6% sold and 16% considered (PBOT 2019)
		Suppress future purchase	EV	6 per shared vehicle (Martin and Shaheen 2016) 55-66% stated willingness (Wang et al. 2017)
	Car VMT	Reduce VMT	EV	-7% for each household (Martin and Shaheen 2016)
			E-scooter	Inconclusive(PBOT 2019)
	Congestion	Increased congestion	E-bike	(Campbell et al. 2016)
Environment	Emission	Reduce GHG emission	EV	-6% for each household (Martin and Shaheen 2016) (Jung and Koo 2018; Vasconcelos et al. 2017)
			E-scooter	Sensitive to scooter life (Hollingsworth et al. 2019)
	Pollution	Increase lead pollution	E-bike	(Campbell et al. 2016)
Health	Health	Annual expected number of deaths	E-bike	Avoid 0.03 deaths per 100 bikes (Otero et al. 2018)
	Safety	Injuries	E-scooter	Low adherence to regulations (Trivedi et al. 2019) (Haworth and Schramm 2019)
Social	Accessibility	Increase job accessibility	E-scooter	(PBOT 2019)
	Equity	Expand accessibility for underserved regions and groups	E-scooter	(PBOT 2019)
Land use	Curb space	Competition of curb space	E-scooter	Illegal parking (Shaheen and Cohen 2019)
	Road	Use of the public right of way	E-scooter	Riding on pedestrian lane (Zarif et al. 2019)

Transportation impacts are the most direct first-order impacts of mobility services and are also addressed by most impact studies. It mostly refers to the following influences on the transport system and people's travel behavior:

Mode substitution: Electric carsharing contributes to emission reduction via replacing miles driven by private fossil-fuel powered car and reducing total VMT in general. (Martin and Shaheen 2016) detailed the impact of carsharing schemes in five cities, in which the system in San Diego is equipped with 100% EV fleet which allows us to compare the impact between carsharing systems with EVs and conventional vehicles. We can see that indeed a larger percentage of electric carsharing users claim to have reduced driving distance rather than increasing their driving distance, while it is the opposite for CV carsharing in which more people increased their driving distance. However, people who decreased their frequency of using public transport are also more than those who increased its usage, although this effect is less pronounced in case of EV sharing compared to conventional cars. Furthermore, a significantly higher percentage of EV sharing users increased their walking frequency compared to CV carsharing users. To summarize, electric carsharing seems to be more effective compared to CV carsharing in reducing driving distance and switching towards active and "green" modes. More systematic research is needed to increase confidence on this conclusion as these varied impacts may be due to other differences between these systems.

As for other electric micro-mobility modes, one of the expectations is to substitute driving and reduce car use. It is not surprising that e-cargo bike substituted the largest percentage of car trips as many of these trips are loaded with goods or kids which are inconvenient to be transported by public transport or walking (Becker and Rudolf 2018). Based on yet limited evidence, e-scooter seems to have larger potential in replacing car trips than e-bikes (34% vs 5 or 17 %) (Campbell et al. 2016; Hollingsworth et al. 2019; Munkácsy and Monzón 2017a), but this may be due to the difference in local transport usage as in the US the car mode is more often used than in Europe or China. More than half of the micro-mobility trips are used to replace trips by public transport or active modes (cycling and walking). In case of e-bike, 30% of the users said they would have taken the trip by public transport had e-bike not been available, which indicates that e-bike can pose as a strong competitor of public transport instead of being a first-mile and last-mile connection as it has been envisioned. Moreover, although the replacement of active modes is around 40-50% in total across several studies, the evidence is mixed regarding whether it mainly replaces walking or cycling.

Induced traveling: the deployment of shared e-mobility systems may also enable trips which would not have been taken due to limited mobility[1]. This effect found support for both e-cargo bikes and e-scooters. These generated trips may pose new challenges to congestion and road use management.

Car ownership reduction: If shared mobility services can meet the travel needs of people then it is expected to reduce car ownership, which can in turn bring even bigger positive impacts such as reducing emission and pollution during car manufacturing and relieve parking pressure. This effect can manifest in two ways, namely households shedding owned cars or postponing planned purchase. There have been many studies on the impact of carsharing on car ownership or identifying factors which influence the decision of giving up car ownership given the existence of carsharing services (Jung and Koo 2018; Liao et al. 2018; Wang et al. 2017). When compared to conventional carsharing systems, the electric carsharing service in San Diego removed fewer cars (7 vs 7-11 per shared car) (Martin and Shaheen 2016); on the other hand,

[1] https://medium.com/sidewalk-talk/seeing-a-big-future-for-micromobility-6db21140bcd8

another study found that users who have the experience of driving shared EVs showed higher willingness to forego car purchase (Firnkorn and Müller 2015).

Reduce car use: Due to changes in car ownership and travel behavior, shared e-mobility services are also supposed to reduce car usage which is usually measured by VMT (Vehicle Miles Travelled). (Martin and Shaheen 2016) estimated the net changes of VMT of carsharing; however, they only considered the VMT changes originated from reduced car ownership and did not take changes in travel behavior into account. They found that electric carsharing (in San Diego) reduces 7% of VMT per household which is less than most gasoline carsharing systems in other cities (10-16%) because EV carsharing did not remove as many cars. As for e-scooter, it did replace motor vehicle use of users, but it may add some other car trips such as those used to relocate scooters, therefore its impact on VMT is so far unclear and needs more evidence (PBOT 2019).

