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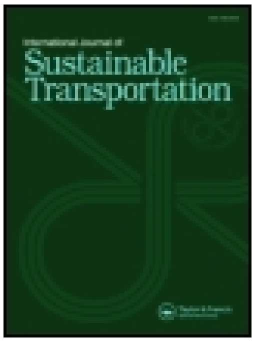

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Electric carsharing and micromobility: A literature review on their usage pattern, demand, and potential impacts

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ABSTRACT

Shared e-mobility is a category of emerging mobility services that includes electric carsharing, e-bike sharing, and e-scooter sharing. These services are expected to reduce the negative externalities of road transport in cities, which is currently dominated by fossil-fuel-powered private car trips. In order to better inform the development and promotion of these services and indicate directions for further research, we conducted a comprehensive review of existing literature on the three shared e-mobility modes focusing on their usage pattern, demand estimation, and potential impacts. We found that despite the different vehicle capabilities, all three shared e-mobility services are mainly used for short trips, and their current users are mostly male, middle-aged people with relatively high income and education. The demand of all shared e-mobility modes share many common predictors: they appeal to people with similar socio-demographic characteristics and generate higher demand in locations with better transport connectivity and more points of interest. Shared e-mobility services can potentially lead to positive impacts on transportation and the environment, such as reducing car use, car ownership, and greenhouse gas emissions. However, the magnitude of these benefits depends on the specific operational conditions of the services such as the fuel type and lifetime of shared vehicles. The impact of each shared e-mobility mode is also expected to be affected by other coexisting shared e-mobility modes due to both complementarity and competition. Future directions should include studying the competition between and integration of multiple shared e-mobility modes.

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1. Introduction

Shared mobility and electrification are two main trends in transport systems evolution 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 that combine the two trends and may achieve synergy regarding the envisioned positive impacts. Currently, it mainly consists of electric carsharing, e-bike sharing, and e-scooter sharing. 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 (potential) users' and other travelers' reaction toward these services (such as current usage pattern, consumer demand, and potential impacts) can be helpful for the decision-making process of public authorities and shared mobility companies.

In many cities, governments and mobility providers introduce multiple modes (e.g. both electric carsharing and e-bike sharing) to reap the maximum benefits from shared e-mobility services; moreover, traditionally powered shared mobility services may already exist as well (fossil fuel carsharing and normal bikesharing). Multiple shared e-mobility services may complement or compete with each other and also with their traditionally powered counterparts. These relations will affect the usage pattern and demand of each mode and eventually influence the total net impact. However, almost all empirical studies choose to focus on only one of the shared e-mobility services. Therefore, an integrated perspective that accounts for multiple shared e-mobility services and their relations is necessary to fully understand their demand and impact and facilitate synergy between different shared e-mobility services.

Our literature review on shared e-mobility service aims to provide a comprehensive synthesis of findings from existing relevant studies. We focus on three main emerging modes: electric carsharing, e-bike sharing, and e-scooter sharing. The review aims to answer the following questions: 1) What are the main themes of shared e-mobility research? 2) What methodologies are applied for each theme? 3) What are the main findings under each theme? 4) What are the similarities, differences and relations between the three shared e-mobility services and between them and their traditionally

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powered counterparts? 5) What recommendations can be given for future research in order to fill in some of the identified gaps and address future development trends?

Electric carsharing 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 buying private EVs due to the high purchase costs and multiple risks and uncertainties (Liao et al., 2017). Apart from the positive environmental impacts achieved by combining sharing and electric motors, deploying EVs in shared car fleets can also be beneficial for operators as it can theoretically reduce operating costs as its energy cost is lower than that of a conventional vehicle (CV). However, in reality, electric carsharing faces higher operational complexity since EVs still need a long charging time, which can increase the overall costs (Perboli et al., 2018).

E-bike and e-scooter sharing are both examples of electric shared micromobility. The term micromobility first appeared in 2017[1] 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 and electric) bikes and scooters, while it also includes other less common modes such as skateboard, gyroboard, hoverboard, and unicycle. Currently, e-bike and e-scooter are the two most promising electric shared micromobility systems. Depending on whether pedal assistance is necessary, e-bikes can be categorized into pedelecs (with pedal-assist) and e-mopeds: most e-bike sharing systems use pedelecs, the top speed of which ranges from 25 to 45 km/h. E-scooter refers to kick scooters which can go up to 20 km/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 collecting scientific articles and reports for this literature review. The keywords used were *sharing* combined with all types of electric modes (electric vehicle, e-bike, e-scooter, e-cargo bike[2]). Afterward, more relevant articles were identified via backward snowballing based on the references of the initially found articles. The literature search was mostly completed in August 2019 (a few studies were added during the revision process). Since research on micromobility is still in its nascent stage, we did not exclude nonacademic gray literature, although the vast majority of the articles included are peer-reviewed academic research. Almost all studies were conducted after 2015 so we did not apply any time filter and only chose articles based on their relevance. During the literature gathering process, we noticed that research on the operation of shared mobility systems has been rather prolific in the last years; however, we do not address this literature in this paper. We choose to especially focus on aspects that are more closely related to the behavior of (potential) users and travelers, while operation strategies strive to make systems more efficient and are mostly service providers' concern.

This article is organized as follows: Section 2 briefly introduces the major themes and methodologies in the reviewed studies on shared e-mobility. Section 3 presents and synthesizes the findings in reviewed articles for each of the identified themes. The final section concludes the article and gives recommendations for future research.

