INTERNATIONAL JOURNAL OF SUSTAINABLE TRANSPORTATION
2022, AHEAD-OF-PRINT, 1-17
https://doi.org/10.1080/15568318.2022.2044097

Dockless electric scooters: A review of a growing micromobility mode

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ABSTRACT

Electric Micromobility (EM) and the use of dockless shared electric scooters (DSES) has rapidly grown in many cities worldwide. They are promoted as an accessible, low-emissions, versatile, and low-effort alternative. This article conducts a systematic review of DSES, considering their evolution, operation, regulations, user profile, environmental impact, safety, and pricing. The review shows age, income, and gender gaps among their users as most of them are young, male, high-income adults. DSES adopters come mainly from public transport, walking, and cycling. Their environmentally friendly label needs to be analyzed according to the city's context; their distribution and collection logistics impacts, and the vehicle's service life. The review shows significant differences in the way cities have regulated the service. One of the most significant potential contributions from DSES to urban mobility is the possibility to be integrated with public transport, implementing the Mobility-as-a-Service concept.

ARTICLE HISTORY

Received 2 July 2021
Revised 4 February 2022
Accepted 4 February 2022

KEYWORDS

Micromobility, dockless scooters, e-Scooters review, shared mobility, electric micromobility, smart mobility

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1. Introduction

Micromobility is a relatively new concept in the transport arena. Although there is not an official definition, it often refers to light, low-speed, eco-friendly, individual (or, at most, two users) transport modes used for short distances (≤5 km) (Mckenzie, 2019). Although the bicycle meets these characteristics, and has been around for years before this concept, light electric two-wheelers (Electric Micromobility, EM) are the vehicles that brought the term micromobility into the agenda. They include electric bicycles, segways and e-scooters, among others. EM has the potential to reduce the carbon footprint, improve transit accessibility and reduce transport costs (Tillemann & Feasley, 2018).

EM has become a trending topic in every city's agenda but —given its sudden appearance and fast-growing use— has also impeded cities' formulation of timely policies and regulations, triggering several issues such as crashes, unregulated operation, and conflict with other road users (Haworth et al., 2021a; Stigson et al., 2021). Frequently, policies have led to bans and prohibitions for dockless scooter companies, only to remove these prohibitions soon after. Another concern is their environmental impact, given that, despite advertising these vehicles as "zero emissions," the life cycle analysis (LCA) conducted by Hollingsworth et al. (2019) concluded that its lifetime and materials used in its production generates skepticism about their sustainability.

In this work, we focus on a specific EM vehicle, the standup, electric scooter (ES), also known as e-Scooters, and the shared system called dockless shared electric scooters (DSES), to be more specific. EM characteristics, including accessibility (Field & Jon, 2021; Scott & Schwieterman, 2018), low emissions (Guo & Zhang, 2021; Shaheen & Cohen, 2019), easiness, low-effort requirements and the possibility to avoid congestion (Gebhardt et al., 2021; Rejali et al., 2021), have led to a fast-growing use in many cities worldwide, reaching more than 136 million trips in the USA during 2019 (National Association of City Transportation Officials, 2020).

The main concerns of DSES operation and fast-growing use are reckless driving; safety and crashes; environmental impact; social gap, and vandalism (City of Santa Monica, 2019; Gössling, 2020). On the other hand, conflicts regarding infrastructure use and parking have also arisen with DSES. Brown et al. (2020) and Fang et al. (2018) agree that parking should not be considered the main issue; instead, efforts should be focused on environmental impact and safety concerns.

Although EM emerged in recent years, a small–but–growing number of studies have been developed. In this work, we conduct a systematic review of DSES, including scientific papers and technical reports, considering different attributes regarding their history, operation, user experiences, regulation, environmental impact, safety concerns, and pricing.

2. Methodology

We conducted a systemic review about EM, emphasizing standup DSES and ES (private use). In total, we cited more than 100 documents between papers and gray literature. The latter was included as complementary information to provide context or ES background. The specific review is developed based only on scientific papers from peer-reviewed journals published since 2018, which was the year when the first specific DSES papers were published. Table 1 presents the summary of papers included in this review per year and topic. The process followed three steps, as explained next.

Table 1. Paper review summary. (Table view)

Year	Environmental impact	Safety	Use/Trips	Total
2019	1	4	2	**7**
2020	3	12	12	**27**
2021	2	8	26	**36**
Total	**6**	**24**	**40**	**70**

1. Browsing metasearch engines (Scopus, Google Scholar, Web of Science, Microsoft Academic and Pubmed) searching for papers and about EM and DSES. The search was conducted from July 2020 to November 2021 using the following keywords "scooter", "e-Scooter" and "micromobility", complemented with "shared", "dockless", "docked", "rental", "sharing", and "electric". As a result, we obtained 128 scientific papers related to this topic (according to their title), most of them published in Science Direct, Taylor & Francis, Springer, and Wiley journals.
2. Reviewing the abstracts, we discarded articles that were not directly related to ES (other types of micromobility, conceptual papers, letter to editor, other types of scooters such as motorcycles and seated scooters), reducing our article database to 92 papers. They studied EM and DSES from different perspectives such as operational schemes; comparisons between micromobility vehicles; demand; trip analysis; environmental impact; safety and security; pricing/costs; integration, and policy-making/regulation.
3. An in-depth analysis looking for papers characterizing ES and those including a sustainability

approach in any of its three dimensions (social, economic and environmental). The database was reduced to 63 articles (this last filter removed papers that did not present specific results for ES; for example, those that mentioned the vehicle only to compare it with other modes and ES were not the main objective). Then, by snowballing (Wohlin, 2014) we identified 17 papers from which, after a complete reading, we obtained 7 new references for our review, for a total of 70 scientific papers, which were strictly reviewed, specific research papers about ES (Figure 1) and are listed in Tables 5–9. The final database includes research papers published between 2018 and 2021.