Congestion: This is a hot topic for ridesharing but did not see many discussions for shared e-mobility probably because these systems are not large-scale enough to have visible impact for road congestion. In the most congested cities of UK and Germany, around half of all car trips are less than three kilometers (2 miles) (INRIX 2019): if many of these trips can be made with smaller micro-mobility vehicles instead, the level of congestion is expected to reduce. On the contrary, (Campbell et al. 2016) mentioned that e-bike sharing may also deteriorate congestion due to its lower efficiency compared to buses and increased conflicts with car drivers caused by the often-erratic behavior of e-bike users. The impact of shared e-mobility on congestion may become more relevant as these services, especially micro-mobility, gain popularity.

The potentially positive **environmental impacts** are one of the most important reasons as to why governments are promoting shared e-mobility services, which mainly consists of reducing greenhouse gas emission.

GHG emission: The comparative study of Martin and Shaheen (2016) found that electric car-sharing systems reduce greenhouse gas (GHG) emissions less than CV systems since EV systems result in fewer shed cars. (Jung and Koo 2018) conducted a more comprehensive simulation of the impacts on GHG emission which not only considers emission impacts that resulted from vehicle disposal but also account for the substituted trips in other modes. They found that when the car-sharing service is equipped with gasoline cars it even increases GHG emission. When part of the fleet is electrified the net GHG emission change becomes negative and emission reduced further as more EVs are deployed in the fleet. This finding also is supported by (Vasconcelos et al. 2017). However, it shall be kept in mind that these analysis are highly sensitive to the assumptions of changes in travel behaviour. Another study (Rabbitt and Ghosh 2013) which simulated the changes in CO_2 emission brought by a car-sharing service concluded that the difference between electric and conventional car-sharing is little since the projected use of car-sharing is low for most people. The emission reduction impact of electric car-sharing only becomes more pronounced when a significant part of car-sharing members were heavy car users and radically change their behaviour reducing the Vehicle Kilometres Travelled (VKT). A study by Percy and Kota (2007) of mode shift from car to bus in Australia found that most (88%) of the calculated reduction in CO_2 emissions was the direct impact of reduced car travel by busway customers.

E-scooter is usually lauded as a mode which can significantly reduce GHG emission; however, (Hollingsworth et al. 2019) showed that its impact is not necessarily intuitive and is quite sensitive to the lifetime of shared scooters, because 50% of carbon impacts of shared e-scooters may be associated with manufacture of and materials for the vehicle, with 43% associated with daily collection for charging. In a study using Monte-Carlo simulations, assuming life times of

0.5 – 2 years, in 65% of cases the emissions associated with the e-mobility scheme were higher than those of the displaced modes. Improved collection schemes drop this value to 35-50% of simulations, whilst assuming a two year lifespan for e-scooters this value further reduced to 4%. Generally, there was a 'universally realised net reduction in environmental impacts' when shared scooter service is compared solely to private conventional vehicle use, but it also consistently leads to higher GHG emission compared to bus with high ridership, private e-bike and bikes. Although more data collection and evidence is needed, this result cast doubt on scooter services' sustainability claim, especially given the fact that currently the average lifetime of a scooter is only 1-2 months[2] which is much shorter than the base case assumptions.

Pollution: For both private and shared e-mobility, the pollution caused by batteries is one of its major negative environmental impact, especially that many micro-mobility vehicles are powered by lead-acid batteries which can result in lead pollution (Campbell et al. 2016). Compared to private vehicles, it should be easier to control the pollution caused by batteries of shared electric modes since they are centrally managed by the service operator and can be processed and recycled in batch.

Health impacts of transport modes is a topic gaining more attention recently especially with the increasing popularity of active modes.

Annual deaths: Transport mode influences the annual number of deaths in three ways: physical activity associated with using the transport mode, pollution caused during the production and usage of the mode and fatalities caused by related traffic accidents. (Otero et al. 2018) estimated the total impact on the annual number of deaths from bikesharing schemes in different cities: the study found that in general bikesharing services provide health benefits mostly due to increased physical activity. However, bikesharing equipped with e-bikes (Madrid) resulted in lower avoided deaths since its activity level is less intense (Langford et al. 2017).

Injuries: The recent proliferation of e-scooters and related injuries raised attention on this worrying impact of e-scooters. The number of injuries and hospital visits of both riders and pedestrians caused by e-scooter is escalating, and the main reasons are mostly failure in adhering to regulations, including not wearing helmets, alcohol consumption, riding over the speed limit and reckless usage (Haworth and Schramm 2019; Trivedi et al. 2019). Given these reports, scooter sharing may still result in a net reduction of injuries since it replaces many car trips which are related to higher number of injuries and fatalities (PBOT 2019).

Social impacts of shared e-mobility mainly refer to those influences on citizen welfare. There have not been many studies focusing on social impacts in the transport research field, although the potential of micro-mobility in providing social benefits are increasingly mentioned in relevant studies and reports.

Accessibility: E-bike and e-scooter generally increase accessibility by enabling users to reach more distant locations which were beyond walking distance and poorly connected by public transport (MacArthur et al. 2017; Smith and Schwieterman 2018). It is found that in Chicago e-scooter can make 16% more jobs accessible within 30 minutes of commuting time, although the impact is vastly different across the entire study area.

Equity: Both e-bike and e-scooter sharing services are found to have the potential in expanding accessibility for regions and groups which are underserved by traditional modes (MacArthur et al. 2017; PBOT 2019). There has been evidence showing that micro-mobility users are different from the typical early adopter profile in traditionally underserved regions (Shaheen and Cohen 2019). It can also enhance mobility even in places which are usually well supported

[2] https://qz.com/1561654/how-long-does-a-scooter-last-less-than-a-month-louisville-data-suggests/, https://www.theinformation.com/articles/inside-birds-scooter-economics

by transport: in dense urban areas which are often highly congested bikes and walking can often be faster than driving, e-bikes and e-scooters can enlarge this speed advantage and provide it for more people (Behrendt 2018). Although in general micro-mobility modes require people with able body and are less suitable for those who are handicapped and overweight. Since shared electric micro-mobility modes are usually more affordable (compared to owning car), convenient and accessible than traditional modes, they are expected to play an important role towards the goal of increasing transport equity and achieving “Universal Basic Mobility”.