2. Major themes and methodologies in reviewed studies

We took an inductive approach in this literature review: no specific topics were assigned before the collection other than the general focus on studies related to user behavior (in contrast to purely technical/operational research). After reading all the collected studies, We extracted three main themes from these studies, namely usage pattern, demand estimation, and impact evaluation.

This section briefly introduces the three themes and presents the methodologies applied in studies under each theme. Most discussion is based on references in Tables 1, 4, and 6 which respectively lists the studies under each of the three themes.

2.1. Usage pattern

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 usage pattern of these systems 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. Table 1 shows that these studies either collect survey data from system users or directly obtain transaction or vehicle data. Due to business secrecy issues, it is often difficult to obtain data from private shared mobility providers; this problem can be alleviated by scraping data from mobility providers' online map (Ampudia-Renuncio et al., 2020; Sprei et al., 2019) or acquiring data from open knowledge bases (McKenzie, 2019). Data analysis of the reviewed studies in this category usually remains at the level of descriptive statistics and geographic visualization.

2.2. (Potential) demand estimation

A strand of studies focuses on exploring factors that determine the potential demand for shared e-mobility services. Depending on their specific perspectives, studies can be further divided into the following two groups:

- Disaggregate approach: this group of studies takes each individual as a unit and investigates his or her choice of using the service. Commonly used dependent variables include portfolio choice regarding whether to become a member of a shared mobility system, the extent of the intention of using the shared mobility system and mode

[1]https://en.wikipedia.org/wiki/Micromobility

[2]Different expressions of the same object were used in the search, such as e-bike and electric bike, etc.

Table 1. Overview of studies on the usage pattern of current systems.

Author year	Mode type	Location	Time of data collection	Data type	Whether publicly available	Topic	Sample size	System
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. (2017)	EV	Montreal, Canada	Reservation: June 2013 to April 2015 GPS location: June 2013 to March 2014	Reservation record and GPS location of vehicle (3 to 4 points per minute)	No	Probability of choosing EV and spatial distribution of trips	14,692 reservations 24,995 trips	Auto-mobile, free-floating
Boldrini et al. (2016)	EV	Paris, France	April 2015	Pickup and drop-off times at 960 stations with 2-min interval	Scraped from the online map	Spatial and temporal patterns of station utilization	1,881,727 observations	Autolib
Ampudia-Renuncio et al. (2018)	EV	Madrid, Spain	November 2016	Survey		Perception	186 students (25% of the users)	Car2go
Sprei et al (2019)	EV	Madrid, Spain and Amsterdam, Netherlands	Between 2014 and 2017	Vehicle availability data with 1-min interval	Sampled from online map	Usage pattern	Amsterdam: 735 days Madrid: 443 days	Car2go
Burghard and Dütschke (2019)	EV and e-bike	Germany (pilot regions for electric mobility)		Survey		Early adopter profile	947	Pilot for electric mobility
Munkácsy and Monzón (2017)	E-bike	Madrid, Spain	June 2014–2016	Survey		Perception, trip substitution	3 waves: 1859, 584, 534	BiciMAD
Romanillos et al. (2018)	E-bike	Madrid, Spain	April 2017	GPS track points with 75-s interval	No	Visualization of spatiotemporal pattern	230,238 trips	BiciMAD
Becker and Rudolf (2018)	E-cargo bike	Germany	July to December 2016	Survey		User characteristics and usage behavior	9750 users	Multiple
NACTO (2019)	E-scooter	US	2018	Data directly provided by cities and operators, survey	No	Usage behavior		Multiple
PBOT (2019)	E-scooter	Portland, US	July 23, 2018–November 20, 2018	Availability, trip, collision and complaint data, survey	No	Usage behavior		Bird, Lime and Skip
McKenzie (2019)	E-scooter	Washington DC, US	June 13 through October 23, 2018	Snapshots of available vehicles with 5-min interval	API[3]	Contrast of spatiotemporal pattern between shared e-scooter and bike	15,960 snapshots 937,590 trips	Lime

[3]https://ddot.dc.gov/page/dockless-api

choice for a specific trip. Given this focus on individuals, the data source of these studies is usually resulting from surveying respondents sampled from the general population or potential users of the systems.

- Aggregate approach: these studies usually directly analyze transaction data of an existing system and take geographic zones as the main unit of analysis. Therefore, the dependent variable can be the number of members or usage frequency of a certain zone during a certain period.

The determinants of demand identified by these two groups of studies are largely overlapping albeit in different forms: for example, "age of individual" in the disaggregate approach would be "average age of a certain zone" in the aggregate approach. Some factors 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 patterns, trip characteristics, and time-varying variables. A 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; second, some variables which are commonly used as a proxy for actual demand such as the intention to use stated before implementation are not necessarily related to the decision of actually becoming a user (Munkácsy & Monzón, 2017).

Depending on the choice of the dependent variable and theoretical underpinning, demand studies have 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, data of actual demand can be collected via transaction records or surveys inquiring respondents' actual behavior. Different methods of data collection have distinct limitations, such as a hypothetical bias for stated choice experiments and self-selection bias for surveys in general. Multiple statistical models are applied to analyze the data depending on the selected dependent variable. When the research question is investigating people's preference for shared mobility services among other modes, the most often used type of model is the discrete choice model. Different variants of choice models such as the mixed logit model and latent class choice model were used to address the limitations of the basic multinomial logit model including accounting for panel effect and preference heterogeneity. When studies aim to directly find out what influences the number of booking requests or profit, regression is typically used. In a small fraction of studies, people have been asked about their intention of using a shared e-mobility service and have focused on soft attitudinal constructs that may influence behavior, with structural equation models being the most common choice for the analysis in these cases. These models can be insightful for explaining potential users' intention and behavior of adoption, but they may be of limited use in practical application since the psychological variables are hard to measure and acquire for a large population. Besides, the causal relationship between constructs such as attitudes and behavior can be bidirectional. See Table 4 for a detailed list of methodologies used in demand studies.

