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Shared e-scooter micromobility: review of use patterns, perceptions and environmental impacts

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ABSTRACT

Recently, a new shared micromobility service has become popular in cities. The service is supplied by a new vehicle, the e-scooter, which is equipped with a dockless security system and electric power assistance. The relatively unregulated proliferation of these systems driven by the private sector has resulted in numerous research questions about their repercussions. This paper reviews scientific publications as well as evaluation reports and other technical documents from around the world to provide insights about these issues. In particular, we focus on mobility, consumer perception and environment. Based on this review, we observe several knowledge needs in different directions: deeper comprehension of use patterns, their function in the whole transport system, and appropriate policies, designs and operations for competitive and sustainable shared e-scooter services.

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1. Introduction

Micromobility, i.e. the use of light vehicles for transportation, has been promoted through the implementation of bike-sharing systems from the beginning of this century (Fishman, 2016; Fishman et al., 2013), when they became a successful solution due to several technologies such as electronically docking stations, telecommunication systems and smart cards and mobile phones among others (DeMaio, 2009). Recently, a fourth generation of these systems has progressively appeared, distinguished by two additional advances: dockless locking systems and the support of electric engines. The former allow a flexible location of vehicles, which leads to higher accessibility (Fuller et al., 2013), and the latter increases the speed and reduces physical constraints for riders (Lazarus et al., 2020). Although these features are implemented also in dockless e-bikes, this generation is differentiated by the use of a new vehicle type: the e-scooter. The new generation of micromobility has been promoted mainly by the private sector without initiative or even approval from public authorities. This is a big difference from previous docking bike sharing systems

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where public administration is generally involved, ranging from full control to the authorisation of private operators with certain economic support (DeMaio, 2009).

According to the National Association of City Transportation Officials (NACTO, 2018), the arrival of the new generation of services doubled the number of shared micromobility trips in United States in 2018. This growth mainly derives from shared e-scooter services. Based on a survey in New Zealand cities, Curl and Fitt (2020) identify that, besides the association between e-scooter and bike use, the former has a wider potential population by partially attracting users that would not ride a bike. Thus the new shared e-scooter services have had a positive effect on the promotion of micromobility, although various issues have been raised about positive and negative consequences of their emergence; in particular, what kind of mobility these services satisfy and their potential contribution to achieve a more sustainable transport system (Gössling, 2020).

In the last years, there have appeared several scientific publications focused on shared e-scooters and various technical evaluation reports from cities where they have been implemented. Motivated by the increasing interest in the performance of this transport alternative, this paper synthesises the main results about how and why users have taken advantage of shared e-scooters, the observed barriers and potentialities, and the environmental impact of current operations and usage. These issues are closely connected since the environmental impact is conditioned by how shared e-scooter are used, in particular, the usage rate during their lifetime and the induced mode substitution. At the same time, the type of use is conditioned by the pros and cons of the service operation perceived by potential riders. For that reason, we focus the literature review first on the description of the current use patterns, second on the associated factors that influence the use and third on the effect of these services on transport sustainability.

The approach distinguishes the contribution of this literature review from others with a narrower scope such as Wang et al. (2022), who mainly focused on the mode displaced by shared e-scooters, or Dibaj et al. (2021) who focused on the type of user. Furthermore, in contrast to other reviews such as Orozco-Fontalvo et al. (2022) and Bozzi and Aguilera (2021), the current paper analyses in more detail use patterns, environmental impact, and in particular, the connection between these two issues. Additionally, this literature review details the use patterns based on the results from the evaluation of pilot programs in 14 North American urban areas and reports that analyse the service in five European cities.

Several relevant topics are out of the scope of this study, in particular, the cohabitation of shared e-scooters with other users in the urban space and transport infrastructure, including safety issues. Other issues also excluded, and less discussed in the literature, are related to the business models and the financial viability of shared e-scooter services, their operating strategies, technological improvement of these devices, the use of scooters for other transportation purposes such as logistics, and the use of this type of vehicle as a privately-owned one. All of them are relevant topics that deserve a critical examination, however, for reasons of space and to present with enough detail the final contents included in the current literature review, we decided to exclude them.

The paper is structured as follows. Section 2 explains how we select the literature for this review. In the next section, we summarise the shared e-scooter trip attributes and the impact on the mobility. Section 4 identifies the advantages, potentialities and barriers of this new transport solution. In Section 5, we discuss the issues related to the environmental footprint of shared e-scooters and their weaknesses to improve the sustainability of the existing transport system. Section 6 includes measures to overcome the current limitations and redirect the negative aspects of the operation and usage. Finally, Section 7 gathers the most relevant knowledge obtained from this review and the necessary directions for future research.

2. Review framework

The first step of this literature review was to search for scientific contributions in the database *Web of Science* (*WoS*). According to Gusenbauer and Haddaway (2020), *WoS* is one of the principal sources for a systematic state-of-the-art search since its comprehensive database covers a large number of disciplines, journals and document types, and allows flexible query options. We used a main keyword "*scooter*" together with "*shared*", "*dockless*", "*mobility*" and "*transportation*". These four keywords are broad enough to provide a high number of documents about a wide variety of topics, limiting possible exclusions of contributions in line with the goal of this literature review. The final review was the result of merging the outcomes of four criteria "scooter AND shared" OR "scooter AND dockless" OR "scooter AND mobility" OR "scooter AND transportation". The search included scientific contributions from the year 2017, which was the year when the first shared mobility service based on e-scooters was launched (Hawkins, 2018), until the end of 2021. In total, we found 695 contributions.

Reading titles and abstracts, we identified 80% of them as not related to the scope of this review. The main reason for removing the first documents comes from the ambiguity of the word "*scooter*". The device chosen to supply shared e-scooter services is a "powered standing scooter" according to the taxonomy of powered micromobility vehicles from the Society of Automotive Engineers (SAE International, 2019), although we use the terms "*e-scooter*" or simply "*scooter*" throughout the paper. However, many authors use the same word to refer to wheelchair scooters and mopeds or powered seated scooters. The second group of contributions removed was broad overviews about general mobility, which superficially address e-scooters. The remaining documents rejected are out of the scope of this review, although they focus on shared e-scooters. They are mostly related to safety, riding behaviour and consumption of urban space, relevant topics that deserve a separate review.

Of the 107 papers read, we included a bit more than half (58) in this review. Further, we used a second database to check if there were missed contributions in *WoS*. In this case, the search was made in *Scopus*, which is also considered a principal academic search system by Gusenbauer and Haddaway (2020). Using the same search criteria only 16 papers went through the first filter without being found in *WoS*, showing that the initial search was comprehensive enough. In the end, we included only four of these other papers. We observe an increasing tendency over the years in the number of contributions, in particular ones related to the topics under review, as shown in Figure 1. Due to this increasing proliferation, we have added some recent papers from the year 2022 that add novelty results to the literature review.