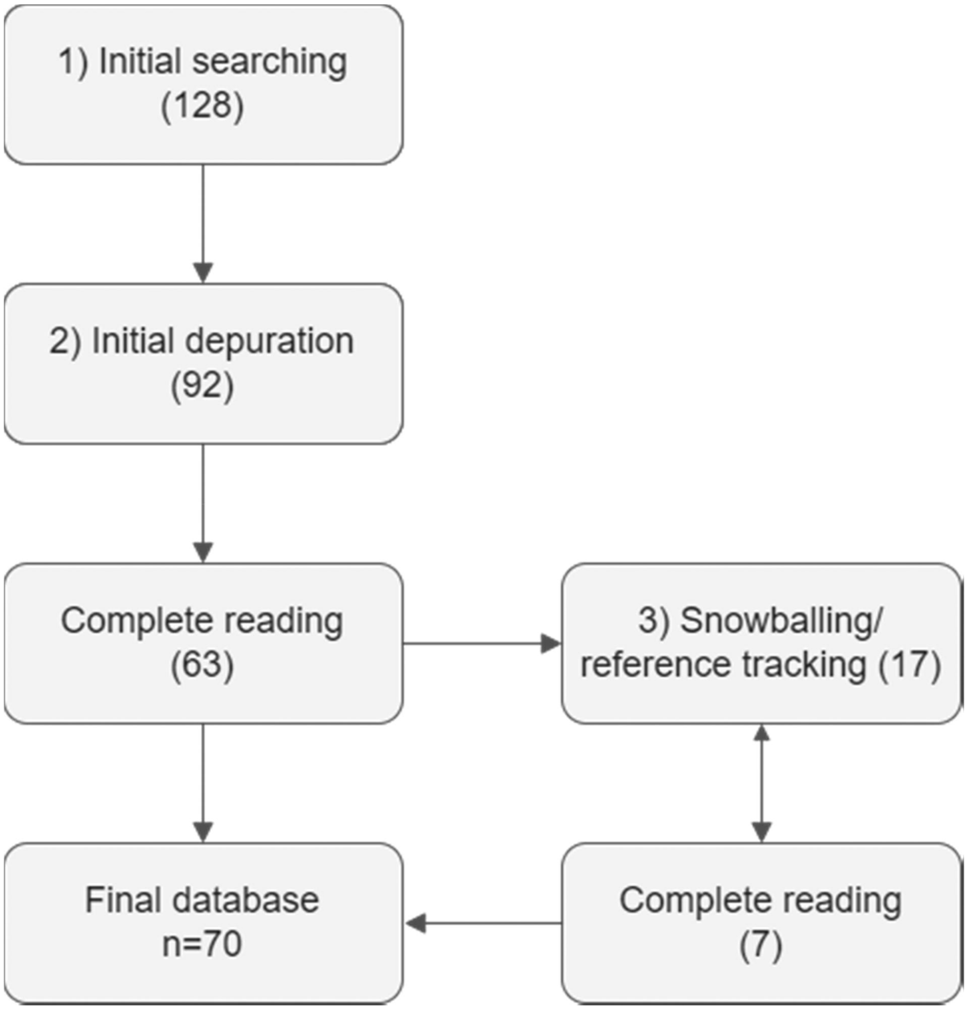

Figure 1. Review flow chart.

Given the short time DSES has been around, the number of research projects and papers is low compared to other means of transport. For this reason, besides scientific and academic documents, we included additional sources such as documents of international entities (NACTO, ITDP, OECD) and local reports (pilot programs conducted by local governments), reports from micromobility companies (e.g., Lime, Bird), and information from the Mobility Data Specification[1] (MDS).

Data sources not included in this review are news, books, and non-official information or data. Furthermore, all information about the small electric motorcycles, also known in Asia as "electric scooters" and other ES vehicles such as self-balancing scooters, three or four-wheel e-scooters (for elderly), or e-Scooters with seats was excluded. An illustration of the DSES and ES considered is shown in Figure 2.

Figure 2. Scooter considered. Source: Author gallery.

Papers published before 2021were mainly based on pilot programs or secondary sources, and the results were mainly descriptive. Since then, more robust research has been published, including survey applications (Almannaa et al., 2021; Cao et al., 2021; Zhang et al., 2021), vehicle performance (Ma, Yang, Mayhue, et al., 2021; Wilhelm et al., 2021), and research presenting different kinds of modeling approaches (Hosseinzadeh et al., 2021a; Lee et al., 2021; Reck & Axhausen, 2021).

3. Micromobility: a definition

The Micromobility concept has not been formally adopted as most research papers lack a direct definition. (Anderson-Hall et al., 2019; Bigazzi & Wong, 2020; Fitt & Curl, 2020; Moran et al., 2020; Yang et al., 2020). Most works use vague definitions or limit them to mentioning some of their characteristics (Eccarius & Lu, 2020), which allows for varying definitions depending on the author.

Definitions of micromobility are usually constructed using multiple criteria such as weight, passenger or payload capacity, powertrain, maximum speeds or ranges, and others. (Dediu, 2018; Eccarius & Lu, 2020; ITDP., 2019; Moore, 2019; Zarif et al., 2019). Most studies define micromobility as electric or human-powered modes of transport that are low speed (comparable to a bicycle), small, lightweight (<500 kg), and typically used for short-distance trips. However, light cars are not excluded from the definition (Dediu, 2019). Whilst most motorcycles weigh less than 500 kg, the weight alone —or at least in this magnitude— should not be regarded as a valid criterion for defining micromobility.

From our review, we define micromobility as "*The action of traveling short distances (<2 km) in an electric vehicle with low autonomy or a human-powered vehicle that can be lifted by a single person without* *much effort and operates with maximum speeds similar to a bicycle (less than 30 km/h). It is deemed as eco-friendly, and its versatility allows reaching a destination rapidly."*

4. E-scooters: a review

Bike-sharing systems are a precursor for DSES. Initially, station-based systems were commonly used for short trips (flat commute trips), typically connecting transit transfers. Then dockless systems emerged and were intended for longer, spatially distributed trips connecting low-density residential areas (Lazarus et al., 2020). Electric scooters emerged in 2017 as a new shared mode of transport in the United States (City of Santa Monica, 2019; Portland Bureau of Transportation, 2019). DSES trips have usually been short, centralized, and mainly in commercial and tourist areas (Bai & Jiao, 2020; Mckenzie, 2019; Merlin et al., 2021). In this way, they have proliferated worldwide (Caspi et al., 2020).

Although some people have bought their own electric scooter, most users rent them from different companies who provide a dockless-sharing service, also known as a free-floating service (e.g., Bird, Lime, Movo, Grin, Jump). To access these services, users should download an app on their phones to unlock the vehicle. For these reasons, DSES are considered as smart mobility and a vehicle-sharing system, which are included in the MaaS (Mobility-as-a-Service) concept (Hietanen, 2014).

4.1. E-scooter trips

DSES experienced a fast-growing use as compared to other micromobility vehicles. In the United States 38.5 million trips were reported in 2018, surpassing bike-sharing systems by 3.6 times. During 2019, trips raised to 86 million, doubling the previous year (National Association of City Transportation Officials, 2019, 2020). Figure 3 presents these variations. The difference between dockless bicycles and scooters is that scooters are "new" vehicles and do not require pedaling. According to Younes et al. (2020), by the end of 2018, the DSES supply was over eighty-five thousand.