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 & Cohen, 2013). There have been a small number of studies aiming to evaluate the impact of existing systems (Martin & Shaheen, 2016) or forecast the potential impact of prospective systems (Vasconcelos et al., 2017). For transportation and environmental effects, most reviewed studies collected directly measurable impacts such as individual behavioral change via survey from (potential) users. The actual usage and behavior change data of sampled users can then be extrapolated to the entire user pool for estimating total actual impact, while both actual and stated behavioral change (and the factors which influence behavior) can be used as input in the simulation models to estimate potential impacts under different scenarios. The several reviewed studies which apply simulation either directly use these behavior data as parameters (Hollingsworth et al., 2019) or use a structural model to characterize demand (Vasconcelos et al., 2017). No complicated interaction mechanisms and models are used (for example, game theoretical models).

3. A synthesis of findings from reviewed studies

This section presents the summary and synthesis of findings from reviewed studies under each of the three identified themes.

3.1. Usage pattern

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 1 lists the papers in which the usage pattern is studied.

User profile: the users of current systems are usually characterized based on their socio-demographics, attitude toward environmental issues, and common travel patterns. Table 2 lists the findings regarding the typical user characteristics of various shared e-mobility systems. The statistics are based on survey responses collected among system users. Because many shared mobility systems are rather new, we were only able to find a few studies per mode. To the best of the authors' knowledge, there have been no census surveys of e-scooter users (NACTO, 2019).

The user profile for shared e-mobility services share some common traits in terms of socio-demographic characteristics: most users are predominantly male, middle-aged (typically between 25 and 45), with a higher education degree and

Table 2. Profile of current shared e-mobility service users.

	EV	E-bike	E-cargo bike	E-scooter
Gender	87% male	∼61% male	63% male	Mostly male but greater gender parity compared to bikesharing
Age	30–40	Average age: 37.5 for frequent users, 34.8 for occasional users Over 50% between 27–40 (Romanillos et al., 2018) Average age: 48 (Burghard & Dütschke, 2019)	38 (widely distributed)	
Education	60–70% with university degree (Burghard & Dütschke, 2019)	Shared of university degree: 78% 60% (Burghard & Dütschke, 2019)		
Income		Middle and upper		
Employment	High level of employment	High level of employment		
Attitude toward environment	Environmentally friendly and open- minded toward shared mobility concepts		Environmentally friendly	
Travel pattern	Mostly multimodal, dominated by PT, travel more often by bike and less by car		Main mode: 71% bike, 13% PT, 6% multimodal, 6% car	
Reference (unless specifically mentioned)	Kramer et al. (2014)	Munkácsy and Monzón (2017)	Becker and Rudolf (2018)	Populus (2018)

Table 3. Length and temporal distribution of shared mobility system trips.

Mode	Trip length	Peak usage
EV	Free-floating: Mean 2.7–3 km (Sprei et al., 2019)	Weekday: 3–8 PM Weekend: 2–8 PM Weekend higher than weekday (Hu et al., 2018)
E-bike	Most frequent trip 2 km (Romanillos et al., 2018) First and third quartile: 1–3.5 km (Guidon et al., 2019)	Weekday: two peaks, morning commute, afternoon, and evening (Romanillos et al., 2018)
E-cargo bike	Mean 15.48 km, Median between 6–10 km (Becker & Rudolf, 2018)	
E-scooter	Mean: 1.85 km (PBOT, 2019) Mean: 0.65 km (McKenzie, 2019) Mean: 1.75–1.96 km[4]	Weekday: 3–6 PM Weekend: 2–5 PM (PBOT, 2019) Midday, small peak at around 8 AM on weekdays (McKenzie, 2019) Afternoons and weekends[5]

above-average income. 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; besides, many of them are multimodal who are being flexible and open-minded regarding transport modes. These results are largely intuitive and fit the image of a typical early adopter of new mobility modes including non-electric shared mobility services. However, the user groups of different shared mobility services (in terms of both vehicles and operational characteristics) may still be distinct in other aspects such as home location (Becker et al., 2017; Kopp et al., 2015).

Trip length: Table 3 presents the typical length range and peak hour of shared mobility trips. This section is based on only a few real-life systems and the conclusion may be subject to changes when these systems become more popular. The typical length of trips conducted by electric shared mobility is different from their non-electric counterparts. In the case of electric carsharing, although the typical trip length is well below the driving range of shared EVs, battery electric vehicles (BEVs) are still chosen for shorter trips compared to conventional vehicles (CV), although it is unclear whether this difference is due to the limited range of EVs (Sprei et al., 2019). Another example is that electric cargo bikes are used for significantly longer trips when compared to normal cargo bikes (Becker & Rudolf, 2018).

The median trip length of e-bike sharing is 2 km and e-scooter trips are even slightly shorter with a mean average of 1.8 km. This range of electric shared micromobility trips overlaps with that of public transport and taxi modes (Guidon et al., 2019) and is also slightly higher than the typical trip length of shared bikes, which is about 1–1.6 km depending on the country (Boor, 2019; Shen et al., 2018). For trips within this range, shared micromobility can be a strong alternative to private cars since they are economically competitive (Smith & Schwieterman, 2018); while for longer trips they tend to cost higher and also require more physical activity. However, if micromobility 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. In general, although different electric modes vary greatly regarding their top speed and

[4]http://scooters.civity.de/en#usage
[5]http://scooters.civity.de/en#usage

capabilities, all free-floating shared mobility services are mostly used for short distances below 3 km.