We complete this review with other kinds of inputs to avoid possible biases derived from the limited, although emerging, scientific literature. The main source is technical evaluation reports from 14 North American cities and 3 reports from Europe that

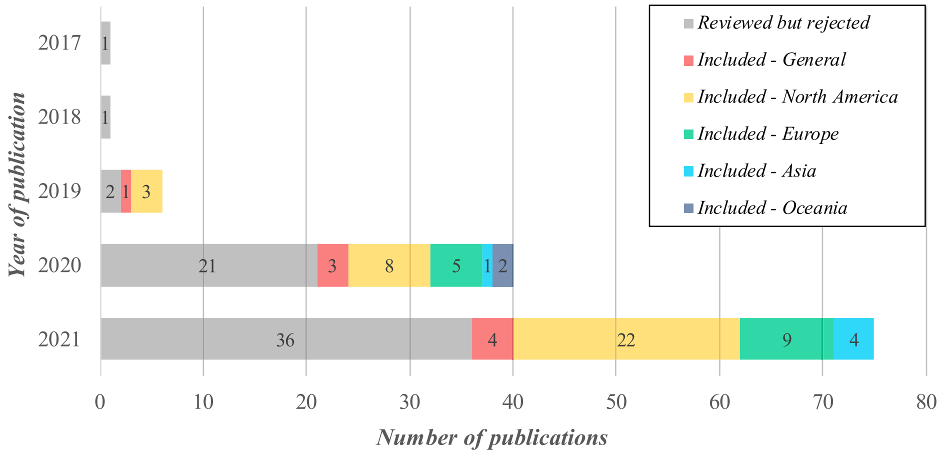


Figure 1. Results of the scientific literature review: number of contributions reviewed and included in this paper classified per geographical area of study.

include 5 cities. These studies provide valuable outputs from the first years of operation. To find these documents, we used the keywords "*shared scooter pilot program evaluation"* on *Google*. During this search, we also found other technical documents focused on the topics of this work. Finally, for some particular issues, when we did not find results in scientific papers or the previous reports from cities, we extended the search to grey sources. We looked on *Google* for shared scooter plus specific keywords such as fare, use terms, equity, lifetime, among others, obtaining inputs from, e.g. consultancy reports, press articles and websites from cities and operators.

In summary, this review includes 111 references. The largest share, around 58%, comes from the literature review while evaluation reports from cities and technical studies are 18% and 6% respectively. Other kinds of input including websites of news media, cities, operators or consultants represent 11%. The remainder (around 7%) is a group of research papers with a wider perspective on transportation and shared micromobility. In Appendix A, we classify the different documents included in the paper by the topic addressed.

3. Use patterns

The characterisation of shared e-scooter mobility is more detailed in the reviewed evaluation studies than in the scientific publications due to larger sample sizes (more than 1000 versus some hundreds) and longer questionnaires. Furthermore, the number of cities assessed in the studies is greater than the ones examined in research papers. We ground this examination on evaluation reports from fourteen North American cities: Alexandria (City of Alexandria, 2019), Atlanta (City of Atlanta, 2019), Arlington (DeMeester et al., 2019), Austin (City of Austin, 2018), Baltimore (Baltimore City, 2019), Calgary (Sedor & Carswell, 2019), Chicago (City of Chicago, 2020), Denver (Denver Public Works, 2019), Hoboken (Hoboken, 2019), Los Angeles (LADOT, 2020), Portland (Orr et al., 2019; PBOT, 2018a and 2018b), San Francisco (SFMTA, 2019), Santa Monica (City of Santa Monica, 2019a) and Tucson (City of Tucson, 2020). Further, we include studies of five

European cities: French cities Paris, Lyon and Marseille (aggregated results reported in 6t-bureau de recherche (2019)), Brussels (SPRB, 2019) and Oslo (Fearnley et al., 2020). In case these cities or the country (France) are mentioned in the following, the reference is the same as cited above if and when we do not point to other sources. The findings from these evaluation reports are complemented by the outcomes from several scientific contributions.

3.1. Characteristics of shared e-scooter riders and trips

Based on a synthesis of the reviewed reports and scientific papers (Christoforou et al., 2021; Dibaj et al., 2021; Laa & Leth, 2020; Reck & Axhausen, 2021), the median user identifies with the male gender (2/3 of the users) and is younger than the rest of the population since the age mean is around 30–35 years. He earns a salary slightly higher than the average and has at least certain university credentials. However, this last statement is biased by the participants of the surveys since all respondents, riders and non-riders, differ from the average population. The type of survey, an on-line questionnaire, probably makes participation difficult for some social groups with lower internet access. In France, more than half of the riders are not parents (6t-bureau de recherche, 2019).

Figure 2 shows three basic trip characteristics of shared e-scooters: length, duration and speed. The mean distance travelled varies between 1 and 4.7 km, and the duration ranges from 7.6 to 20 min. The discrepancies comparing length and travel time derive from dissimilar commercial speeds, with a mean of 8 km/h approximately. Distinguishing between mean and median trip distance (France, Arlington, Indiana, San Francisco and Washington), higher means than medians denote the presence of long trips; exceeding in some cases more than 1 hour of duration. As suggested by the report from France and supported by the differences between local riders and visitors, the main purpose of those trips is recreation without a clear trip end (e.g. tourism). The average trip for visitors takes around half an hour, twice the travel time of local users. Speeds also differ between short and long trips. In recreational trips, users do not give relevance to travel time and make stops in the middle of the trip, while users with an explicit destination travel there without delay. Along these lines, the trip length in Denver is a little longer during weekends than weekdays, and longer and slower in Austin.

The trip duration is affected by the pricing of the services (Lazo, 2019), which are cheaper than public transport and bike-sharing systems only for short distances; for instance, in Chicago, shared e-scooters are more expensive for trips longer than 1.5 km (Smith & Schwieterman, 2018). NACTO (2018) also shows that shared scooters are more expensive than shared bikes, approximately double the price for the same trip length. According to the previous trip particularities, shared e-scooters seem an option between pedestrian and bicycle. von Stülpnagel et al. (2019) and Schellong et al. (2019) examine the mean trip length of these alternative active modes and identify that the distance travelled by scooter riders is double that for walking and 50% lower than for cycling. Despite the difference in trip length, McKenzie (2019) and Younes et al. (2020) observe that the trip duration is similar, that is, the average velocity for cycling multiplies by two the one for e-scooters. Almannaa et al. (2021) compared shared e-bikes and e-scooters in Austin and identified that cycling speed is around 35% higher than for scooters (12 and 9 km/h, respectively).

Figure 2. Length, duration and commercial speed of trips made by shared e-scooters. (Extra references to the evaluation reports from cities: (1): Jiao and Bai (2020); (2): McKenzie (2020); (3): Younes et al. (2020); (4): Mathew et al. (2019)).

3.2. Temporal distribution

All the studies show analogous temporal distributions of trips where weekends present the greatest volume of trips per day, in particular on Saturdays, with a lengthened demand peak from around noon to early evening (McKenzie, 2019; SPRB, 2019). On the other hand, weekdays have the principal peak period in the evening, although in several cities such as Arlington and Chicago, and also identified by Younes et al. (2020) and Huo et al. (2021), reduced peaks appear about 8 am (i.e. the general morning peak) and approximately at noon. Hence, the temporal trip pattern does not exhibit the standard two predominant peaks in the morning and evening. The temporal distribution along the day (Bai et al., 2021) and between days (Hosseinzadeh et al., 2021b) is connected with the main purpose of these trips shown below: recreational and social activities.