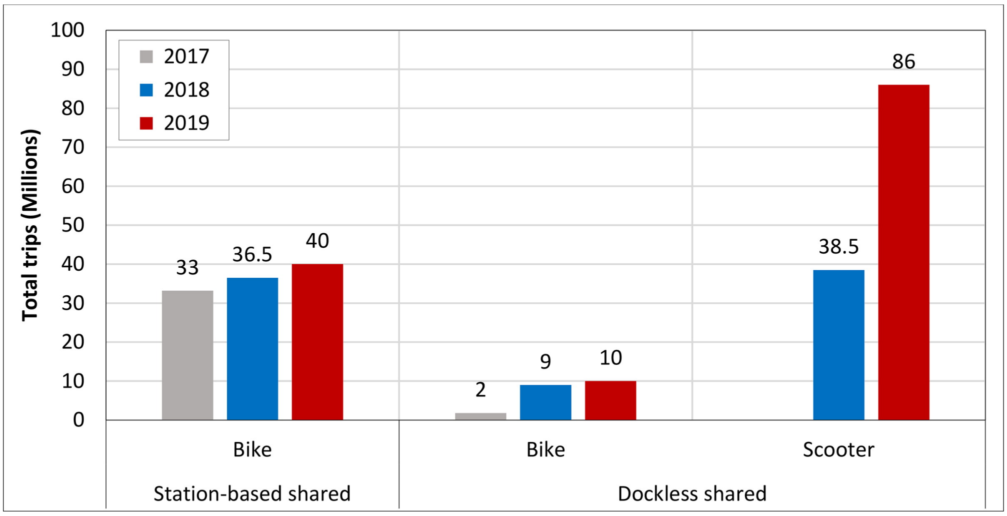

Figure 3. Total trips in the USA Source: NACTO (2019, 2020).

As mentioned before, the growth rate of DSES revealed legal pitfalls about its operation, making some municipalities conduct pilot programs to characterize trips, user profiles, real impact, and quantify the future demand.

The city of Santa Monica, California, implemented one of the first pilot programs with 2.000 DSES and 500 E-bikes between October 2018 and September 2019, reporting 2.6 million trips: just about 8.000 daily trips with an average trip duration of 14 minutes and a 2.1 km distance (City of Santa Monica, 2019). In

Portland, a pilot program was implemented with 2.043 DSES between July and November 2018, reporting 700,000 trips, nearly 6.000 daily trips with an average trip distance of 1.85 km. (Portland Bureau of Transportation, 2019). In Washington D.C., Zou et al. (2020) found that the average trip distance is 1.54 km, with an average speed of 7.2 km/h meaning 13 minutes per trip, with most trips during the afternoon. In Paris, Lime (2019) reported 1.2 million trips between June 2018 and September 2019.

The available information regarding trip characteristics using DSES shows similarities worldwide. Data from the United States (Bai & Jiao, 2020; City of Santa Monica, 2019; Murray et al., 2020), Germany (Civity Management Consultants, 2019), Colombia (Secretaría de Movilidad, 2019), and France (6t-bureau de recherche, 2019; Lime, 2019) indicate that, in most cases, trip distances are less than 2 km. Trip distribution per day of the week is also similar among countries, with half of the DSES trips made from Friday to Sunday in the afternoon (Bai & Jiao, 2020; Mckenzie, 2019), as shown in Figure 4.

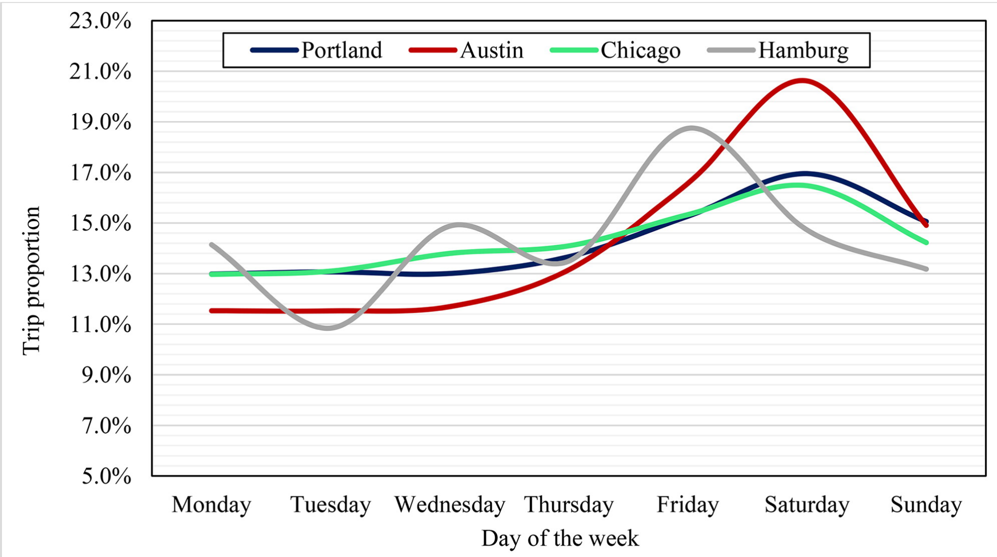

Figure 4. Trips by day of the week. *Source*: Portland Bureau of Transportation (2019); City of Chicago (2020); City of Austin Transportation Department (2020); Civity Management Consultants (2019).

4.2. User profile

DSES demand is strongly related to the user profile. In Santa Monica (2019), 67% of users are male, 64% are 34 years old or less, and around half belong to the high-income population. In Los Angeles (2020), 30% of users were nonresidents, 64% were males, 58% were young adults between 18 and 38 years old, and most reported high income levels. A study in three different French cities (Paris, Lyon and Marseille) reported that 58% of users were residents, 66% young males, 19% students, and 53% were office workers. Similar to the USA, most users reported a higher income than the city average (6t-bureau de recherche, 2019). These conclusions are in line with the findings of Christoforou et al. (2021) regarding factors influencing the gender and social equality gap in DSES use (Aman et al., 2021; Campisi et al., 2021).

Related to the motivations for using DSES, the French study reported that the primary reason was that these vehicles are "fun to ride", followed by timesaving and versatility (6t-bureau de recherche, 2019). The same two main motivations were reported in Santa Monica (City of Santa Monica, 2019). On the other hand, 71% use DSES for the daily commute in Portland, while the remaining 29% use them for recreational purposes (Portland Bureau of Transportation, 2019). In Austin (2019), 96% reported using DSES only for recreational purposes at least one time. Similarly, Tricity (Poland) citizens use DSES mainly for recreational or leisure reasons (Bieliński & Ważna, 2020). Likewise, Guo and Zhang (2021) found that people who ride DSES for dining and leisure are more likely to be regular users. Table 2 summarizes the user profile and motivations to use DSES in different American and European cities.