Time-saving compared to other modes: Time-saving can be one of the main reasons for mode switching. Electric powered cars do not have any strengths compared to their fossil-fuel-powered counterparts in this respect. Free-floating carsharing (electric or conventional) rental times are generally longer than cycling but considerably shorter compared to public transport (Sprei et al., 2019). As for other electric micromobility modes, they are supposed to be faster than normal bikes due to higher top speed; furthermore, their compact size does not take much road space and they enable travelers to save time compared to driving for short trips especially during a congested period. Therefore, shared micromobility can be attractive alternatives for cars and public transport. Guidon et al. (2019) found that e-bikes are faster than both taxi and public transport at the first quartile and the median of all trip distances. Similarly, Arnell et al. (2020) observed that e-scooters, in general, are faster than public transport for short trips. The authors took a random sample of 10,000 shared e-scooter trips in San Diego and recalculated the travel time value for trips between the same OD-pairs using public transport mode. The 10th to 80th percentile of these scooter trips (duration between 2 and 15 min) took less time than the corresponding category for public transport trips.

Trip purpose: Similar to bike sharing, a large percentage of shared e-bike trips correspond to 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, 2019). Despite the suitability of the vehicle 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 3 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 is similar: rides are more dispersed throughout the day compared with e-bike and usage is on a continuously high level starting from early afternoon to the evening (NACTO, 2019). As for spatial distribution, the pattern of shared e-scooter trips is found to be quite dissimilar to both frequent and casual bike sharing 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 & Schwieterman, 2018) since they can be used to serve first-mile and last-mile trips for connecting to transit systems (Romanillos et al., 2018).

The three shared electric modes we investigate in this article vary greatly in terms of their vehicle feature and top speed; however, their user profile and typical trip distance are quite similar, which suggests that they may share the same target customers in the early stage. The time-saving potential of electric micromobility is higher than carsharing due to their small size. Trips conducted by shared e-mobility are used for different trip purposes depending on the vehicle and therefore differ in spatiotemporal distribution, which indicates that they have different use cases and are possible to establish a complementary relationship if well-managed. Since most of the studies focus on only one mode of electric shared mobility, their use case and usage pattern may change due to direct competition if they co-exist with other share e-mobility services. For example, currently, the trip distance of electric carsharing is quite short (average 2.7–3 km) which can be easily covered by e-bike; therefore, if e-bike sharing is widely available, carsharing will probably be more frequently used for longer trips. This may pose an extra challenge for electric carsharing since it is now used for shorter trips compared to conventional carsharing. On the other hand, their different use cases indicate complementarity among different share e-mobility services: their combination allows the coverage of trips of a wider range of purposes and distances, which may provide a feasible alternative to the private car and increase the market share of shared mobility as a whole.

3.2. Demand estimation

This section presents an overview of the findings of demand estimation studies on shared e-mobility services. A list of studies can be found in Table 4. The vast majority of these studies aim to explore the determinants of shared e-mobility service demand. Since e-scooter sharing is the newest shared mobility service, so far there has been no study exploring the determinants of its demand. We will discuss the factors which were found to have a significant impact on choice and demand regarding shared e-mobility. Table 5 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. So far all studies focusing on system attributes concern carsharing systems and only a few considered electric shared cars (Hu et al., 2018; Jung & Koo, 2018; Zoepf & Keith, 2016). The most commonly investigated attributes include price level, availability of a shared car, access distance, shared car type, etc. These attributes largely determine the quality of the entire service and have a great influence on consumers' willingness to use the service. The service attributes which play a role in adopting conventional carsharing services are mostly found to be influential in the case of electric carsharing as well. Previous studies provided mixed evidence regarding the preference for fuel type: compared to conventional shared cars, EVs have been found to be preferred (Dieten, 2015; Jung & Koo, 2018; Liao et al., 2020), less preferred (Zoepf & 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 the

Table 4. Overview of demand studies.

Author (year)	Type of mode	Country	Time of data collection	Population	Sample size	Dependent variable	Modelling approach
Zoepf and Keith (2016)	EV	US mostly big cities	October 2013	Zipcar members	1605	Mode choice for a trip	Discrete choice model (DCM): mixed logit model (MXL)
Wang and Yan (2016)	EV	Shanghai, China	May 2014–November 2014	General population	394	Intention to use	DCM: multinomial logit model (MNL)
Wielinski et al. (2017)	EV	Montreal, Canada	June 2013 to April 2015	Transactional and GPS data		Shared vehicle choice	DCM: MNL
Yoon et al. (2017)	EV	Beijing, China	2013 Summer	General population	1010	Mode choice for a trip	DCM: binary logit
Wang et al. (2017)	EV	China	June 2015 to November 2015	General population	826	Mode choice	Hierarchical tree-based regression
Liao et al. (2020)	EV	Netherlands	June 2015	Potential car buyer	1003	Intention of replacing private car trips	Latent class choice model
Jung and Koo (2018)	EV	Korea	April 2017	General population	807	Mode choice	DCM: MXL, linear regression
Hu et al. (2018)	EV	Shanghai, China	January 1, 2017 to December 31, 2017	Transaction data of EVCARD	5,790,000 trips	Number of booking requests and turnover rate	Generalized additive mixed model (GAMM)
Lan et al. (2020)	EV	Shanghai, China	Dec 2017	(Potential) users of EVCARD	602	Intention of use	Structural Equation Model (SEM)
Kaplan et al. (2015)	E-bike	Copenhagen, Denmark	November 2013	Tourists	655	Intention to use during holidays	SEM
Campbell et al. (2016)	E-bike	Beijing, China	July and August 2012	General population	496	Mode choice	DCM: MNL
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	Transaction data of Smide	72,648 trips	Number of daily bookings	Regression
He et al. (2019)	E-bike	Park city, Utah, US	July to November 2017	Transaction data of Summit	7921 trips	Number of daily rides on station level	Regression
Hess and Schubert (2019)	E-cargo bike	Basel, Switzerland	2017 summer	Members of Carvelo2go and nonmembers	202 members 128 nonmembers	Membership to user segment	Multilevel regression