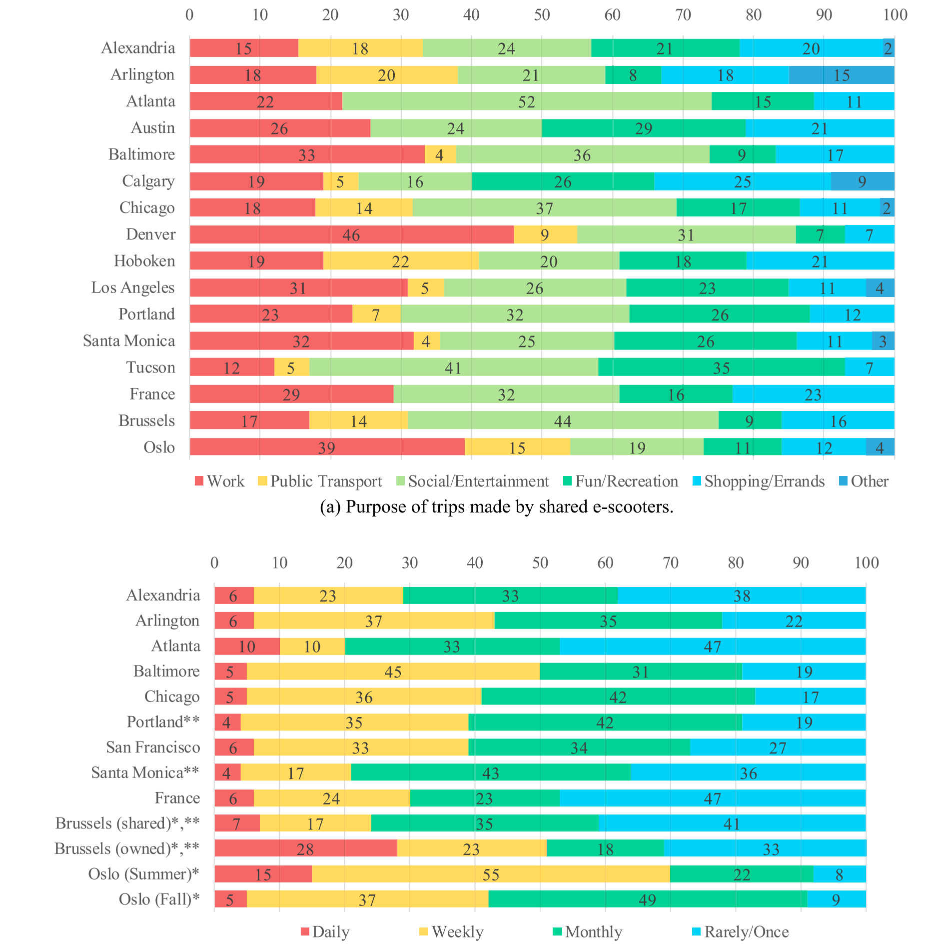
The pattern is similar to casual bike riders, who also have social and recreational activities as main trip purposes but distinct from frequent bike users, who mainly travel in workdays and show two main peaks with higher levels of demand as the regular temporal commuting distribution (McKenzie, 2019; Younes et al., 2020). Therefore, Younes et al. (2020) identify that shared e-scooters make the demand of bike-sharing systems smaller by mostly attracting occasional bike users without being an opponent of bike-sharing card holders. Similarly, in Chicago, the reduction of shared bike ridership caused by the arrival of scooters sharing is eight times larger for non-members than for members (Yang et al., 2021). However, the absence of membership programs for shared e-scooter services limits close competition for regular riders.

3.3. Spatial distribution

The majority of trips occur in the city centre or other central highly demanded locations. This result denotes that e-scooters operate in zones with elevated concentrations of inhabitants, jobs and activities. This operating strategy is reasonable since usage rates are higher in those areas than elsewhere, that is, more profitable business. However, the unbalanced distribution limits access to shared e-scooters for a large share of the population (Aman et al., 2021b), increasing transport inequities instead of reducing current deficits. Huo et al. (2021), Hawa et al. (2021), Tuli et al. (2021), Jiao and Bai (2020) and Caspi et al. (2020) corroborate this spatial behaviour and identify additional factors: high street connectivity, good coverage of bike lanes and docking bike-sharing stations, and limited car parking space.

3.4. Purpose

We distinguish between six types of purpose: work (commuting, work-related trips and school), public transport (connection to stops/stations), social/entertainment (restaurants, visits to friends, etc.), fun/recreation (exercise or tourism among others), shopping/errands (e.g. health appointments), and other. As shown in Figure 3(a), e-scooters principally satisfy leisure trips, which include a pair of types: social/entertainment and fun/recreation. The common quota exceeds 50% in half of the urban areas, and the minimum around 30% in Arlington (DeMeester et al., 2019) and Oslo (Fearnley et al.,



* ≥ 5 trips/week are considered as daily use; ** Distribution adapted to riders, removing the percentage of survey respondents that do not ride e-scooters (2% in Portland, 53% in Santa Monica, and 13% for shared and 58% for owned e-scooters in Brussels)

(b) Frequency of use of shared e-scooters.

Figure 3. Shared e-scooter services: purpose of trips and frequency of use.

2020). In France, the percentage is in line with the high share of riders who are visitors (42%); they are occasional users with a recreational reason. Shopping and errands have a share that mostly ranges from 10% to 20%. On the other hand, commuting accounts for a percentage below 20% in more than a half of the cases, although we observe opposite examples such as Denver (49%), Oslo (39%), Santa Monica, Los Angeles and France (all roughly 30%). As commented in Section 3.2, these results are similar to casual bike riders where leisure trips dominate, but different from membership users (Fishman, 2016; Fishman et al., 2013). The absence of membership programs limits the number of commuting travellers.

E-scooter sharing systems are commonly advertised as an effective booster to feed public transport. However, the numbers in Figure 3(a) do not support this capacity in the daily operation. Less than 10% of trips have this purpose in 7 cities over the 13 that give this information and the maximum quote is bounded to 20% (e.g. Arlington and Hoboken). However, we find contradictory messages on this matter. On the one hand, the study in Denver does not identify scooters as a usual complement for public transport: just 19% at least once a week while 37% less than that and 44% never. In Los Angeles, a share below 7% of origins and destinations are located closer than 100 m from a metro station. According to Zuniga-Garcia and Machemehl (2020), shared scooters displace more than improve public transport trips in Austin. On the other hand, public transport is the main complementary mode for shared e-scooters according to the surveys in France and Brussels. Combinations with other modes occur for 23% and 46% in these two cities respectively, where the highest share is with public transport (66% and 56%) while walking (19% and 21%) occupies the second position. Just like the conclusion from the San Francisco pilot program where the last e-scooter ride fed public transport for 34% of the survey participants, who would not use public transport without an available scooter. In Atlanta, combinations of shared e-scooters with public transport occur in 31% of trips for frequent users and in 18% for casual riders; commuting trips are one of the main trip purposes for the former and one of the least relevant for the latter.