Table 2. User profile summary. (Table view)

City	Gender (% male)	Age	Income level	Occupation	Reasons for using
Atlanta	54%	26-35	High	-	1. Timesaving 2. Convenience
Auckland, Hutt Valley, Dunedin, Christchurch	57%	18-24	High	1. Employee 2. Student	1. Timesaving 2. Fun/recreation
Calgary	53%	25-34	High	-	1. Fun/recreation 2. Timesaving
Los Angeles	64%	18-34	High	-	1. Job related 2. Fun/recreation
Paris, Lyon, Marseille	66%	25-34	High	1. Employee 2. Student	1. Fun/recreation 2. Timesaving
Santa Monica	67%	<34	High	-	1. Job related 2. Fun

Source: Atlanta Department of Transportation (2019); Fitt, H., & Curl, A. (2019), City of Calgary (2020); Los Angeles Deparment of Transportation (2020), 6t-bureau de recherche (2019), City of Santa Monica (2019).

4.3. Modal shift

A relevant discussion is about the impact of DSES on modal shift. Reports from different cities are not conclusive. While American cities such as Los Angeles, Santa Monica and Portland reported that trips made using DSES were previously made using private cars or ride-hailing services such as Uber and Lyft (City of Santa Monica, 2019; Murray et al., 2020; Portland Bureau of Transportation, 2019), in French cities, users stated that they would have used a bicycle (10%), public transport (29%) and walking (47%) if DSES would not exist; something similar was also observed in Canadian cities (Mitra & Hess, 2021). Nevertheless, only 6% reported a reduction in walking or using public transport after DSES appeared.

Table 3 presents the percentage of trips that shifted from each mode toward DSES from different American and European cities. Differences among countries are similar to those found when the shared electric bicycles (SEB) appeared (Cherry, 2007). Montgomery (2010) found that more than a half of SEB users in Asia came from public transport and sustainable modes such as cycling and walking. The opposite occurred in Australia and the United States of America, where almost 60% of users came from private vehicles (Johnson & Rose, 2013; MacArthur et al., 2014).

Table 3. Modal shift. (Table view)

Mode	Santa Monica	Auckland, Christchurch, Dunedin, and Hutt Valley	Paris, Lyon, and Marseille	Calgary
Private car	49%	14.3%	3.3%	17.7%
Ride hail/Shared car/Taxi		8.9%	5.4%	15.5%
Walking	39%	52.4%	46.6%	55.2%
Cycling	7%	4.5%	9.8%	3.8%
Motorcycle		0.2%	2.2%	
Public transit	4%	5.3%	28.6%	5.9%

Mode	Santa Monica	Auckland, Christchurch, Dunedin, and Hutt Valley	Paris, Lyon, and Marseille	Calgary
Would not have traveled	–	10.5%	3.0%	–
Other	1%	3.9%	1.2%	1.8%

Source: 6t-bureau de recherche (2019); City of Calgary (2020); City of Santa Monica (2019); Fitt and Curl (2019).

In this framework, DSES cannot be limited to being conceived as a full-trip vehicle only; integration with public transportation systems should be considered (Nawaro, 2021; Zhang et al., 2018). For instance, in France, 23% of users reported intermodal trips using DSES, combining it with public transport (66%) and walking (19%) (6t-bureau de recherche, 2019). Baek et al. (2021), Scott and Schwieterman (2018), and Kondor et al. (2021) concluded that DSES is a competitive alternative for a typical last mile.

4.4. DSES costs

DSES are advertised as a low-cost, individual and versatile mode of transport for those commuters who cannot afford to buy a vehicle, bridging the gap of urban transport equity (Eccarius & Lu, 2020). However, as discussed previously, the majority of DSES users belong to high-income sectors. In this section, we present the different fees found in our review in different regions worldwide.

In most cases, the DSES fee has two parts. The first, a fixed cost, is used to "unlock" the vehicle, while the second is variable according to the trip distance or time. The total fee has an average value of $1.00 to unlock in the USA, plus an average cost of $0.15 per minute (Younes et al., 2020). However, this value varies depending on the state and renting company. Some companies do not charge an unlock fee, but have a higher cost per minute (i.e., Skip scooters in California). In some cities, such as New York, the service can be hired for a monthly fee varying from $39 to $99 (i.e., Brooklyness and Unagi Scooters). In Canada, Lime and Bird offer a fee of $0.86 to unlock and $0.26 per minute.

In other regions such as Latin America, characterized by a lower GDP per capita than the USA, the service is provided at a lower cost; for example, the unlock fee ranges from $0.54 (Colombia, Brazil) and $1.00 (México), while the cost per minute ranges from $0.10 to $0.16.

To analyze whether this service can be labeled a low-cost alternative, we compared the hourly minimum wage in each city/country to the DSES fees. Table 4[3] shows that a minimum-wage hour earner could afford almost two 10-minute trips in most of these cities. However, there are some cases with huge differences; for example, while in Paris, a DSES user could afford four 10-minute trips with the earnings from one minimum-wage hour, however, in Mexico City, this wage is not enough to afford even a single 10-minute trip.

Table 4. DSES fees worldwide. (Table view)

City	Minimum hourly wages[3]	Unlock	$/Minute	10-min trip	Worked hours for a 10-min trip
Phoenix	$ 12.00	$ 1	$ 0.15 - $ 0.39	$ 3.70	0.31
Santa Monica	$ 12.00	$ 1	$ 0.20 - $ 0.39	$ 3.90	0.33
Chicago	$ 9.25	$ 0	$ 0.25	$ 2.50	0.27
Minneapolis	$ 9.08	$ 1	$ 0.25	$ 3.50	0.39
New York	$ 11.80	$ 1	$ 0.15	$ 2.50	0.21
Portland	$ 11.25	$ 1	$ 0.15 - $ 0.39	$ 3.70	0.33

City	Minimum hourly wages[3]	Unlock	$/Minute	10-min trip	Worked hours for a 10-min trip
Austin	$ 7.25	$ 1	$ 0.15 - $ 0.39	$ 3.70	0.51
Washington D.C.	$ 13.50	$ 1	$ 0.15 - $ 0.39	$ 3.70	0.27
Calgary	$ 10.00	$ 0.86	$ 0.26	$ 3.50	0.35
Paris	$ 11.20	$ 1.17	$ 0.18	$ 3.00	0.27
Madrid	$ 6.80	$ 1.17	$ 0.18	$ 3.00	0.44
Berlin	$ 10.30	$ 1.17	$ 0.18 - $ 0.23	$ 3.20	0.31
Mexico City	$ 0.70	$ 0.50 - $ 1	$ 0.10 - $ 0.14	$ 1.90	2.71
Bogotá	$ 1.20	$ 0.30 - $ 0.54	$ 0.08 - $ 0.10	$ 1.30	1.08
Santiago de Chile	$ 2.20	$ 0.26 - $ 0.53	$ 0.10 - $ 0.16	$ 1.70	0.77
Sao Paulo	$ 1.30	$ 0.29 - $ 0.58	$ 0.10 - $ 0.15	$ 1.70	1.31

Source: Minimum hourly wages from USA (U.S. Department of labor, 2019); Minimum hourly wages outside the USA (OECD., 2019).