Land use impacts refer to the influences on use of space. In the case of electric micro-mobility, the most visible impacts are regarding the use of curb space. Some scooter riders do not want to use the main road and prefer to ride on the pedestrian lane, while their relatively high speed can cause nuisance and even injuries for pedestrians. Furthermore, most scooters are parked on the sidewalk and probably illegally placed in locations which can block passage of handicapped people and other pedestrians. It calls for better regulations and smarter management (such as geofencing) in order to relieve the negative impacts of scooters for other road users. If micro-mobility usage sees considerable increase in the future, it may eventually require a new allocation of road space which assigns wider lanes for bikes and scooters.

One last point for discussion is that the impact of a transport mode is different depending on whether it is privately owned or shared, because the operational process of a shared mobility service would also result in impacts apart from the trips conducted by the mode. This effect is obvious in the contrast between private car ownership and carsharing, but the difference may also be quite relevant in the case of micro-mobility modes which are supposed to reduce negative externalities. For example, the CO_2 emission of private bike is only 8g per mile while the number for dockless bikesharing is 190g per mile, which is mainly a result of the rebalancing trip conducted by cars (Hollingsworth et al. 2019).

4. Incentives for electric mobility deployment

In order to promote and accelerate the uptake of electric mobility, there have been a wide range of policy incentives on national, regional and local level. Policy incentives for electric mobility can be categorized based on the following dimensions:

- *Vehicle type*: major vehicle types include electric vehicle (can be further divided into BEV (battery electric vehicle) and PHEV (plug-in hybrid vehicle)) and e-bikes. E-scooters are still mostly being promoted by shared scooter service providers and have not yet been covered by incentive policies.
- *Business model*: as access-based consumption becomes more widespread, passengers can also access vehicles via leasing or using shared mobility services apart from the traditional business model of purchasing. Policy makers are also starting to address these alternative business models as well.
- *Focus of incentive*: most incentives focus on the adoption of vehicle/usage of service, while there are also policies aiming at developing the complementary infrastructure and facilities such as charging stations and shared mobility hubs.
- *Addressed stakeholder*: incentives can concern the government itself (such as public procurement), vehicle manufacturers, mobility service providers and end users such as consumers of vehicles and mobility services.

Table illustrates the typology of electric mobility deployment incentives and lists examples for each class of policies.

Table 9. Typology of electric mobility deployment incentives

		Purchase		Shared mobility	
		EV	E-bike	EV	E-bike
Vehicle/service	Consumer	Monetary; Non-monetary; Information campaigns	Monetary, trials	/	/
	Government	Public procurement	/	/	Provision of public shared mobility service
	Product provider	Regulatory (Setting targets and standards); subsidies	/	Facilitation and coordination, taxation	Facilitation and coordination
Infrastructure	Consumer	Install chargers	Build bike lanes, install parking and chargers	Establishing shared mobility hubs	
	Product provider	/	/	Providing parking spots for shared vehicles	

Most policies fall into the first cell which incentivizes consumers to purchase EVs. A diverse set of incentives have been implemented by governments. Since high purchase price is deemed one of the biggest barriers for EV adoption, the most common incentive is EV price reduction in different forms such as direct purchase grants and tax rebates. Other monetary incentives target at reducing the operational cost of EV such as exemption of road tax and tolls. Some countries also grant non-monetary incentives for EV users such as access to specific lanes and dedicated parking spots. Apart from giving direct benefits to EV owners, governments also run information campaigns which aim to familiarize people with the benefits of EV and motivate potential EV adopters.

Compared to the large portfolio of EV purchase incentives for consumers, e-bike purchase incentives are much smaller in number, mostly on regional or local level (instead of national) and are mostly only in the form of price reduction. In some places like Brussels, only buyers who hand in the license plate of their scrapped vehicle are qualified for the incentive (ECF 2016). As e-bikes offer the potential to replace cars, more attention shall be paid on e-bike incentives. Even without many incentives, the sale number of e-bike is already much higher compared to EV due to its cheaper price (ECF 2016), some policy supports can help e-bike to achieve its full potential.

Apart from consumer incentives, governments have also implemented other EV promotion policies targeting at vehicle manufacturers such as setting sale targets for EV and subsidizing EV sales. Governments can also promote EV and increase its visibility by public procurement and electrification of the public fleet. As for other business models such as shared e-mobility service, there is hardly any governmental incentives targeting at potential consumers. Governments either operate their own shared e-bike service (such as BICIMAD in Madrid) or facilitates the operation of shared mobility service providers.

Another main barrier for the uptake of electric mobility is its demand for different infrastructure; consequently, some policies aim to boost electric mobility adoption by developing the complementary infrastructure. In the case of EV, most policy efforts focus on the installation of private and public chargers. As for e-bikes, other bike infrastructure also needs to be improved such as bike lanes and parking stalls. Shared e-mobility services mainly demand the use of public space; therefore, governments who wish to promote such services would grant access to parking spots of the shared fleet at a discounted price; moreover, they can coordinate between different shared mobility providers and facilitate the development of multi-modal mobility hubs which increase the attractiveness of the services.