3.5. Frequency of use

As shown in Figure 3(b), on average across the cities, only 6% of riders reported daily use, while no less than 6 out of 10 users travel by scooter with a frequency lower than weekly. The predominant usage ratio is at least once per month in the majority of cases. Nevertheless, Atlanta, Brussels and France are exceptions where more than 40% of the riders have an even lower degree of use. For France, we can connect this result with the high percentage of visitors. As noted above, there exists a correlation between the level of use and trip purpose. According to Guo and Zhang (2021), commuting is as relevant as leisure for riders that use shared scooters almost daily, but infrequent users reduce the magnitude of the work-related aim. Therefore, the current observed level of utilisation is not regular enough as the required for a commuting behaviour but represents a sporadic use closely related to social and recreational activities. According to this, the authors of the report about Oslo introduce the notion of "last-minute trip", that is, the shared e-scooter customers take one of these devices when arriving late at an appointment, make certain sort of unexpected trip or the usual transport mode fails. Along these lines, 44% of travellers in the study from France only took the scooter in one direction while they used another solution (generally public transport or walking) for the return trip.

The low utilisation rate is a characteristic of shared e-scooter clients and distinguishes them from e-scooter owners. For instance, in Brussels (Figure 3b), 50% of the holders of an e-scooter employ it weekly or more, that is, double than the clients, and the daily use is four times greater. Laa and Leth (2020) confirm the lower use frequency of shared e-scooter users in Vienna. The low utilisation rate extends to other shared mobility solutions (Fishman, 2016). This is more accentuated for non-membership users, but a substantial share of membership riders, in some cases up to 50%, have a less than monthly frequency.

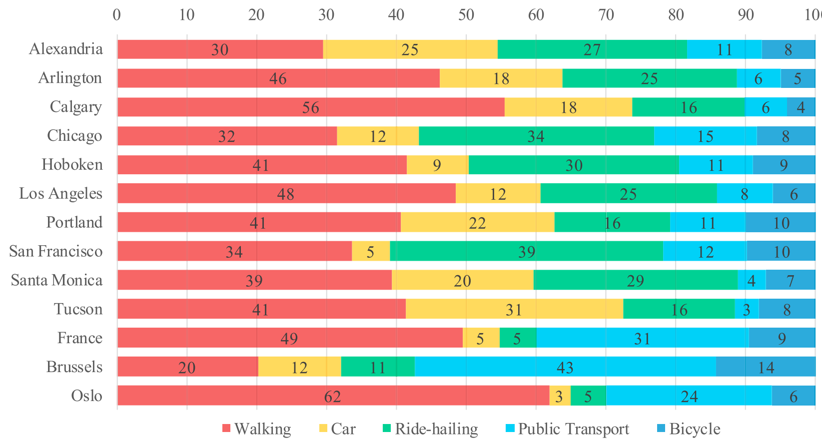
Usage frequency has a seasonal pattern. In Oslo, the share of daily users triples in the summer compared to the autumn and 70% take at least one ride per week. This behaviour is the result of weather conditions. As for shared bikes (Fishman, 2016; Fishman et al., 2013), the number of trips is lower during winter months (Arlington, Los Angeles, San Francisco and Tucson) and the trip length is shorter (Portland). Several authors such as Noland (2021), Hosseinzadeh et al. (2021b), Tuli et al. (2021) and Younes et al. (2020) confirm that usage rates (number of trips, duration and distance) are lower on days with rain, wind, humidity, low visibility or extreme temperature (too low and too high). In certain circumstances, the results can be contradictory; in Chicago, for instance, scooters can be an instrument to make walking trips shorter, increasing demand on rainy days.

3.6. Impacts of shared e-scooter services on the modal split

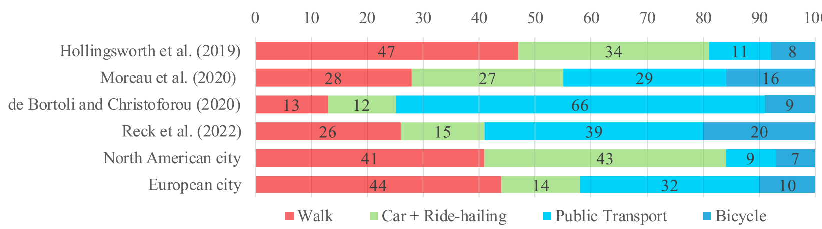
Based on the results of the survey question "*what transport mode would you have taken if an e-scooter was not available?*" included in many of the reviewed studies, we conclude that at least 5 out of 10 shared scooter travellers substitute other kinds of sustainable modes (walking, public transport and cycling). There is an evident disparity comparing European and North American urban areas: In the latter, the substitution is around 50% −60% of the total trips while the value is 80% or higher in the former. Walking is in general 40% and cycling below 10% in both groups; thus, the discrepancy stems from the share of public transport, which is on average four times greater in Europe than in North America. Conversely, car in its different forms (private, taxi, car and ride sharing), is displaced in more than 40% of e-scooter trips in North American cities while the share is 20% or smaller in Europe. These results are a consequence of the city characteristics: North American cities tend to be dispersed, and consequently more car dependent, while European ones are denser and have public transport as a competitive solution. On the other hand, a first comparison with bike sharing shows that shared scooters can displace a higher percentage of car-based trips, in particular, ride-hailing services (Fishman, 2016; Fishman et al., 2013). Both micromobility solutions displace a high number of walking trips, but shared bikes cause a greater reduction in public transport.

One could erroneously interpret the previous percentages without linking the number of trips by shared e-scooters about the overall quantity of trips across all transport modes. For instance, the study from France estimates that the percentage of shared scooter trips in the modal split would vary from 0.8% to 1.9% in Paris. Consequently, the reduction in public transport and walking would be around 0.3%–0.8%. Similarly, Krier et al. (2021) identify a limited effect on overall mobility in Paris, and Ziedan et al. (2021b) estimate a reduction of bus ridership around 0.08% in Nashville (Tennessee, US). Ziedan et al. (2021a) do not find significant impacts on bus demand in Louisville (Kentucky, US) since the two modes differ with regard to trip purpose, trip length and socio-economic characteristics of users. However, the effects contribute with a picture about the consequences of a scenario where shared e-scooters consolidate with current operating, supply and business strategies. Looking at the overall image of the modal split, Weschke et al. (2022) compare it with the mode substitution degree by e-scooters. The results show that walking and bike trips are oversubstituted while motorised alternatives (car or public transport) are undersubstituted. Thus e-scooters proportionally displace more trips from other active transport solutions.

We identify discrepancies in the mode displacement between the previous results and others from scientific papers (Figure 4b). These differences derive from the assumptions of each study. Hollingsworth et al. (2019) and the evaluation reports introduced in Figure 4 (a) compute the displacement portion calculated from volume of trips. Meanwhile,



(a) Degree of displacement for transport modes by shared e-scooters according to the evaluation reports from several North American and European cities.



(b) Degree of displacement for transport modes by shared e-scooters according to Hollingsworth et al. (2019), Moreau et al. (2020) and de Bortoli and Christoforou (2020) and the average from North American and European cities.

Figure 4. Alternative transport mode in case an e-scooter is not available.

Moreau et al. (2020) include the trip frequency to estimate that quote and de Bortoli and Christoforou (2020) and Reck et al. (2022) also consider the trip length. The introduction of these weights achieves a more accurate estimation of the kilometres displaced per transport mode. According to the results, the weights reduce the substitution of walking and car in favour of public transport, that is, scooters substitute more frequent and longer trips by public transport than by other alternatives.