Different methodologies have been applied to analyze DSES users and trip characteristics, including logistic regressions, geo-spatial analysis, structural equations modeling (SEM), and hurdle models. Among the most important results are the user profile, mainly young males with a high income, the influence of weather as a choice variable, and the importance of providing adequate infrastructure for its operation. A summary of the literature regarding this topic is presented in Table 5.

Table 5. DSES user and trip characteristics review. (Table view)

Authors & year	Location	Methods	Key findings
(Almannaa et al., 2021)	Riyadh, Saudi Arabia	Logistic regression models (n = 439) with surveys among users (18%) and nonusers (82%)	People who use ride-hailing services expressed more willingness to use ES. Males are twice as likely to use the ES if available than females. The major obstacle for deploying ES in Saudi Arabia is the lack of sufficient infrastructure, weather, and safety. Half of the respondents believed that COVID-19 will not affect their willingness to ride.
(Anderson-Hall et al., 2019)	USA	Manual review of policies, programs, and regulations	Summary of fares, regulations, vehicle specifications of ES.
(Baek et al., 2021)	Seoul, South Korea	Stated Preference experiment and Mixed Logit model for ESS for last-mile trips	ES are a competitive alternative in last-mile situations.
(Bai & Jiao, 2020)	Austin y Minneapolis, USA	GIS hotspot spatial analysis and negative binomial regression models	Proximity to the city center, better access to transit, and greater land-use diversity, are positively correlated with higher ES ridership.
(Bai et al., 2021)	Austin, Texas, USA.	Spatiotemporal similarity analysis	ES use is significantly correlated to daily dining and drinking, shopping, and recreational activities. Also, clustered to downtown and university campus areas.

Authors & year	Location	Methods	Key findings
(Bieliński & Ważna, 2020)	Tricity, Poland	Quantitative analysis from a survey using Computer-Assisted Personal Interviewing technique (CAPI) (n = 633)	ES are more often used for leisure rides. ES users are on average younger than e-bike users. Providing electrically assisted vehicles does not reduce the gender gap, or help retired and disabled people in the adoption of shared micromobility services.
(Brown et al., 2020)	Austin, TX, Portland, OR, San Francisco, CA, Santa Monica, CA, and Washington, DC.	Quantitative analysis of e-scooters, bikes, motor vehicles parking (n = 3666), and sidewalk objects.	One of the main problems with electric scooters is the misuse of public space. However, this study concludes that ride-hailing services and private cars block driveways or park badly more often than ES.
(Cao et al., 2021)	Singapore Central Area	Stated preference survey (n = 758) to estimated mixed logit models	Higher level of transit indirectness, more transfers, and longer access-egress walking result in a higher probability of using ES. Male, young, and high-income groups are more heterogeneous in ES preferences.
(Caspi et al., 2020)	Austin, Texas, USA.	Analysis of trip patterns and spatial regression	Usage of DSES is associated with areas with high employment rates, and in areas with bicycle infrastructure. ES may substitute other modes for some short non-work trips, reduce car usage, and benefit the environment.
(Christoforou et al., 2021)	Paris, France.	Binary logit models using face-to-face road survey among e-scooter users	Results indicate that riders rarely own an ES, are mostly men, aged 18–29, and have reached college studies. They shifted mainly from walking and public transport.
(Eccarius & Lu, 2020)	Taiwan	Theory of planned behavior model, survey (n = 471), Structural equation modeling.	Young adults who do not use/own private vehicles may have a higher intention to use ES
(Fitt & Curl, 2020)	New Zealand	Quantitative and descriptive analysis	ES users consider that in many cases, they travel in unsuitable conditions, sharing space with pedestrians.
(Gössling, 2020)	Brisbane, Christchurch, Copenhagen, Dallas, Los Angeles, Málaga, Paris, Stockholm, Vienna, Zurich.	Mining news (n = 173)	Recommendations: establishing maximum speeds, mandatory use of bicycle infrastructure, and dedicated parking, as well as limiting the number of licensed operators.
(Ham et al., 2021)	Seoul, South Korea	Demand and unmet demand prediction using a latent feature and deep learning	Grid of predicted origin and destination trips as output.
(Haworth et al., 2021b)	Brisbane, Australia	Logistic regression with observational data from user's characteristics	Illegal riding was more prevalent among shared than private ES. Nonuse of helmets was more common among riders of DSES. More than 90% of ES were ridden on the footpath. Risky behaviors are more prevalent among users of shared ES. There are frequent interactions with pedestrians but conflicts rarely occur in footpath riding.