Based on the above summary, several recommendations can be made regarding future policy incentives for electric mobility deployment: first, instead of focusing only on EV, provide policy support for other electric micro-mobility modes (e-bike and e-scooter) as well; second, policies can also incentivize the use of shared e-mobility services instead of merely focusing on vehicle adoption; third, watch out for the possible rebound or side effects of incentives which go against the goal of sustainable mobility (such as induced sale of EV as the second vehicle); last, when multiple policies are being implemented governments shall be aware of how they influence each other.

5. Discussion of future trends

In this section we discuss several potential directions for the development of shared e-mobility in the future.

5.1 Service organization: roundtrip, one-way station-based or free-floating?

Carsharing as the oldest form of shared mobility started as a roundtrip service; as smartphones and mobile internet become more common, nowadays carsharing services also allow one-way trips between stations or even parking in any allowed spot (free-floating). As for shared micro-mobility services with e-bikes and e-scooters, they are generally all one-way services whether being dockless or not. The difference between free-floating or station-based may not be so obvious in the future: virtual stations can be easily created with geofencing and both the size and location of stations can be easily adjusted based on need, which results in an organized yet flexible system, combining the strengths of both free-floating and station-based systems.

5.2 Relations between different modes: complementary or competitive?

Every single mode within shared e-mobility is expected to reduce the high negative externalities of fossil fuel-based car transport by replacing more car use and reduce private car ownership. This impact has been demonstrated by many existing shared e-mobility services. Moreover, shared e-scooters have also been replacing ridesharing trips; major ridesharing operators including Uber and Lyft have been acquiring shared e-scooter and bike operators in order to offer more micro-mobility services.

However, when all micro-mobility modes become available they may also cannibalize each other’s share. Last year, albeit dockless e-scooter share is still a new player, half of micro-mobility trips were taken on them while another half was taken on station-based bikeshare. Dockless bikeshare have almost gone extinct in US cities due to the appearance of scooters (NACTO 2018). This is definitely worth considering in decision making as the sustainability impact of micro-mobility modes are largely different and the cannibalization of share within these modes may not be necessarily proceeding in the ideal direction. Shared e-mobility mode can also replace other more efficient transport modes: the review above already showed that the vast majority of e-scooter and e-bike trips would have been taken by public transport and active modes (biking and walking): this replacement is probably resulting in higher GHG emission and fewer health benefits.

Therefore, more research should be done on exploring the behavior change when more than one shared e-mobility modes coexist and estimating their total impact on transportation and sustainability aspects. The insights can be used to foster a complementary relationship among different modes which lead to higher accessibility and mobility without resulting in a net increase of negative externalities.

5.3 Integration of operators and modes: from the perspective of Mobility-as-a-Service

Some major transport network companies such as Lyft and Uber are expecting network effects and have commenced with vertical integration across different mobility modes. However, shared mobility is a capital-intensive industry (unlike platform providers such as ridesharing and peer-to-peer carsharing) and consists of many different modes; therefore, it is unlikely to be a winner-take-it-all market. The integration of different operators can increase the utilization and better serve the mobility needs of the entire community.

The integration between different modes of shared mobility and public transport is also beneficial. Earlier we have mentioned that a sound public transport service can facilitate the proliferation and strengthen the positive impacts of shared e-mobility: the vast majority of shared mobility users would use public transport when a shared vehicle is not available (Ampudia-Renuncio et al. 2018). This indicates that public transport provides a fallback option which helps to ensure the reliability of shared services and reduce barriers for adoption; furthermore, there has been evidence showing that the combination of public transport and micro-mobility modes can achieve synergy in their impacts (Fishman et al. 2013). In order to maximize the potential of reducing car dependency and the negative externalities of car transport, a diverse set of shared mobility modes which are well coordinated and integrated with public transport is called for.

Compared to door-to-door car trips, travelers usually face extra physical, cognitive and affective efforts if they would take a multi-modal trip (Stradling et al. 2000): physical effort is needed during transfer between modes when the stations for different modes are not at the same location; it is also cognitively demanding to deal with searching and payment of different mobility services; as a result, these extra efforts will harm the perception of shared mobility service as an inconvenient and uncomfortable option compared to car (Berg et al. 2019). Therefore, the integration shall aim to reduce these different aspects of extra effort and lower the barriers for switching towards adopting shared e-mobility service:

Mobility hubs: It is a one-stop location which provides a wide range of mobility modes, usually including multiple shared mobility services and public transport. The easy access to multiple travel options can relieve the cognitive effort in searching and also physical efforts in transferring between different stations. There have been pioneering cities which adopted the concept of mobility hubs: Already since 2003 the city of Bremen has started to deploy Mobil.Punkt ("Mobility Point") stations which are often situated next to high-frequency public transport stops and provide carsharing and bike parking spots. They are also accompanied by Mobil.Punktlichen (small point) which are located close to residential neighborhoods in order to be close to users. With all the new shared mobility modes, future mobility hubs can incorporate different combinations of modes according to the specific needs of each location and provide a better-rounded and easy-to-use mobility service.

MaaS integration: now the term MaaS mostly refers to a package subscription with capped or unlimited usage of all mobility options included (Durand et al. 2018). However, a wider definition of the term can refer to an "integration within and between different types of transport” (Lyons et al. 2019) which can happen on different levels and aspects. Under this point we are stressing the integration of information search and payment between different modes apart from the physical integration of mobility hub, which can greatly reduce the cognitive effort of multi-modal trips.

5.4 Relation with automation

Automation is another main trend of future transport apart from electrification and sharing. It can also be combined with shared e-mobility: apart from the hype in autonomous vehicles, there has also been effort in research and development of autonomous micro-mobility vehicles such as e-scooters. Unlike autonomous vehicles which are expected to reduce the cost of drivers, autonomous micro-mobility vehicles can save the cost of rebalancing trips and also reduce the access distance of shared-vehicles. However, just like autonomous vehicles, these vehicles probably will not be seen on streets in the near future. An interesting point for research can be investigating whether the preference for these modes (car, bikes, and scooters) will change when all of them are (partially or fully) automated.