4. Consumer perception

4.1. Motivations

Based on the studies from France, Brussels, Atlanta and Arlington and scientific papers such as Christoforou et al. (2021) and Reck and Axhausen (2021), the main motivations for trying shared e-scooters are the perceived playfulness and novelty and the convenience derived from shorter travel times and the flexibility of door-to-door trips. These last factors have the potential to consolidate users, while fun or curiosity are weak drivers associated with sporadic trips. A secondary motivation is the lower pollution of vehicles. Based on results from surveys in Stockholm and Copenhagen, Flores and Jansson (2021) confirm that users of shared micromobility show a greater interest in green perceptions than non-users.

However, the choice factors vary among the (potential) users and the different intentions of how to take advantage of the scooters (Kopplin et al., 2021; Lee et al., 2021a; Weschke et al., 2022). Travel times are relevant for those who want to make walking trips faster. Other users try to avoid bad connections by public transport due to long, slow, hard accessible and crowded services. The substitution of car trips occurs when there is a certain level of traffic congestion, and limited or expensive car parking slots. Additionally, the service could be cheaper than car-based solutions such as taxis, in particular for unipersonal trips (Guo & Zhang, 2021). As shown in Figure 4(a), car displacement mainly comes from these ride-hailing services.

4.2. Barriers

The extent of shared e-scooter usage is limited by several factors that dissuade potential riders (6t-bureau de recherche, 2019; Buehler et al., 2021; City of Atlanta, 2019; DeMeester et al., 2019; Nikiforiadis et al., 2021; Sanders et al., 2020; SPRB, 2019). The main barrier is the low feeling of safety, derived mainly from interaction with other motorised vehicles. In general, there is a demand for more separated infrastructure for micromobility and improved pavement conditions. For non-riders, negative safety perceptions also come from ignorance of how to ride vehicles. Other limitations arise from the type of vehicle, which is inconvenient under some weather conditions, for long trips or when transporting goods. Some barriers arise from the service such as restrictive deployment areas, low availability of scooters near the origins, technical problems with the vehicles and high price. Aman et al. (2021a) add further limitations such as the lack of payment methods and the need of smartphones, non-integration in public transport passes, and lack of information about regulations.

The externalities originating from how people ride and park the e-scooters and the interactions with other consumers of the urban space imply that regulations may be required to improve cohabitation. Several measures have been implemented such as limitations on the service area, ban on riding on sidewalks, speed limits, parking rules and restricted locations, and mandatory helmet or driver license (Ma et al., 2021). These regulations have impacts in different directions since non-users, in general more conservative, request them while early users consider them a negative factor. According to Lo et al. (2020), the most rejected measure is the ban on riding on sidewalks, forcing e-scooters to share the space with motorised vehicles. The next is fixed parking locations, limiting the flexibility of door-to-door trips. For frequent users, mandatory helmet would have a high impact. Speed limits are the regulations with the least objections.

4.3. Potential benefits

There are several market niches for shared e-scooter services. On the one hand, scooters operate as an independent transport mode. One option is the displacement of walking trips for those users that want to shorten their trips (Kopplin et al., 2021). Another option, proposed by Cao et al. (2021), is the substitution of short public transport trips to reduce crowding and focusing public transport on long trips. The potential to attract those users is derived from the indirectness, multiple transfers and long access walking distance associated with existing public transport services. Abouelela et al.

(2021) identify the attractiveness of shared e-scooters for car-sharing users, in particular, for those who complete trips shorter than 4 km. On the other hand, shared scooters can provide solutions in combination with public transport taking the role of a feeder service. Baek et al. (2021) identify that the main attraction of shared e-scooters is the reduction of travel times, although there are initial reservations overcome only in some population groups (age, income, riding experience, renting requirements and safety).

The development of these roles depends on the location (Luo et al., 2021; Mitra & Hess, 2021). In city centres, shared e-scooters can substitute walking and public transport. In suburban areas, they can complement public transport where the level of service is low, and substitute car trips as an independent mode for short distances or cover the first/last mile for long distances. Until now, the former prevails due to the current spatial distribution of e-scooters focused on downtowns.

5. Environmental impact

E-scooter sharing services are regularly seen as an eco-friendly transport solution, which is a motivation for some users. However, Life Cycle Assessments (LCA) conducted by de Bortoli and Christoforou (2020), Moreau et al. (2020), Severengiz et al. (2020) and Hollingsworth et al. (2019) – in shared e-scooter systems in Paris, Brussels, Berlin and Raleigh (North Carolina, US), respectively – show several environmental threats in this kind of shared micromobility systems. According to current use patterns and operations, the new services do not imply a reduction of the environmental impact in comparison to the transport modes that they displace, leading the transport system to less sustainable scenarios.

5.1. Environmental impact of shared e-scooter services

According to the papers introduced above, there is high variability in the environmental impact estimates depending on assumptions regarding the vehicle and service characteristics. In particular, the global-warming potential (GWP), measured as CO_2 equivalent emissions, starts with 60 g CO_2 eq/pax-km and exceeds 500 g CO_2 eq/pax-km depending on the scenario under study.

The main limitation to become a more sustainable solution is the low daily usage ratios and short lifetimes, which distribute the initial impact derived from materials and manufacturing processes across a low number of kilometres travelled. Materials and manufacturing are the main contributors to the GWP with more than half of the total environmental impact, growing sharply up to 80% in the identified scenarios with lowest utilisation levels. For instance, Moreau et al. (2020) consider the most extreme case where the daily usage is only 1.2 km during 7.5 months (i.e. 270 km in total), reaching 593 g CO_2 eq/pax-km. To reach the identified minimum value (58 g CO_2 eq/pax-km), Moreau et al. (2020) assume a lifespan equal to 4500 km through an increase of the daily usage to 20 km/scooter-day.

Nevertheless, several of the pilot program reports provide the required information to estimate the current daily usage, which ranges from 1 to 4 trips/scooter-day, and the travelled distance, which varies between 1.76 and 6.85 km/day (Table 1). Similar results as von Stülpnagel et al. (2019), where the volume of trips per day and device ranges from

1.5 to 5 in different cities from Europe. In the same way, this value is under 4 in 30 US urban areas (NACTO, 2018). Compared to bike-sharing systems, there is space for improvement. The number of daily trips per scooter is below the average for shared bikes, which ranges from less than 1 to around 7 according to Fishman (2016) and Fishman et al. (2013). If we also consider the trip length, which is double for a bike than for a scooter (Section 3.1), the difference in daily usage grows.

Additionally, it would be desirable a lifetime around twelve months. Moreau et al. (2020) estimate 9.5 months to make the environmental impact comparable with the substituted means of transport. However, operators look for a lifetime of two years (VOI, 2019), when a significant fall in the ecological footprint from materials is reached. There is no available data to estimate the lifetime of shared e-scooters, but based on the few references found the lifetime was very short at the beginning. The devices used to require replacement just 1–1.5 months after the commissioning according to Griswold (2019) and Chester (2019). An improvement in the scooter robustness is a key factor for the continuation of the companies; only the ones that got it survived 1 year after their implementation in Brussels (Moreau et al., 2020).