Authors & year	Location	Methods	Key findings
(Hosseinzadeh et al., 2021a)	Louisville, Kentucky, USA.	Generalised Additive Modeling using trips density and Traffic Analysis Zones characteristics	ES trip density at a TAZ level is influenced by Commercial land use, industrial land use, Walk Score and Bike Score.
(Hosseinzadeh et al., 2021b)	Louisville, Kentucky, USA.	Geographical Weighted Regression (GWR) in Traffic Analysis Zones	Land use, age distribution, gender distribution, Walk Score and Park Score impacted the density of ES trips in the TAZ.
(Kopplin et al., 2021)	Bayreuth, Germany	Unified Theory of Acceptance and Use of Technology (n = 749) among owners (n = 73) and non-owners (n = 676)	ES are mostly viewed as fun objects. Perceived safety impedes ES usage. Environmental concerns and individual convenience represent the main reasons for using ES. ES substitute walking over short distances.
(Lee et al., 2021)	Seoul, South Korea	Latent class adjacent-category ordinal logit model from a survey (n = 363) people who knew about or had seen the ESS service	Preferred trip situation and purpose for using DSES services could vary not only depending on people's socio-demographics but also on the quality of public transport.
(Ma, Yang, Ma, et al., 2021)	USA	Manual review of E-Scooter user guidelines	Municipalities should introduce guidelines for parking, riding, sharing road space and speed limits driven by quantitative performance metrics.
(Mckenzie, 2019)	Washington D.C., USA	Spatial and temporal quantitative analysis	DSES trips support leisure, recreation, or tourism activities, more than commuting.
(Merlin et al., 2021)	Washington D.C., USA	Hurdle models for OD trips using open data	Tourist attractions and hotels are a great portion of ES trips destinations. Young adults with bachelor's degrees are frequent users. Most trips origin and destination are in the city center.
(Mitra & Hess, 2021)	Greater Golden Horseshoe, Ontario, Canada.	Weighted logistic regression model based on an online survey (n = 1640)	The majority would replace their existing walking (60%) and transit (55%) trips with DSES. Trip efficiency, and environment and health-consciousness, were positively associated with potential ES consideration.
(Moran et al., 2020)	Vienna, Austria	Spatial analysis	The public sector should define the areas of operation, the number of operators and guarantee that this service is offered to peripheral areas.
(Nikiforiadis et al., 2021)	Thessaloniki, Greece.	Classification tree model and latent variable logit model. Using (n = 578) observations (271 users, 307 nonusers)	DSES mostly replaced walking and public transport trips. People traveling by bicycle or motorcycle were not at all attracted by ES. Women use less ES compared to men. People living downtown are more regular users compared with those living longer distances from the city center.
(Reck & Axhausen, 2021)	Zurich, Switzerland	Multivariate probit model (MVP) using 1454 surveys	Users of DSES are mainly young males. However, more females use DSES than shared bikes. DSES users are more representative of the overall population than bike-sharing users.

Authors & year	Location	Methods	Key findings
(Reck et al., 2021)	Zurich, Switzerland	Modal choice model estimation	Mode choice is dominated by distance and time of day. Docked modes are preferred for commuting. Docking infrastructure for currently dockless modes could be vital for bolstering micromobility as an attractive alternative to private cars.
(Sanders et al., 2020)	Tempe, Arizona, USA.	Regressions and Statistical tests included the Chi2 and Kruskal Wallis tests. A survey in a campus staff (N = 1256, 32% had ridden ES)	ES is seen as a convenient way to travel, particularly in the heat and compared to walking. Demographic differences were notable. ES is also associated with concerns about traffic safety (particularly for women).
(Tuncer et al., 2020)	Paris, France	Video recordings for quantitative and descriptive analysis of ES users riding behavior	ES users do not stop at red traffic lights and, in dense traffic, slow down to blend in with pedestrians and keep moving.
(W. Zhang et al., 2021)	Virginia, USA.	Recursive Logit route choice model using revealed preferences data	ES riders are willing to travel longer distances to ride in bikeways. Also prefer shorter and simpler routes and slopes are not a determinant for ES route choice.
(Wilhelm et al., 2021)	Berlin, Germany	Naturalistic observation study (n = 2972) and a survey (n = 156)	Only one third was able to identify the braking system of the ES. Right hand and foot brake levers were used less frequently than the left one. There is a lack of knowledge about ES regulation and illegal behavior by riders.
(Younes et al., 2020)	Washington, D.C. USA	Negative-binomial regression model using big data trips from vendors	DSES users are less sensitive to weather changes than users of station-based bikes and more sensitive to changes in the cost of gasoline. Complementing station-based bikes with DSES may be the most cost-effective approach to help meet transport-related climate change targets.
(Zou et al., 2020)	Washington, D.C. USA	Descriptive statistics analysis and exploratory analysis	Arterial roads and local streets with heavy traffic are the most popular facilities used by DSES. If the streets are equipped with bike lanes, then they will likely attract more DSES traffic.
(Kondor et al., 2021)	Singapore	Shareability network	Autonomous DSES can solve the first- and last-mile problem and will be financially reasonable over conventional vehicles. At the same time, these vehicles can replace active modes (i.e. walking and cycling).
(Nawaro, 2021)	Warsaw, Poland	Kernel density estimation and quantitative analysis	ES's trip data shows that they are more complementary to rapid public transport than e-bikes and may solve the last-mile problem. Well-planned bicycle sharing system may still be complementary to e-scooters.
(Guo & Zhang, 2021)	Tampa, Florida,USA.	Random parameter models from an online survey (n = 698)	Whoever has higher exposure to DSES is likely to buy/own a private e-Scooter.Ride DSES in bike lanes, and ride DSES for dining and leisure trip purposes are more likely to be regular users. Users who prefer lower speed limits ride shared e-Scooters less frequently.

Authors & year	Location	Methods	Key findings
(Luo et al., 2021)	Indianapolis, Indiana, USA.	Spatial, temporal analysis, and difference-in-difference (DID) analysis	ES trips could potentially compete with the bus system and they are concentrated downtown. The complementary trips (29%) are mainly located outside of downtown, where the bus coverage is low.
(Campisi et al., 2021)	Sicily, Italy.	Ordinal regression model from an online survey (n = 1000)	Age, job occupation, and the perceived safety level of micromobility modes are the most influential factors of the gender equality variable.
(Aman et al., 2021)	Austin, Texas, USA.	Lorenz curve, Ordinary Least Squares (OLS), and Geographically Weighted Regression (GWR) models	Almost 80% of residents have no access to bikes and ES. Access is even worse for transit-dependent people when compared to the general population.

4.5. Environmental impacts[2]

Micromobility sharing systems, including DSES, have been advertised as environmentally friendly or as zero-emissions operating vehicles (Weiss et al., 2015). Green image perceptions are significantly related to the use of DSES (Flores & Jansson, 2021). However, this is an ongoing discussion, and as new methodologies to assess the environmental impacts arise, the seeming benefits of these systems have started creating doubts among the scientific community. Until now, only a few specific papers have studied the environmental impacts of both ES and DSES (Table 6). The main concern is about the vehicle's life cycle, regarding the materials needed and energy consumption in the different stages of its production, the carbon footprint during its transport and its final disposal (de Bortoli, 2021). Therefore, the most appropriate approach to determine the actual environmental impact of DSES is to apply the Life Cycle Assessment (LCA) (de Bortoli & Christoforou, 2020).