driving range of shared EV. The preference for using an EV is lower if the user is male, the trip distance is longer and the weather is cold (Wielinski et al., 2017; Zoepf & Keith, 2016). Apart from the general fuel type preference, so far there is no study investigating the impact of EV-specific attributes on mode choice, such as battery state of charge, the need to charge a shared car, charging infrastructure density, etc.

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 shared e-mobility demand is found to be significant, although there are also cases in which they appear non-significant. The direction of estimated effects on both electric carsharing and e-bike sharing demand 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-monotonic (Hu et al., 2018), as most early adopters of shared e-mobility also tend to be people with a middle-upper level income. Across different shared mobility modes, the impact of variables can also vary, such as females being found to have a higher intention of using e-bike sharing compared to males (Kaplan et al., 2018) which contradicts the typical early adopter profile of new mobility modes.

Psychological variables are mostly investigated in studies that 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 that is environmentally friendly, risky, or satisfying human needs, which can, in turn, be studied using different psychological theories and corresponding constructs. One point worth mentioning is that seemingly similar modes may be vastly different: higher

Table 5. Overview of determinants of shared e-mobility demand.

Factor type	Factor	Operationalization	Mode type	Studies which find it has a significant positive effect	Studies which find it has a 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);
		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)	
	ERG theory of needs		E-bike	Kaplan et al. (2018)	
	Perceived scarcity risk of the EV-sharing		EV		Lan et al. (2020)
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	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)	

(*continued*)

Table 5. Continued.

Factor type	Factor	Operationalization	Mode type	Studies which find it has a significant positive effect	Studies which find it has a significant negative effect
		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)

interest in bike technology, lower perception of cycling ease, and lower subjective norms toward cycling are related to the higher appeal of e-bike for tourists; while the direction of all these impacts is the opposite for normal bike sharing (Kaplan et al., 2015). Diez (2017) also found that the attitude toward cycling is not significantly related to the intention of using e-bike sharing, which suggests that bike and e-bike usage behavior are distinct.

Transport connectivity denotes the accessibility and transport service level of a location. 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 for electric carsharing and e-bike sharing. Several possible reasons that can explain this fact are: first, shared mobility services are used as the first-mile and last-mile trips for connecting to transit stations; second, public transport provides the necessary backup when a 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 on all other days of the week (Guidon et al., 2019)

Land use variables consist of the use purpose and the number of different types of POIs (point of interest) of an area. 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. As for the impact of POIs, Table 5 shows that most types of POIs have a positive impact on electric carsharing and e-bike sharing demand, while some recreational POI such as sports facilities and cinemas do not have a significant impact on e-bike sharing, probably because the 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).

Travel patterns refer to individuals' use of different transport modes and the availability of modes such as car and bike ownership. Several studies found that people who use public transport and bike are more often inclined to use shared e-mobility, which fits the early adopter profile. As for the impact of car ownership, it is positive for one-way carsharing but negative for roundtrip carsharing (Yoon et al., 2017), which indicates that the impact of car ownership is not unidirectional and depends on the operational 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 decreases probably because the driving range of EVs is lower when it is cold.

3.2.1. Summary and discussion

To sum it up, shared e-mobility demand is determined by 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.

Electric carsharing and e-bike demand share many common predictors, especially socio-demographic variables, transport connectivity, and land-use variables. In short, both services have higher demand among people who fit the "early adopter" profile and places with good public transport connectivity and many POIs. The signs of factor impacts may differ depending on how mobility services are organized (e.g. the impact of car ownership on the demand of one-way carsharing is opposite from the impact on round-trip carsharing).

The impacts of different factors are correlated with each other. For example, 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 the level of car ownership 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 or be considered when interpreting results.

As for the modes and factors which can be included in shared e-mobility demand studies, many candidates have not been explored yet. So far there has been no study on exploring influential factors for e-scooters through statistical analysis, probably because it only appeared recently. Many factors are only explored in one shared mode (e.g. psychological variables for e-bike, system operational attributes for EV) while they are also expected to be related to the demand for other shared mobility services. Some factors which are found to play a role in other transport-related decisions have not been investigated in shared mobility decisions yet, such as experience with the transport mode and social influence (Ampudia-Renuncio et al., 2018). Furthermore, mode choice between different shared e-mobility modes is worth further research.

Quantitative demand estimation studies are usually conducted to identify barriers for adoption. However, there are many factors that can appear as barriers for the adoption of shared modes in the actual implementation of the systems which can be difficult to include in quantitative studies, such as familiarity with sharing procedure (Hess & Schubert, 2019), legislation, 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 6 lists the studies focusing on the potential impacts of shared e-mobility. The most often investigated impacts include transportation, environmental, health, and social impacts. An overview of the impacts can be found in Table 7.