The use phase is the second largest contributor to emissions, where the distribution and collection of scooters and/or batteries are most important in comparison to the energy consumed by the scooters. According to the reviewed papers, the former represents a share below 40% of the GWP in most of the evaluated scenarios, while battery charging produces less than 10% in the worst case. In this sense, the mileage travelled by the supplementary devices used for collection and distribution tasks is crucial in comparison to their characteristics (energy efficiency and energy source). Hollingsworth et al. (2019) reduce that distance by half and the emissions of those vehicles with regard to the base case. The GWP of 126 g CO_2 eq/km decreases 30% with the first improvement and 13% with the second one. Regarding the electricity consumed by e-scooters during the service, Li et al. (2022) estimate that a substantial portion, roughly one-third, is wasted when the vehicle is not in use waiting for the next user. This wasted energy is a consequence of the current low usage ratios. The services need a

Table 1. Daily usage of shared e-scooters.

City	e-scooters in operation	# daily trips	Daily trips per e-scooter	Avg. trip length (km)	Daily usage (km)
Alexandria	780	852 (230,000 trips in 9 months)	1.09	1.61	1.76
Arlington	863	1680 (453,690 trips in 9 months)	1.95	1.51	2.95
Calgary	1500	5556 (750,000 trips in 4.5 months)	3.70	1.85	6.85
Chicago	1722	3392 (406,984 trips in 4.5 months)	1.97	2.42	4.77
Los Angeles	-	-	2.1-2.7	1.56	3.28-4.22
Portland	2043	5836 (700,369 trips in 4 months)	2.86	1.85	5.29
San Francisco	Scoot 235; Skip 382	-	3.43 (Scoot 2-3; Skip 2-6)	1.61	5.52
Tucson	-	-	1.33	1.39	1.85

*Source: Alexandria (City of Alexandria, 2019), Arlington (DeMeester et al., 2019), Calgary (Sedor & Carswell, 2019), Chicago (City of Chicago, 2020), Los Angeles (LADOT, 2020), Portland (Orr et al., 2019; PBOT, 2018a and 2018b), San Francisco (SFMTA, 2019, and Tucson (City of Tucson, 2020).

better balance between the level of service supplied and the potential demand that they can attract. However, according to the results from different cities, reduction of fleet size is not always the solution since the areas with a higher density of scooters and more devices per person have shorter times between bookings.

5.2. Comparison with other transport modes

The comparison of the global-warming potential of the new micromobility service with other transport modes confirms that the new ones do not seem a sustainable alternative in current operations. Based on the average GWP values for shared e-scooters (that is, 104 g CO_2 eq/pax-km) and for other modes considered by de Bortoli and Christoforou (2020), Severengiz et al. (2020) and Hollingsworth et al. (2019), the conclusion is that shared e-scooters only have a lower environmental impact than automobiles (204 g CO_2 eq/pax-km). Emissions from shared e-scooters are similar to buses (88 g CO_2 eq/pax-km), private e-mopeds (97 g CO_2 eq/pax-km) and dockless bike sharing systems (118 g CO_2 eq/pax-km), at least twice as high as shared mopeds (29 g CO_2 eq/pax-km), private e-bikes (33 g CO_2 eq/pax-km), trams (39 g CO_2 eq/pax-km) and shared docking bikes (59 g CO_2 eq/pax-km), and 10 times greater than owned bikes (9 g CO_2 eq/pax-km). However, the uncertainty of the estimates is high and in the worst-performing scenarios shared scooters would not even be competitive to cars.

The wide range of estimated emissions is a consequence of the variability of the assumed values for some parameters. As commented above, the total mileage travelled by shared e-scooters during their lifetime is the main limitation of their competitiveness. de Bortoli and Christoforou (2020) assume usage of 3750 km which is lower than for other small vehicles (e.g. 4500 km for shared docking bicycles, 15,000 km for owned bikes and 50,000 km for mopeds). Thus, there is no agreement to define the current scenarios and the final values chosen are debatable. However, the preliminary insights indicate that this new mobility solution would have a negative net impact on the sustainability of the transport system depending on the scenario and the mode replaced with shared e-scooters.

The average displaced mode is the resultant mix derived from the level of substitution of the respective means of transport (Figure 4), and this average has an impact one-third lower than the shared scooters (i.e. 74 versus 118 g CO_2 eq/pax-km). These values are the mean from Reck et al. (2022), de Bortoli and Christoforou (2020), Moreau et al. (2020) and Hollingsworth et al. (2019). In Figure 4(b), we show that these studies are less optimistic than the evaluations from the North American cities since the car substitution is lower. The opposite occurs for the European urban areas for which car displacement estimates are higher.

6. Measures to improve the limitations of shared e-scooter services

The review so far shows that today's e-scooter sharing services need transformations to turn into a strategic instrument for improving transport accessibility from different points of view (spatial, temporal, economic and technological) and sustainability. Current services are expensive, have low utilisation rates, are highly concentrated in time (afternoons, due to the main trip purpose) and space (city centres, derived from the size of deployment areas), and displace more environmentally friendly modes. The devices have short lifetimes and require collection and distribution tasks. To overcome the problems and limitations regarding travel patterns and environmental impact, public authorities and operators have introduced several measures, although some of them are contradictory and have effects in multiple directions.

Regarding the high price, companies on the one hand have created membership programs to encourage more frequent use such as period passes (VOI, 2020a). Further, suppliers recompense users through loyalty programs with price discounts or other benefits such as free vehicle booking before starting the trip (Bird, 2020; VOI, 2020b). On the other hand, cities have collaborated with the operators to facilitate equity programs (e.g. District Department of Transportation, n.d.; City of Tucson, 2020; LADOT, 2020; PBOT, n.d.; DeMeester et al., 2019). These programs provide access for low-income populations and include low-price monthly passes, a monthly number of free rides with a maximum trip duration, free unlocking of the scooters and discounts of the normal fare. Along the same lines, local governments have compelled shared e-scooter suppliers to allow alternative payment options and non-digital access. However, the current equity programs do not seem enough to overcome the correlation between lower income and lower usage (Frias-Martinez et al., 2021).

To maximise the productivity of the fleets, operators limit the service to small, central areas where they expect higher vehicle usage ratios and collection tasks imply shorter distances travelled (e.g. Moran et al., 2020). However, this policy reduces the potential trips that can be completed by the service and the served population. To counteract this, transport authorities have promoted the implementation of micromobility services in underserved areas to achieve an equitable transport system and increase the number of potential users (Riggs et al., 2021). Cities have encouraged or forced companies to distribute a percentage of their fleets in the mentioned zones (e.g. City of Chicago, 2020; PBOT, 2018a; SFMTA, 2019) or allow a larger vehicle fleet on the condition that they are deployed in those areas (e.g. City of Tucson, 2020; LADOT, 2020). These zones tend to have low densities and low-income inhabitants, factors that discourage companies to supply the service due to low economic productivity. The absence of subsidies to support this type of policies makes their implementation difficult.

Operation in large, low-density areas implies longer distances travelled by auxiliary vehicles. For that reason, companies need to reduce the distances and emissions of such vehicles. Recent versions of scooters have swappable batteries and operators do not have to collect all the device for charging and the scooters are a longer time available for the service (Intelligent Transport, 2019). Further, operators may use vehicles with a lower fuel consumption (e.g. electric vans or cargo bikes) and renewable energy sources (e.g. solar panels) for charging (Hollingsworth et al., 2019; Severengiz et al., 2020). Again, there are measures with conflicting effects: a fleet management where scooters remain in the street overnight reduces the number of times for collection, but implies unprotected vehicles against vandalism reducing the life length.