6. Conclusions

This literature review aims to identify the main themes of shared e-mobility research and the main methodologies applied. Most existing papers focus on three themes, namely performance description of existing systems, demand estimation studies which explore factors influencing the demand for shared e-mobility services and impact assessment studies which evaluate the impact of existing systems or simulate potential impacts of a service under different scenarios. A wide range of methodologies are used depending on the specific research question, mainly including various models of statistical modelling and simulations.

We summarized the early adopter profiles, trip characteristics and usage patterns of existing shared e-mobility services. We also listed the factors which are found to have significant influence on service demand and synthesized findings regarding the various impacts of these services. Finally, we discussed several trends of future shared e-mobility development.

As for recommendations for future research on shared e-mobility, we have already mentioned some limitations under each theme of research above which can be addressed by further studies. In general, the research on shared e-mobility especially shared electric micro-mobility is still in its infancy period, both the influence of different factors on service demand and the impact of these services still need much more evidence to be conclusive. Studies in different countries are also necessary, as the adoption and impact of micro-mobility modes seem to be more influenced by local culture and there may not exist a universally valid solution.

Last but not least, most studies so far only focused on a single mode. There shall be more focus and attention for the perspective of a multi-modal mobility service which integrates multiple transport modes on physical, informational and payment level. For example, there has been several studies on the preference for MaaS in terms of a mobility package subscription, while it is also valuable to explore people’s actual travel behavior (change) and mode share after adopting the subscription and evaluate the net environmental and transportation impact of MaaS subscriptions.

References

Ajzen, I.: The theory of planned behaviour. Organizational Behaviour and Human Decision Processes, 50(2), 179-211 (1991).

Ampudia-Renuncio, M., Guirao, B., Molina-Sanchez, R.: The impact of free-floating carsharing on sustainable cities: analysis of first experiences in Madrid with the university campus. Sustain. Cities Soc. 43, 462–475 (2018). doi:10.1016/j.scs.2018.09.019

Becker, H., Ciari, F., Axhausen, K.W.: Comparing Car-Sharing Schemes in Switzerland: User Groups and Usage Patterns. Transp. Res. Part A Policy Pract. 97, 17–29 (2017). doi:10.1016/j.tra.2017.01.004

Becker, S., Rudolf, C.: Exploring the Potential of Free Cargo-Bikesharing for Sustainable Mobility. 156–164 (2018)

Behrendt, F.: Why cycling matters for electric mobility: towards diverse, active and sustainable e-mobilities. Mobilities. 13, 64–80 (2018). doi:10.1080/17450101.2017.1335463

Berg, J., Henriksson, M., Ihlström, J.: Comfort First ! Vehicle-Sharing Systems in Urban Residential Areas : The Importance for Everyday Mobility and Reduction of Car Use among Pilot Users. (2019)

Boldrini, C., Bruno, R., Conti, M.: Characterising demand and usage patterns in a large station-based car sharing system. Proc. - IEEE INFOCOM. 2016-Septe, 572–577 (2016). doi:10.1109/INFCOMW.2016.7562141

Boor, S.: Impacts of 4th generation bike- sharing, (2019)

Burghard, U., Dütschke, E.: Who wants shared mobility? Lessons from early adopters and mainstream drivers on electric carsharing in Germany. Transp. Res. Part D Transp. Environ. 71, 96–109 (2019). doi:10.1016/j.trd.2018.11.011

Burkhardt, J. E., Millard-Ball, A.: Who is attracted to carsharing? Transp. Res. Record, 1986(1), 98-105 (2006). doi:10.1177/0361198106198600113

Campbell, A.A., Cherry, C.R., Ryerson, M.S., Yang, X.: Factors influencing the choice of shared bicycles and shared electric bikes in Beijing. Transp. Res. Part C Emerg. Technol. 67, 399–414 (2016). doi:10.1016/j.trc.2016.03.004

Carley, S., Krause, R. M., Lane, B. W., Graham, J. D.: Intent to purchase a plug-in electric vehicle: A survey of early impressions in large US cites. Transp. Res. Part D: Transport and Environment, 18, 39-45 (2013). doi:10.1016/j.trd.2012.09.007

Chiarlotti, F., Pielli, C., Zanella, A., Zorzi, M.: A dynamic approach to rebalancing bike-sharing schemes. Sensors 18(2), 512 (2018). doi:10.3390/s18020512

DEFRA. Emissions Factors Toolkit Version 9.0 (2018). Department for Environment, Food and Rural Affairs, London, UK. Online resource: https://laqm.defra.gov.uk/review-and-assessment/tools/emissions-factors-toolkit.html [Accessed: 20/11/19].

Degele, J., Gorr, A., Haas, K., Kormann, D., Krauss, S., Lipinski, P.: Identifying E-scooter Sharing Customer Segments using Clustering. In: 2018 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC) (2018)

Dewulf, J., Van der Vorst, G., Denturck,K., Val Langenhove, H., Ghyoot, W., Tytgat, J., Vandeputte, K.: Recycling rechargeable lithium ion batteries: Critical analysis of natural resource savings. Resources, Conservation and Recycling 54(4) 229-234 (2010). doi:10.1016/j.resconrec.2009.08.004

Dieten, R.: Identifying preferences regarding carsharing systems, (2015)

Diez, M.L.S.: Which factors influence potential consumers to adopt to the new e-bike sharing system in their mobility behaviour ?, (2017)

Durand, A., Harms, L., Hoogendoorn-lanser, S., Zijlstra, T.: Mobility-as-a-Service and changes in travel preferences and travel behaviour : a literature review. (2018)

ECF: Electromobility for all - Financial incentives for e-cycling. (2016)

EEA (2019). Overview of electricity production and use in Europe. European Environment Agency. Online resource: https://www.eea.europa.eu/data-and-maps/indicators/overview-of-the-electricity-production-2/assessment-4 [Accessed: 20/11/19].