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 cars 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 allowing 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 of 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 the 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 toward active and "green" modes. More systematic research is needed to increase confidence in this conclusion as these varied impacts may be due to other differences in terms of operational attributes between these systems. If there exist multiple carsharing operators equipped with cars powered by different fuels (gasoline and electricity), the effect of self-selection shall also be accounted for since users who choose EV sharing may be more concerned about environmental issues.

As for electric micromobility 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 toddlers which are inconvenient to be transported by public transport or walking (Becker & Rudolf, 2018). There is a scarcity of studies on e-bike sharing, but several studies on private e-bike show that it has a high substitution rate of private car trips (Cairns et al., 2017; Kruijf et al., 2018), which suggests that e-bike sharing shall have a stronger effect on substituting private car use than traditional bike-sharing. Based on yet limited evidence, e-scooter seems to have even larger potential in replacing car trips than e-bikes (34% vs 5 or 17%) (Campbell et al., 2016; Hollingsworth et al., 2019; Munkácsy & Monzón, 2017), 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.

However, electric micromobility modes also seem to substitute public transport or active trips as well. More than half of the micromobility trips are used to replace trips by public transport or active modes (cycling and walking). In the 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.

Although shared mobility services are all relatively new, there are already observations of substitution between different shared modes: for example, six months after Uber acquired e-bike sharing company Jump, e-bike sharing trips on Uber platform have increased 15% while ridesharing trips

Table 6. Overview of studies on the (potential) impacts of shared e-mobility.

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

reduced 10%.[6] This suggests that shared mobility services may need to revise their use case when other shared modes enter the field: for example, carsharing may make less sense for very short trips (~2 km) and first- and last-mile trips when e-bike sharing or e-scooter sharing also exists. This internal substitution within shared e-mobility can also lead to adjustments in supply: due to the strong demand for e-scooters, dockless bikesharing has almost disappeared from most US cities as a result of their providers switching focus toward the more promising e-scooters (NACTO, 2019).

Induced traveling: the deployment of shared e-mobility systems may also enable trips that would not have been taken due to limited mobility.[7] 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 that they should reduce car ownership, which can, in turn, bring even greater positive impacts such as reducing emission and pollution during car manufacturing and relieve parking pressure. This effect can manifest itself in two ways: households shedding owned cars or postponing a planned purchase. There have been many studies on the impact of carsharing on car ownership or identifying factors that can influence the decision of giving up car ownership given the existence of carsharing services (Jung & Koo, 2018; Liao et al., 2020; 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 & Shaheen, 2016); on the other hand, another study found that users who have the experience of driving shared EVs showed higher willingness to forego car purchase (Firnkorn & 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 total 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 into account changes in travel behavior. 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 electric carsharing did not remove as many cars. As for e-scooter, it did replace motor vehicle usage 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 we did not see much discussion for shared e-mobility probably because these systems are not large-scale enough to have a visible impact on road congestion. In the most congested cities of the 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 micromobility 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 (such as red-light running, illegal turns, failed to yield to right-of-way of automobiles) of e-bike users (Ma et al., 2020). The impact of shared e-mobility on congestion may become more relevant as these services, especially micromobility, 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: Martin and Shaheen (2016)'s comparative study found that electric carsharing systems reduce GHG emissions less than CV carsharing systems since EV systems result in fewer shed cars. Jung and Koo (2018) conducted a more comprehensive simulation of impacts on GHG emissions which not only considers emission impacts that resulted from vehicle disposal but also accounts for the substituted trips in other modes. They found that when the carsharing service is equipped with gasoline cars it even increases GHG emission. When part of the fleet is

[6]Matt McFarland, "Uber's e-bikes are cannibalizing rides from Uber's cars," CNN, July 19, 2018

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

Table 7. 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 & Shaheen, 2016)
			E-bike	17% would have used car (Campbell et al., 2016)
				4–6% (Munkácsy & Monzón, 2017)
			E-cargo bike	46% (Becker & Rudolf, 2018)
			E-scooter	34% (Hollingsworth et al., 2019; PBOT, 2019)
		Public Transport	EV	8% increased frequency, 26% decreased (Martin & 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 & Shaheen, 2016)
			E-bike	27% would have walked (Campbell et al., 2016)
			E-scooter	41% (Hollingsworth et al., 2019)
				37% (PBOT, 2019)
		Cycling	EV	34% increased frequency, 9% decreased (Martin & Shaheen, 2016)
			E-bike	11% would have biked (Campbell et al., 2016)
			E-cargo bike	15% (Becker & Rudolf, 2018)
			E-scooter	7% (Hollingsworth et al., 2019)
				5% (PBOT 2019)
	Trip creation	Enabling trips which would not have been taken	E-cargo bike	13% (Becker & Rudolf, 2018)
			E-scooter	7% (Hollingsworth et al., 2019)
	Car ownership	Sold car	EV	1 per shared vehicle (Martin & Shaheen, 2016)
			E-scooter	6% sold and 16% considered (PBOT 2019)
		Suppress future purchase	EV	6 per shared vehicle (Martin & Shaheen, 2016)
				55–66% stated willingness (Wang et al., 2017)
	Car VMT	Reduce VMT	EV	−7% for each household (Martin & 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 & Shaheen, 2016; Jung & 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 (Haworth & Schramm, 2019; Trivedi et al., 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 & Cohen, 2019)
	Road	Use of the public right of way	E-scooter	Riding on pedestrian lane (Zarif et al., 2019)

electrified, the net GHG emission change becomes negative and emissions reduced further as more EVs are deployed in the fleet. This finding is also supported by Vasconcelos et al. (2017). However, it shall be kept in mind that these analyses are highly sensitive to the assumptions of changes in travel behavior: another study which simulated the changes in CO_2 emissions brought by a carsharing service (Rabbitt & Ghosh, 2013) concluded that the difference between electric and conventional carsharing is little since the projected use of carsharing is low for most people. The emission reduction impact of electric carsharing only becomes more pronounced when a significant part of carsharing members were heavy car users and radically change their behavior. A more comprehensive assessment shall also account for the emission during vehicle production and the influence of the power generation mix (the so-called life-cycle assessment).