Another strategy to increase the usage rates of scooters in operation is to rationalise the supply based on the demand levels. Cities have introduced regulations to limit the number of companies and their fleet sizes, avoiding uncontrolled proliferation (e.g. City of Tucson, 2020; Janssen et al., 2020; SFMTA, 2019). Local authorities select companies through a competitive process and fix their fleet sizes. However, there is high variability in the number of operators and fleet sizes across cities, and it is not clear how cities fix them about levels of utilisation without a clear idea of demand volumes. Some regulations include dynamic modifications on the number of vehicles in operation grounded on the utilisation level (e.g. City of Santa Monica, 2019b). The company has to eliminate devices from the service when the mean of daily trips per scooter is below a threshold, but the fleet can be expanded when the utilisation rate exceeds an upper bound. Janssen et al. (2020) examine nine US cities, and six of them introduced the same requirement for fleet expansion, at least 3 trips/scooter-day, and the same limit to reduce the number of scooters, below 2 trips/scooter-day. These values are still low compared with the levels required to increase the sustainability of the service discussed in Section 5.1.

Other strategies seek to promote the combination of shared scooters and public transport to compete with cars, or to promote the use of scooters for commuting trips to broaden their utilisation across the day and in suburban districts. Grosshuesch (2019) and Oeschger et al. (2020) collect diverse actions to promote the role of e-scooters as last-mile transport. Some measures are related to the development of infrastructure such as lanes for micromobility vehicles and traffic calming paths to connect public transport stations with their surroundings in a safe way. Additionally, there is a demand for satisfactory e-scooter parking slots around public transport hubs. Regarding the service, city governments should encourage the supply of shared e-scooters in districts outside the city centre where public transport accessibility is limited. Public administration should think about the subsidisation of this kind of trips and propose discounts and fidelity programs for recurrent users to increase their attractiveness.

Another relevant issue is the implementation of an integrated ticketing system, for example, paying both services with the same smartcard or mobile phone app. Such a system could also provide real-time information for an easier combination of these two modes. An example of a common platform is the *Transit app* that we can find for instance in Chicago (Freund, 2019). This platform includes multiple shared e-scooter services, other micromobility systems and public transport, and gives the opportunity to make travel plans combining different transport options. Although this app allows payment for some of the transport services included, others still require payment through their apps. Further, there is no fare integration among modes, limiting the usefulness of intermodal trips involving shared e-scooters.

7. Conclusion and further research directions

Users travel by shared e-scooters on average one-mile trips with a duration of ten minutes at speed lower than 10 km/h. Various determinants restrict the covered length per trip: slow velocity, uncomfortable riding due to the standing position for extended lengths, and expensive fees. The use is sporadic where only a minority are daily or weekly clients. Until now, these services have not become a transport alternative for everyday mobility needs, for which a main hindrance is the unsafe feeling. The most popular travel motivation is related to leisure activities; thus, the demand of shared scooters grows in weekends and weekday evenings. The travel pattern has similarities to sporadic riders of bike-sharing services.

There is the idea that shared e-scooters are an eco-friendly mode that would increase the sustainability of the transport system; although different concerns show a contrary opinion. Short lifetimes, low usage rates, and the emissions derived from collection and distribution tasks go against the original impression. Further, the new mobility service substitute in a high degree walking trips, which is an unfavourable consequence. Up to now, the volume of trips by shared e-scooter is too insignificant to induce any important change, but the mode displacement today should be adapted to centre on cars rather than pedestrians. Another motivation that would justify the development of e-scooter sharing systems is the role as a first/last-mile support for public transport users, which could increase the substitution of automobiles. At this stage, there are no unequivocal evidences of this function. The majority of shared e-scooters are deployed in city centres generally characterised by public transport with sufficient spatial coverage. In those locations, scooters become a competitor instead of a complement.

According to this state of the art, we observe various knowledge gaps at different levels of analysis. From a mobility point of view, many existing studies characterise the shared e-scooter trips and some provide first insights about user profiles and choice factors based on more detailed surveys and complex modelling. However, we need a deeper description of travel patterns and the identification of key drivers related to service and built environment characteristics. Recently, Yang et al. (2022) identify thresholds of different built environment variables (density of intersections, roads and public transport stops among others) that are associated with a jump in e-scooter ridership. Extending the analysis of these relationships to other urban environments will explain the variability of behaviour among different European and North American cities. Further, the current results belong to the first years of operation, but several factors derived from the consolidation of scooters as a transport device may modify the initial use patterns. An example is the introduction of membership subscriptions by many companies, increasing the affordability of their services for a frequent use and tending to use patterns similar to bike-sharing members. On the other hand, Covid-19 has become an external factor that reshapes mobility behaviour due to a higher interest in individual transport solutions (Dias et al., 2021), but reducing the role as a first/last-mile step of public transport trips (Zhou et al., 2021).

Comprehensive knowledge of how the population uses the new shared e-scooter systems is key for effective planning towards an increasingly eco-friendly transport system. In this sense, we should quantify the number of trips currently made by other means of transport that could be satisfied by e-scooters in a competitive way. The results would allow us to estimate the target market of this new micromobility alternative. Currently, most studies limit the comparison to bimodal scenarios, for instance, with bus (Cao et al., 2021) or car sharing (Abouelela et al., 2021), or only involve micromobility alternatives (Reck et al., 2021). A global perspective is needed where we include the diversity of urban transport modes and shared micromobility is assessed as a component of a multimodal alternative to car-based mobility. Lee et al. (2021b) take a first step in this research direction.

Moreover, urban planners and managers require a deeper understanding of this phenomenon to implement effective measures and policies about these services to overcome the current deficits. Although public authorities have implemented various actions and regulations, there is a need to assess their effectiveness. Several issues should be discussed, such as fleet dimensioning and environmental characteristics where the service is more effective, considering what roles should be promoted. In this regard, authorities should determine the spatial characteristics associated with the generation of e-scooter trips (e.g. Hosseinzadeh et al., 2021a), the impacts derived from different operating strategies, and the policies that drive the service in a suitable direction. There is a need for further research on whether this new mobility service is a useful tool to improve the transport system or, conversely, whether the negative impacts derived from its deployment exceed the positive outputs. To achieve these goals, we need detailed data on how each operator manages its fleet and how users take advantage of its service. For that reason, cities should encourage companies that get an operating license to provide data. These data should be available in standard formats to facilitate the processing and analysis. Some cities have required data sharing in pilot programs, such as Los Angeles (LADOT, 2020), Chicago (City of Chicago, 2020) and San Francisco (SFMTA, 2019) among others.

At the operating level, current systems have limitations about shareability, repositioning and charging (Zhu et al., 2020). Companies are thinking about how to improve the performance of the systems from a business and ecological angle. On the one hand, operators need strategies to increase the utilisation rates of scooters using a better adjustment between supply and demand. They also need guidelines about where the implementation of this type of services could be more productive. On the other hand, tasks related to the gathering and distribution of the devices for charging or repositioning have to be carried out in a more efficient way, in particular, adapted to the demand requests (Ham et al., 2021). Osorio et al. (2021) analyse rebalancing strategies allowing charging on the auxiliary vehicles. Another solution is the implementation of docking infrastructure being simultaneously scooter parking and battery charging point (Martínez-Navarro et al., 2020), which could reduce the length travelled by collection and distribution vehicles. A flexible service could operate with a floating fleet at daytime period and fixed docks in the night time. An improvement of these processes reduces the cost, and consequently the present fare, and makes shared e-scooters an eco-friendlier transport solution.