Table 6. DSES environmental papers review. (Table view)

Authors & year	Location	Methods	Key findings
(de Bortoli & Christoforou, 2020)	Paris, France.	Consequential Life Cycle Assessment (CLCA)	Shared ES generated an extra 13.000 tons of CO2eq under an assumption of one million users, mainly due to major shifts coming from lower-emitting modes.
(de Bortoli, 2021)	Paris, France.	Life Cycle Assessment (LCA) on field data for bikes, second-generation e-scooters, and e-mopeds.	Vehicle manufacturing globally drives environmental impacts. The vehicle lifetime mileage is what affects the environmental performance. Electric micromobility environmental impacts rank between active modes and conventional personal modes.
(Hollingsworth et al., 2019)	Raleigh, North Carolina, USA	Monte Carlo Analysis	ES environmental impacts come mainly from manufacturing (50%) and daily collection for charging (43%).
(Severengiz et al., 2020)	Bochum, Germany	Quantitative analysis of environmental impacts under different modal shift scenarios	Shared ES could reduce the environmental impacts of urban mobility, but the modal shift is important in this matter.

Authors & year	Location	Methods	Key findings
(Flores & Jansson, 2021)	Copenhagen, Denmark and Stockholm, Sweden	Linear and Multiple Logistic Regression, t-test, and Analysis of Variance from a survey to nonusers (n = 515), DSES users (n = 586) and shared e-bike users (n = 400)	Consumer innovativeness and green perceptions are significantly related to the use of DSES. DSES users do not primarily use these microvehicles because of their perceived greenness. Shared micromobility users are more likely to perceive the environmental benefits of shared microvehicles than nonusers.

According to Severengiz et al. (2020), the environmental impact of DSES depends directly on its influence on modal shift. In countries where DSES replaces private car trips, there is a positive environmental impact. Meanwhile, when replacing public transport, cycling, or walking, it would have a negative impact. The last is the case of Paris, where most DSES trips are replacing sustainable modes generating the equivalent of 13,000 tons of CO_2 a year (de Bortoli & Christoforou, 2020).

When analyzing the different stages of electric vehicle production, the environmental impact is similar to conventional vehicles —and even higher in some cases— because of lithium batteries. However, these vehicles are designed to mitigate this impact thanks to low emissions during their operational service life (Nealer et al., 2015). For DSES, given their operational schemes, the service life is usually too short (product of vandalism, misuse, weathering) to diminish its manufacturing impact. Unlike other electric vehicles and station-based systems, being dockless requires collecting scooters at midnight and distributing them in the morning, which is done mainly by trucks (Arias-Molinares & Palomares-García, 2020), eliminating the "zero-emission" label of DSES. Furthermore, Hollingsworth et al. (2019) estimated that during their life cycle DSES generate 202 g CO_2-eq per mile, concluding that almost 50% of these emissions are generated in the manufacturing stage, 43% in the collection and distribution, and 4.7% from the energy sources used for battery charging. This is equivalent to a midsized electric car's environmental impact per mile (Nealer et al., 2015).

During its pilot program, Los Angeles estimated a reduction of 1,802 metric tons of CO_2 emissions from the 8.4 million miles traveled on DSES. However, after applying LCA, the results showed emissions equivalent to 1,707 metric tons of CO_2, resulting in a net reduction of only 5% (Murray et al., 2020).

In this framework, we can state that the environmental impact of DSES is not zero and that it depends on where the trips came from, the operational scheme and service life. Aware of this, DSES companies have new plans to extend scooters' service life (Lime, 2019). Therefore, the second ES generation has been deployed, and a new LCA has found that their environmental impacts rank between active modes and conventional personal modes (de Bortoli, 2021).

4.6. Safety

One of the main concerns of local governments regarding DSES is user vulnerability and conflicts with other road users, pedestrians, and cyclists (Che et al., 2021; Sikka et al., 2019). ES users tend to commit traffic offenses such as speeding, not wearing a helmet (Beck et al., 2020; Dhillon et al., 2020), riding while intoxicated (Faraji et al., 2020; Kobayashi et al., 2019), riding without a license requirement in some cities (Anderson-Hall et al., 2019), and developing risky behavior (Gioldasis et al., 2021). However, this is more common for DSES than private ES (Haworth et al., 2021a).

Given these systems' relative novelty, there are not enough crash databases specifically for DSES that allow for analyzing or identifying crash patterns. The first efforts found in the literature used bicycle crash data to determine risk zones for DSES (Zou et al., 2020). It explains why state of the art regarding these vehicle crashes is built from pilot programs and data gathering employing the Mining News methodology (Yang et al., 2020). However, the latter methodology could lead to biased information, given that only crashes with severe injuries or fatalities are reported in the news, ignoring minor injuries and leading to underreporting. Nevertheless, it is still helpful to address safety issues and identify critical or unsafe zones within the urban perimeter.

Safety issues of DSES found in cities like Austin, Los Angeles, Santa Monica, and Portland are now evident resulting from the pilot programs. They showed that most crashes are direct collisions, but very few involve pedestrians. Restriction to ride scooters on the sidewalk may explain this finding. However, in Washington, D.C., the most common e-scooter injuries occurred on the sidewalk or road (Cicchino et al., 2021). In these reports, there were no casualties, and 10% of crashes caused severe injuries to users. (City of Santa Monica, 2019; Murray et al., 2020; Portland Bureau of Transportation, 2019).

Information collected from the pilot program in Austin was used to estimate the first DSES crash frequency rates, resulting in 20 injured DSES users per 100,000 trips (Austin Public Health & City of Austin, 2019). Meanwhile, in Auckland (New Zealand), an injury rate of 60 injuries per 100.000 trips was found. However, if only those who required hospital treatment were considered, the rate would be similar to Austin's (Bekhit et al., 2020). A comparison between modes was also conducted in Austin and found that the observed vehicle-miles-traveled base injury rate for ES was approximately 175 to 200 times higher than the same injury rates for motor vehicles (Rix et al., 2021).

Regarding crash severity, some authors have conducted studies using information gathered in injury report systems from hospitals and health institutions (i.e., Medstar Georgetown University Hospital, The National Electronic Injury Surveillance System, Austin public health syndromic surveillance system, Vienna General Hospital, Donauspital, and Wilhelminenspital Wien, among others). Nellamattathil and Amber (2020) concluded that DSES crashes lead to musculoskeletal injuries; specifically, head injuries are the most common among users, including concussions or fractures. Moreover, dislocations and fractures of lower limbs are also frequent (Aizpuru et al., 2019; Bloom et al., 2021; Dhillon et al., 2020; Stigson et al., 2021). Faraji et al. (2020) found that fracture of the midface is the most common head injury, while English et al. (2020) and Moftakhar et al. (2020) state that besides head injuries, upper limbs are the most affected as a result of falls. These studies present the parts of the body most affected in DSES accidents. Figure 5 summarizes this information.