E-scooter is usually lauded as a mode which can significantly reduce GHG emissions; however, Hollingsworth et al. (2019) showed that its impact is not necessarily intuitive and is quite sensitive to the lifetime of shared scooters because most lifecycle GHG emissions of shared scooters come from the manufacturing process of scooters (nearly 50%) and those trips are taken to collect, recharge and relocate scooters (43%). Only when all shared e-scooters can last at least two years can the system achieve a universal net reduction of CO_2 in all Monte Carlo simulations in that study. The base case assumed that lifetime ranges from 0.5 to 2 years and in 65% of simulations shared scooter usage ended up with higher CO_2 emission when compared to the status quo. Shared scooter service also consistently leads to higher GHG emissions compared to a bus with high ridership, private e-bike, and bikes, which may increase the extent of negative impact on emission considering its substitution of other zero-emission modes such as walking and conventional biking. Although more data collection and evidence are needed, this result casts doubt on scooter services' sustainability claim, especially given the fact that currently, the average lifetime of a scooter is only 1–2 months[8] which is much shorter than the base case assumptions.

[8]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

Pollution: For both private and shared e-mobility, the pollution caused by batteries is one of its major negative environmental impacts: widespread use of lithium batteries can potentially lead to extra pollution during lithium mining, battery production, and improper disposal; while many micromobility vehicles are still powered by lead-acid batteries in developing countries such as China 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 are 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 bike sharing schemes in different cities: the study found that in general bike sharing services provide health benefits mostly due to increased physical activity. However, bike sharing systems equipped with e-bikes (Madrid) resulted in fewer avoided deaths since their activity level is less intense (Langford et al., 2017).

Injuries: The recent proliferation of e-scooters and related injuries raised attention to 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 due to a failure in adhering to regulations, including not wearing helmets, alcohol consumption, riding over the speed limit, and reckless usage (Haworth & 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 a higher number of injuries and fatalities (PBOT, 2019).

The 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 micromobility 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 that were beyond walking distance and poorly connected by public transport (MacArthur et al., 2017; Smith & Schwieterman, 2018). It is found that in Chicago e-scooters can make 16% more jobs accessible within 30 min 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 micromobility users are different from the typical early adopter profile in traditionally underserved regions (Shaheen & Cohen, 2019). It can also enhance mobility even in places which are usually well supported 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 micromobility modes require people with an able body and are less suitable for those who are handicapped and overweight. Since shared electric micromobility modes are usually more affordable (compared to owning a car), convenient and accessible than traditional modes, they are expected to play an important role toward the goal of increasing transport equity and achieving "Universal Basic Mobility".

Land use impacts refer to the influences on the use of space. In the case of electric micromobility, the most visible impacts regard 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 that can block the passage of handicapped people and other pedestrians. It calls for better regulations and smarter management (such as geofencing) to relieve the negative impacts of scooters for other road users. If micromobility usage sees a 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 micromobility modes which are supposed to reduce negative externalities. For example, the CO_2 emissions of a private bike are only 8 g per mile while that number for dockless bike sharing is 190 g per mile, which is mainly a result of the rebalancing trip conducted by cars (Hollingsworth et al., 2019).

4. Conclusion and research agenda

This section first presents the main findings of our literature review and then gives some recommendations for future research based on these findings.

4.1. Main findings

This literature review focuses on three main themes of shared e-mobility research, namely performance description of existing systems, demand estimation studies that explore factors influencing the demand for shared e-mobility services, and impact assessment studies that evaluate the impact of existing systems or simulate potential impacts of a service under different scenarios.

In terms of the usage pattern of existing systems, we summarized the early adopter profiles and trip characteristics of existing shared e-mobility services. Users of current shared e-mobility systems generally fit the typical characteristics of early adopters of other transport innovations. Despite possessing different vehicle features, all shared e-mobility modes are mainly used for short trips. Apart from e-bike sharing (which is found to be used for commuting trips), other shared e-mobility systems are mostly used for leisure trips.

Many factors are found to be significantly related to service demand. Depending on the unit of demand (individual or location), it can be affected by the operational attributes of the shared mobility system, the socio-demographic characteristics, psychological variables, and travel patterns of the individual, and also the level of transport connectivity and land use pattern of a specific location. The demand for different modes of shared e-mobility share many common predictors.

We also reviewed studies assessing the wide-ranging impacts of shared e-mobility systems. They are found to have positive impacts on transportation and the environment as expected. However, the size of these benefits depends on the operational conditions of the specific shared mobility services.

4.2. Research agenda: addressing limitations in previous studies

Since we mentioned some limitations under each theme of research above, in this section we propose some recommendations for future research aiming to address these limitations.

In general, the research on shared e-mobility especially shared electric micromobility 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 micromobility modes can be subject to the influence of local culture. For example, shared e-scooters seem to be less compatible with places which already have a strong bike culture.[9] Furthermore, future research shall consider that the findings may be dynamic and change with time: for example, the preference for service attributes may change as the services reach more users instead of early adopters only; the number of accidents and injuries resulted from e-scooters may reduce as users gain more experience, etc.