Egbue, O., Long, S.: Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions. Energy Policy, 48, 717-729 (2012). doi:10.1016/j.enpol.2012.06.009

Emisia. COPERT: The Industry Standard Emissions Calculator (2018). Emisia, Thessaloniki, GR. Online resource: https://www.emisia.com/utilities/copert/ [Accessed: 20/11/19].

Firnkorn, J., Müller, M.: Free-floating electric carsharing-fleets in smart cities: The dawning of a post-private car era in urban environments? Environ. Sci. Policy. 45, 30–40 (2015). doi:10.1016/j.envsci.2014.09.005

Fishman, E.: Bike share: A review of recent literature. Transp. Reviews, 36(1), 92-113 (2016). doi:10.1080/01441647.2015.1033036

Fishman, E., Washington, S., Haworth, N.: Bike Share: A Synthesis of the Literature. Transp. Rev. 33, 148–165 (2013). doi:10.1080/01441647.2013.775612

Gatersleben, B.: Affective and symbolic aspects of car use. In Threats from car traffic to the quality of urban life: Problems, Causes and Solutions (pp. 219-233). Emerald Group Publishing Limited (2007). doi:10.1108/9780080481449-012

Guidon, S., Becker, H., Dediu, H., Axhausen, K.W.: Electric Bicycle-Sharing: A New Competitor in the Urban Transportation Market? An Empirical Analysis of Transaction Data. Transp. Res. Rec. 2673, 15–26 (2019). doi:10.1177/0361198119836762

Haworth, N.L., Schramm, A.: Illegal and risky riding of electric scooters in Brisbane. Med. J. Aust. (2019). doi:10.5694/mja2.50275

Hayden, S., Health, A.P., Spillar, R., Transportation, A.: DOCKLESS Electric scooter-related INJURIES STUDY. (2019)

He, Y., Song, Z., Liu, Z., Sze, N.N.: Factors Influencing Electric Bike Share Ridership: Analysis of Park City, Utah. Transp. Res. Rec. 2673, 12–22 (2019). doi:10.1177/0361198119838981

Hess, A.K., Schubert, I.: Functional perceptions, barriers, and demographics concerning e-cargo bike sharing in Switzerland. Transp. Res. Part D Transp. Environ. 71, 153–168 (2019). doi:10.1016/j.trd.2018.12.013

Hinkeldein, D., Schoenduwe, R., Graff, A., Hoffmann, C.: Who Would Use Integrated Sustainable Mobility Services–And Why? In Sustainable Urban Transport (pp. 177-203). Emerald Group Publishing Limited (2015). doi:10.1108/S2044-994120150000007019

Hollingsworth, J., Copeland, B., Johnson, J.X.: Are e-scooters polluters ? The environmental impacts of shared dockless electric scooters. Environ. Res. Lett. 14, (2019)

Howe, E.: Global Scootersharing Market Report. (2018)

Hu, S., Chen, P., Lin, H., Xie, C., Chen, X.: Promoting carsharing attractiveness and efficiency: An exploratory analysis. Transp. Res. Part D Transp. Environ. 65, 229–243 (2018). doi:10.1016/j.trd.2018.08.015

INRIX: Micromobility Potential in the US , UK and Germany. (2019)

Jakobsson, C.: Instrumental motives for private car use. In Threats from Car Traffic to the Quality of Urban Life: Problems, Causes and Solutions (pp. 205-217). Emerald Group Publishing Limited (2007). doi:10.1108/9780080481449-011

Jensen, A. F., Cherchi, E., Mabit, S. L.: On the stability of preferences and attitudes before and after experiencing an electric vehicle. Transp. Res. Part D: Transport and Environment, 25, 24-32 (2013). doi:10.1016/j.trd.2013.07.006

Jung, J., Koo, Y.: Analyzing the effects of car sharing services on the reduction of greenhouse gas (GHG) emissions. Sustainability. 10, 1–17 (2018). doi:10.3390/su10020539

Kaplan, S., Manca, F., Nielsen, T.A.S., Prato, C.G.: Intentions to use bike-sharing for holiday cycling: An application of the Theory of Planned Behavior. Tour. Manag. 47, 34–46 (2015). doi:10.1016/j.tourman.2014.08.017

Kaplan, S., Wrzesinska, D.K., Prato, C.G.: The role of human needs in the intention to use conventional and electric bicycle sharing in a driving-oriented country. Transp. Policy. 71, 138–146 (2018). doi:10.1016/j.tranpol.2018.09.010

Kephalopoulos, S., Pavotti, M., Anfosso-Lédée, F.: Common noise assessment methods in Europe (CNOSSOS-EU). JRC Reference Reports (2012). Ispara, IT. Online resource: https://ec.europa.eu/jrc/sites/jrcsh/files/cnossos-eu%2520jrc%2520reference%2520report_final_on%2520line%2520version_10%2520august%25202012.pdf [Accessed: 20/11/19].