Finally, future generations of e-scooters will be equipped with, for instance, remote control (Ford, 2021) or even automated driving (Kondor et al., 2021). These new developments would reduce the counter-productive effects and expenses derived from collection and distribution operations since auxiliary vehicles would be unneeded. Furthermore, autonomous rebalancing would make the adjustment between supply and demand easier, increasing the usage rates and providing services with superior quality with less devices. These new e-scooters would offer entire door-to-door trips, which would eliminate the access cost and increase the attractiveness of this transport mode.

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Appendix A. Classification of documents according to topic addressed

Table A1. Classification of scientific papers and grey literature about the topic under analysis.

Topic	Scientific literature	Grey literature (city evaluations, technical reports and others)
General	Bozzi and Aguilera (2021), Curl and Fitt (2020), DeMaio (2009), Dibaj et al. (2021), Fishman (2016), Fishman et al. (2013), Fuller et al. (2013), Gössling (2020), Lazarus et al. (2020), Orozco-Fontalvo et al. (2022),Wang et al. (2022)	NACTO (2018)
Use patterns		
User type and Trip characteristics	Almannaa et al. (2021), Christoforou et al. (2021), Dibaj et al. (2021), Jiao and Bai (2020), McKenzie (2019), Mathew et al. (2019), McKenzie (2020), Younes et al. (2020)	6t-bureau de recherche (2019), City of Alexandria (2019), City of Austin (2018), City of Chicago (2020), City of Tucson (2020), DeMeester et al. (2019), Denver Public Works (2019), Fearnley et al. (2020), LADOT (2020), Orr et al. (2019), PBOT (2018a; 2018b), Sedor and Carswell (2019), SFMTA (2019), SPRB (2019) Schellong et al. (2019), Smith and Schwieterman (2018), von Stülpnagel et al. (2019),
Temporal distribution	Bai et al. (2021), Hosseinzadeh et al. (2021b), Huo et al. (2021), McKenzie (2019), Yang et al. (2021), Younes et al. (2020)	City of Alexandria (2019), City of Chicago (2020), City of Tucson (2020), DeMeester et al. (2019), Denver Public Works (2019), Fearnley et al. (2020), Orr et al. (2019), PBOT (2018a; 2018b), Sedor and Carswell (2019), SPRB (2019)
Spatial distribution	Aman et al. (2021b), Caspi et al. (2020), Jiao and Bai (2020), Hawa et al. (2021), Huo et al. (2021), Tuli et al. (2021)	City of Alexandria (2019), City of Austin (2018), City of Chicago (2020), DeMeester et al. (2019), Denver Public Works (2019), Fearnley et al. (2020), LADOT (2020), Orr et al. (2019), PBOT (2018a; 2018b), Sedor and Carswell (2019), SFMTA (2019)
Purpose	Zuniga-Garcia and Machemehl (2020)	6t-bureau de recherche (2019), Baltimore City (2019), City of Alexandria (2019), City of Atlanta (2019), City of Austin (2018), City of Chicago (2020), City of Santa Monica (2019a), City of Tucson (2020), DeMeester et al. (2019), Denver Public Works (2019), Fearnley et al. (2020), Hoboken (2019), LADOT (2020), Orr et al. (2019), PBOT (2018a; 2018b), Sedor and Carswell (2019), SPRB (2019)
Frequency of use	Guo and Zhang (2021), Hosseinzadeh et al. (2021b), Laa and Leth (2020), Noland (2021), Tuli et al. (2021), Younes et al. (2020)	6t-bureau de recherche (2019), Baltimore City (2019), City of Alexandria (2019), City of Atlanta (2019), City of Chicago (2020), City of Santa Monica (2019a), DeMeester et al. (2019), Fearnley et al. (2020), Orr et al. (2019), PBOT (2018a; 2018b), SFMTA (2019), SPRB (2019)
Mode displacement	de Bortoli and Christoforou (2020), Hollingsworth et al. (2019), Krier et al. (2021), Moreau et al. (2020), Reck et al. (2022), Weschke et al. (2022), Ziedan et al. (2021a; 2021b)	6t-bureau de recherche (2019), City of Alexandria (2019), City of Chicago (2020), City of Santa Monica (2019a), City of Tucson (2020), DeMeester et al. (2019), Fearnley et al. (2020), Hoboken (2019), LADOT (2020), Orr et al. (2019), PBOT (2018a; 2018b), Sedor and Carswell (2019), SFMTA (2019), SPRB (2019)

(*Continued*)

Table A1. Continued.

Topic	Scientific literature	Grey literature (city evaluations, technical reports and others)
Consumer acceptance		
Motivations	Christoforou et al. (2021), Flores and Jansson (2021), Guo and Zhang (2021), Kopplin et al. (2021), Lee et al. (2021a), Reck and Axhausen (2021), Weschke et al. (2022)	6t-bureau de recherche (2019), City of Atlanta (2019), DeMeester et al. (2019), SPRB (2019)
Barriers	Aman et al. (2021a), Buehler et al. (2021), Lo et al. (2020), Ma et al. (2021), Nikiforiadis et al. (2021), Sanders et al. (2020)	6t-bureau de recherche (2019), City of Atlanta (2019), DeMeester et al. (2019), SPRB (2019)
Potential benefits	Abouelela et al. (2021), Baek et al. (2021), Cao et al. (2021), Kopplin et al. (2021), Luo et al. (2021), Mitra and Hess (2021)	
Environmental impact		
Impact of shared e-scooter services	de Bortoli and Christoforou (2020), Hollingsworth et al. (2019), Li et al. (2022), Moreau et al. (2020), Severengiz et al. (2020)	City of Alexandria (2019), City of Chicago (2020), City of Tucson (2020), DeMeester et al. (2019), LADOT (2020), Orr et al. (2019), PBOT (2018a; 2018b), SFMTA (2019), Sedor and Carswell (2019) Chester (2019), Griswold (2019), NACTO (2018), VOI (2019), von Stülpnagel et al. (2019)
Comparison with other modes	de Bortoli and Christoforou (2020), Hollingsworth et al. (2019), Moreau et al. (2020), Severengiz et al. (2020), Reck et al. (2022)	
Redirection measures	Frias-Martinez et al. (2021), Grosshuesch (2019), Janssen et al. (2020), Moran et al. (2020), Oeschger et al. (2020), Riggs et al. (2021)	City of Chicago (2020), City of Tucson (2020), DeMeester et al. (2019), LADOT (2020), PBOT (2018a), SFMTA (2019) Bird (2020), City of Santa Monica (2019b), District Department of Transportation (n.d.), Freund (2019), Intelligent Transport (2019), PBOT (n.d.), VOI (2020a; 2020b)
Conclusions and future research	Abouelela et al., (2021), Cao et al. (2021), Dias et al. (2021), Ham et al. (2021), Hosseinzadeh et al. (2021a), Lee et al. (2021b), Martínez-Navarro et al. (2020), Osorio et al. (2021), Reck et al. (2021), Yang et al. (2022), Zhou et al. (2021), Zhu et al. (2020)	Ford (2021), Kondor et al. (2021)