The design of most existing demand estimation studies is rather simple. Given the limitations identified in the review, future studies can improve in the following aspects. First, apply more sophisticated statistical models which account for preference heterogeneity and correlations between variables. Second, as shared mobility systems become more common, revealed preference data is expected to become more easily available which can serve as a source for correcting the hypothetical bias in stated preference data. Even if disaggregate data of individual choice is not available, ridership data can also be used to estimate the short-term effect of operational attributes: Kabra et al. (2019) estimated the impact of vehicle availability and access distance on shared bike use based on ridership data via a structural model. Third, more modes and potentially influential factors can be included, such as investigating the preference for e-scooter and the effect of social influence on demand.

Last but not least, the interplay between vehicle ownership, shared service membership and the usage of privately owned/shared vehicles is worth investigating. The decisions of acquiring vehicle ownership and registering for shared service membership may involve different factors for consideration: earlier in the review it was mentioned that the characteristics of current carsharing members roughly match the early adopter profile of other new mobility modes instead of conventional car owners. Moreover, the usage of privately owned vehicles and shared vehicles are also expected to be vastly different since they involve completely different attributes of consideration such as uncertain availability and payment of usage fee. When the transport vehicle itself is innovative (such as e-scooter and e-bike), it is interesting to explore the difference between acquiring ownership and using the corresponding shared service: whether they are influenced by the same group of factors, whether their adopters overlap, etc. Furthermore, it is valuable to find out whether using shared service constitutes a stable travel pattern or merely a temporary gateway toward ownership.

4.3. Research agenda: future trends and new topics

In this section, we propose another set of recommendations for future research in shared e-mobility. Different from the above section which mainly focuses on addressing limitations in existing studies, this section aims to expand the scope and propose several potential trends and new directions for future research and development of shared e-mobility. These topics have already been studied in terms of other transport modes (such as non-electric carsharing, ride-sharing); but our review shows that these topics have not yet been sufficiently covered by studies on shared e-mobility which calls for future research.

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

Being the oldest form of shared mobility, carsharing has started as a roundtrip service; as smartphones and mobile internet became more common, nowadays carsharing services also allow one-way trips between stations or even parking in any allowed spot (free-floating). As for shared micromobility services with e-bikes and e-scooters, the vast majority are one-way services whether being dockless or not, although there are also roundtrip systems (such as Urbee e-bike sharing in Netherlands). As mentioned earlier, for each specific shared e-mobility mode, the user group, usage pattern, determinants of demand and impacts may

[9] https://time.com/5659653/e-scooters-cycles-europe/

differ depending on whether the system is one-way, round-trip or free-floating, as previous studies demonstrated in the case of conventional carsharing (Becker et al., 2017). The pattern and extent of these differences for all electric shared modes shall be explored in future research.

The difference between free-floating and station-based may not be so obvious in the future: virtual stations can be 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. Future studies can explore whether adjustable geofencing have any negative impact on demand, since uncertainty and confusion may also be introduced together with such extra flexibility.

4.3.2. 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, they have already started to substitute for non-electric shared mobility: earlier we mentioned that both shared e-scooters and e-bike sharing have been shown to replace ridesharing trips. However, the sustainability impact of micromobility modes is largely different and the cannibalization of the share between these modes may not be necessarily proceeding in the ideal direction in terms of reducing sustainability impacts, such as the aforementioned e-scooter sharing substituting dockless bikesharing. Shared e-mobility modes 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.

Our review shows that although each shared e-mobility mode has its own distinct use case, all of them are mostly used for short trips, share a similar early adopter group in terms of socio-demographic characteristics and have many common demand predictors; which suggests that cannibalization and substitution among shared e-mobility modes are quite likely when they coexist. Therefore, more research should be done on exploring traveler behavior and usage pattern change when more than one shared e-mobility modes coexist. 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.

4.3.3. Integration of operators and modes: from the perspective of mobility hubs and mobility-as-a-service

The review has shown that each shared e-mobility service has its own distinct use case: the most suitable trip purposes and distance of each shared e-mobility mode are different. Compared to a private vehicle which can be seen as an all-around mobility package meeting all needs, each shared e-mobility mode has its own inconveniences. For example, it is tiring to use e-scooters for long trips while e-bike is less suitable for a leisure trip with friends. Therefore, in order to realize the potential of shared e-mobility in reducing private car ownership and usage, it would be ideal to integrate different shared modes and make shared mobility a viable option for private vehicles in more cases.

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 micromobility 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 that 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 an inter-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 services 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 toward adopting shared e-mobility service.

The use of mobility hubs can provide a one-stop location that makes available 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 for transport and also physical efforts in transferring between different stations. There have been pioneering cities that 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 e-mobility modes, future mobility hubs can incorporate different combinations of modes according to the specific needs of each location and provide a more well-rounded and easy-to-use mobility service. Last but not least, it can also provide an easy solution for charging infrastructure installation and charging operation when all shared electric modes can be charged while parking in a fixed location. A potentially interesting avenue for future research is investigating its added value for travelers and measure how their presence influences people's travel behavior.

Mobility-as-a-Service (MaaS) can also play an integration role as it 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. There have been several studies on the preference for MaaS in terms of a mobility package subscription. 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. Another set of topics of interest that deserve more attention in academic studies are practical issues that are vital in actual MaaS implementation. These issues include but are not limited to: the motivation of and benefits for joining MaaS service from the for-profit mobility provider's perspective, the institutional mechanisms and possible incentives of organizing and integrating different mobility providers and modes, etc.

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