Kramer, S., Hoffmann, C., Kuttler, T., Hendzlik, M.: Electric Car Sharing as an Integrated Part of Public Transport: Customers' Needs and Experience. Presented at the (2014)

Krupa, J. S., Rizzo, D. M., Eppstein, M. J., Lanute, D. B., Gaalema, D. E., Lakkaraju, K.,
Warrender, C. E.: Analysis of a consumer survey on plug-in hybrid electric vehicles. Transp. Res. Part A: Policy and Practice, 64, 14-31 (2014). doi:10.1016/j.tra.2014.02.019
Lan, J., Mangalagiu, D., Ma, Y., Thornton, T.F., Zhu, D.: Modelling consumption behaviour changes in a B2C electric vehicle-sharing system : a perceived systemic risk perspective. Clim. Chang. (2019)
Langford, B.C., Cherry, C.R., Bassett, D.R., Fitzhugh, E.C., Dhakal, N.: Comparing physical activity of pedal-assist electric bikes with walking and conventional bicycles. J. Transp. Heal. 6, 463–473 (2017). doi:10.1016/j.jth.2017.06.002
Liao, F., Molin, E., Timmermans, H., van Wee, B., Wee, B. Van: Carsharing: the impact of system characteristics on its potential to replace private car trips and reduce car ownership. Transportation (Amst). (2018). doi:10.1007/s11116-018-9929-9
Lieven, T., Mühlmeier, S., Henkel, S., Waller, J. F.: Who will buy electric cars? An empirical study in Germany. Transportation Research Part D: Transport and Environment, 16(3), 236-243 (2011). doi:10.1016/j.trd.2010.12.001
Lois, D., López-Sáez, M.: The relationship between instrumental, symbolic and affective factors as predictors of car use: A structural equation modelling approach. Transp. Res. Part A: Policy and Practice, 43(9-10), 790-799 (2009). doi:10.1016/j.tra.2009.07.008
Lyons, G., Hammond, P., Mackay, K.: The importance of user perspective in the evolution of MaaS. Transp. Res. Part A Policy Pract. 121, 22–36 (2019). doi:10.1016/j.tra.2018.12.010
MacArthur, J., Kobel, N., Dill, J., Mummuni, Z.: Evaluation of an Electric Bike Pilot Project at Three Employment Campuses in Portland, Oregon. (2017). doi:10.15760/trec.158
Martin, E., Shaheen, S.: Impacts of Car2go on vehicle ownership, modal shift, vehicle miles traveled, and greenhouse gas emissions: An analysis of five North American cities. (2016)
Mattia, G., Mugion, R. G., Principato, L.: Shared mobility as a driver for sustainable consumptions: The intention to re-use free-floating car sharing. Journal of Cleaner Production, 237, 117404 (2019). doi:10.1016/j.jclepro.2019.06.235
McKenzie, G.: Spatiotemporal comparative analysis of scooter-share and bike-share usage patterns in Washington, D.C. J. Transp. Geogr. 78, 19–28 (2019). doi:10.1016/j.jtrangeo.2019.05.007
Moons, I., De Pelsmacker, P.: Emotions as determinants of electric car usage intention. Journal of Marketing Management, 28(3-4), 195-237 (2012). doi:10.1080/0267257X.2012.659007
Morton, C., Schuitema, G., Anable, J.: Electric vehicles: Will consumers get charged up. In Universities' Transport Study Group Conference January (2011, January).
Munkácsy, A., Monzón, A.: Impacts of smart configuration in pedelec-sharing: Evidence from a panel survey in madrid. J. Adv. Transp. 2017, (2017)(a). doi:10.1155/2017/4720627
Munkácsy, A., Monzón, A.: Potential User Profiles of Innovative Bike-Sharing Systems: The Case of BiciMAD (Madrid, Spain). Asian Transp. Stud. 4, pp 621-638 (2017)(b). doi:10.11175/eastsats.4.621
NACTO: Shared Micromobility in the U.S.: 2018. (2018)
Notter, B., Keller, M., Althaus, H-J., Cox, B., Knörr, W., Heidt, C., Biemann, K., Räder, Jamet, M.: HBEFA 4.1 Development Report (2019). INFRAS, IFEU and FVT, on behalf of Bundesamt für Umwelt BAFU (CH), Umweltbundesamt UBA (DE), Umweltbundesamt UBA (AT), Agence de l'Environnement et de la Maîtrise de l'Energie ADEME (FR), Trafikverket (SE), Miljødirektoratet (NO).
Otero, I., Nieuwenhuijsen, M.J., Rojas-Rueda, D.: Health impacts of bike sharing systems in Europe. Environ. Int. 115, 387–394 (2018). doi:10.1016/j.envint.2018.04.014
Paundra, J., Rook, L., van Dalen, J., Ketter, W.: Preferences for car sharing services: Effects of instrumental attributes and psychological ownership. Journal of Env. Psychology, 53, 121-130 (2017). doi:10.1016/j.jenvp.2017.07.003
PBOT: 2018 E-Scooter Findings Report. (2019)
Perboli, G., Ferrero, F., Musso, S., Vesco, A.: Business models and tariff simulation in car-sharing services. Transp. Res. Part A. 115, 32–48 (2018). doi:10.1016/j.tra.2017.09.011
Populus: The Micro-Mobility Revolution: The introduction and adoption of electric scooters in the United States. 18 (2018)
Rabbitt, N., Ghosh, B.: A study of feasibility and potential benefits of organised car sharing in Ireland.

Transp. Res. Part D Transp. Environ. 25, 49–58 (2013). doi:10.1016/j.trd.2013.07.004
Rezvani, Z., Jansson, J., Bodin, J.: Advances in consumer electric vehicle adoption research: A review and research agenda. Transp. Res. Part D: Transport and environment, 34, 122-136 (2015). doi:10.1016/j.trd.2014.10.010
Romanillos, G., Moya-gómez, B., Zaltz-austwick, M., Patxi, J., Romanillos, G.: The pulse of the cycling city : visualising Madrid bike share system GPS routes and cycling flow and cycling flow. 5647, (2018). doi:10.1080/17445647.2018.1438932
Rycerski, P., Koutra, S., Genikomsakis, K.N., Ioakimidis, C.S.: A university survey with a comparative study of an E-bikes sharing system. EVS 2016 - 29th Int. Electr. Veh. Symp. 1–11 (2016)
Satz, D., Ferejohn, J.: Rational choice and social theory. The Journal of Philosophy, 91(2), 71-87 (1994). doi:10.2307/2940928
Schaefers, T.: Exploring carsharing usage motives: A hierarchical means-end chain analysis. Transp. Res. Part A: Policy and Practice, 47, 69-77 (2013). doi:10.1016/j.tra.2012.10.024
Schuitema, G., Anable, J., Skippon, S., Kinnear, N.: The role of instrumental, hedonic and symbolic attributes in the intention to adopt electric vehicles. Transp. Res. Part A: Policy and Practice, 48, 39-49 (2013). doi:10.1016/j.tra.2012.10.004
Shaheen, S., Cohen, A.: Shared Micromoblity Policy Toolkit: Docked and Dockless Bike and Scooter Sharing. (2019). doi:10.7922/G2TH8JW7
Shaheen, S.A., Cohen, A.P.: Carsharing and Personal Vehicle Services: Worldwide Market Developments and Emerging Trends. Int. J. Sustain. Transp. 7, 5–34 (2013). doi:10.1080/15568318.2012.660103
Shaheen, S.A., Guzman, S., Zhang, H.: Bike sharing in Europe, the Americas, and Asia: Past, present, and future. Transp. Res. Record, 2143(1), 159-167 (2010). doi.org/10.3141/2143-20
Shaheen, S., Sperling, D., Wagner, C.: Carsharing in Europe and North American: Past, present, and future. Transp. Quarterly, 52(3), 35-52 (1998). https://escholarship.org/uc/item/4gx4m05b
Shen, Y., Zhang, X., Zhao, J.: Understanding the usage of dockless bike sharing in Singapore. (2018). doi:10.1080/15568318.2018.1429696
Smith, C.S., Schwieterman, J.P.: E-Scooter Scenarios: Evaluating the Potential Mobility Benefits of Shared Dockless Scooters in Chicago. (2018)
Sprei, F., Habibi, S., Englund, C., Pettersson, S., Voronov, A., Wedlin, J.: Free-floating car-sharing electrification and mode displacement: Travel time and usage patterns from 12 cities in Europe and the United States. Transp. Res. Part D Transp. Environ. 71, 127–140 (2019). doi:10.1016/j.trd.2018.12.018
Steg, L.: Car use: lust and must. Instrumental, symbolic and affective motives for car use. Transportation Research Part A: Policy and Practice, 39(2-3), 147-162 (2005). doi:10.1016/j.tra.2004.07.001
Steg, L., Vlek, C., Slotegraaf, G.: Instrumental-reasoned and symbolic-affective motives for using a motor car. Transp. Res. Part F: Traffic psychology and behaviour, 4(3), 151-169 (2001). doi.org:10.1016/S1369-8478(01)00020-1
Stradling, S.G., Meadows, M.L., Beatty, S.: Helping drivers out of their cars Integrating transport policy and social psychology for sustainable change. 7, (2000)
Trivedi, T.K., Liu, C., Antonio, A.L.M., Wheaton, N., Kreger, V., Yap, A.: Injuries Associated With Standing Electric Scooter Use. JAMA Netw. Open. 2, 1–9 (2019). doi:10.1001/jamanetworkopen.2018.7381
Vasconcelos, A.S., Martinez, L.M., Correia, G.H.A., Guimarães, D.C., Farias, T.L.: Environmental and financial impacts of adopting alternative vehicle technologies and relocation strategies in station-based one-way carsharing: An application in the city of Lisbon, Portugal. Transp. Res. Part D Transp. Environ. 57, 350–362 (2017). doi:10.1016/j.trd.2017.08.019
Wang, N., Yan, R.: Research on Consumers ' Use Willingness and Opinions of Electric Vehicle Sharing : An Empirical Study in Shanghai. (2016). doi:10.3390/su8010007
Wang, Y., Yan, X., Zhou, Y., Xue, Q., Sun, L.: Individuals' acceptance to free-floating electric carsharing mode: A web-based survey in China. Int. J. Environ. Res. Public Health. 14, (2017). doi:10.3390/ijerph14050476
Wielinski, G., Trépanier, M., Morency, C.: Differences Between Electric and Hybrid Car Use in a Free Floating Carsharing System. 8318, 15p (2016). doi:10.1080/15568318.2016.1220653

Yoon, T., Cherry, C.R., Jones, L.R.: One-way and round-trip carsharing: A stated preference experiment in Beijing. Transp. Res. Part D Transp. Environ. 53, 102–114 (2017). doi:10.1016/j.trd.2017.04.009

Zarif, R., Pankratz, D., Kelman, B.: Small is beautiful - Making micromobility work for citizens, cities, and service providers. (2019)

Zhang, Y., Yu, Y., Zou, B.: Analysing public awareness and acceptance of alternative fuel vehicles in China: The case of EV. Energy Policy, 39(11), 7015-7024 (2011). doi:10.1016/j.enpol.2011.07.055

Zoepf, S.M., Keith, D.R.: User decision-making and technology choices in the U.S. carsharing market. Transp. Policy. (2016). doi:10.1016/j.tranpol.2016.01.010