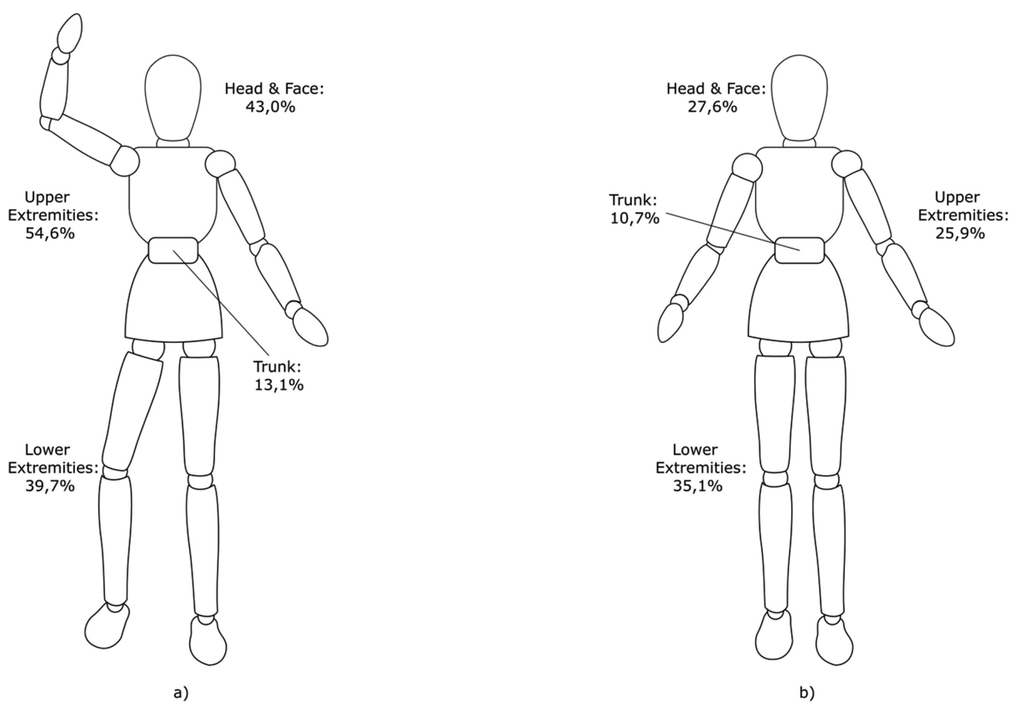

Figure 5. Injuries location. Source: Authors[2] based on **a)** English et al. (2020) and Moftakhar et al. (2020) **b)** Aizpuru et al. (2019).

Moftakhar et al. (2020) applied the Injury Severity Score (ISS) to quantify crash severity involving DSES in Vienna, obtaining a 3.4 score, meaning that the average DSES crash is classified as mild (Bolorunduro et al., 2011; Puzio et al., 2020), but clarifying that this score tends to rise with the age of the user. They also found that 39.2% of crashes with injuries occurred in the night, between 8 pm and 1:59 am.

Considering that evidence and literature show head injuries as the most common outcome of a DSES crash, wearing a helmet becomes essential in reducing the severity of injuries. However, these services are often advertised without any prevention or requirement to ride (Allem & Majmundar, 2019). One of the central policies implemented to mitigate the safety issues is the speed limit, ranging from 20 to 25 km/h. Most studies in the literature review used quantitative or descriptive analysis to characterize user injuries or crashes. Regressions, Mining news, mobile sensing and virtual reality tests were also applied. However, as shown in Table 7, few papers assessed factors influencing ES crashes, such as infrastructure, weather conditions and vehicle characteristics. This could be due to the lack of specific crash databases, one of the primary voids regarding ES safety.

Table 7. DSES safety papers review. (Table view)

Authors & year	Location	Methods	Key findings
(Aizpuru et al., 2019)	USA	Quantitative and descriptive analysis using The National Electronic Injury Surveillance System data	Head injuries were the most injured body part, while fractures or dislocations were the most common diagnosis.
(Allem & Majmundar, 2019)	Los Angeles, CA, USA	Descriptive analysis of Instagram post	ES are not promoted considering safety gear.
(Beck et al., 2020)	Dunedin, New Zealand	Quantitative and descriptive analysis	The number of bicycle and ES related injuries admissions were similar. Most ES injuries were minor, but over two-thirds required imaging, and on average, each day, one bed was occupied for almost three hours by a patient with an ES crash injury.
(Bekhit et al., 2020)	Auckland, New Zealand	Quantitative and descriptive analysis	ES related injuries have had a significant impact on regional healthcare costs.
(Bloom et al., 2021)	USA	Quantitative analysis from an urban hospital network	Loss of balance was the most common cause of injury. Most incidents occurred in the street. Facilities costs were greater for patients under the influence of alcohol and marijuana.
(Che et al., 2021)	Singapore	Risk perception evaluation via virtual reality (VR)	Risk perception is positively correlated with anger level. ES riders rated increasing safety with decreasing riding speed, but 10 km/h was relatively slow. The lack of a clear code of conduct was touted as a key contributory factor in pedestrian-ES crashes.
(Cicchino et al., 2021)	Washington D.C., USA	Logistic regression to examine the association of incident location and circumstances of injured ES users	The most common locations of ES injuries occurred on the sidewalk (lower severity) or road. Greater injury severity for riders injured on the road may reflect higher travel speeds.

Authors & year	Location	Methods	Key findings
(Dhillon et al., 2020)	Southern California, USA.	Quantitative and descriptive analysis using Trauma registry data from January to December 2018	Injuries from electric scooter crashes are primarily to the head, face, and extremities, with approximately 1 in 5 patients requiring ICU. Helmet use was uncommon.
(English et al., 2020)	Austin, Texas, USA.	Quantitative and descriptive analysis	Falling from the scooter was the most common crashes, and males' young adults were the most involved in these accidents.
(Faraji et al., 2020)	San Diego, USA	Quantitative and descriptive analysis using single-institution craniofacial injury data	Most patients with craniofacial trauma sustained an acute bony fracture, most often to the midface.
(Lavoie-Gagne et al., 2021)	San Diego, USA	Multivariable regressions of characteristics of patients (n = 442)	Factors with a higher likelihood of hospital admission included age > 40 years, alcohol or other substance intoxication, loss of consciousness, or transport to the hospital by ambulance.
(Ma, Yang, Mayhue, et al., 2021)	Norfolk, Virginia, USA.	Adding a mobile sensing system to an ES to data collection to understand riding risk associated with E-Scooters on different facilities	Compared to bicycle riding, DSES presented more vibration events. Riding on concrete pavement is riskier than asphalt. Riding on both sidewalks and vehicle lanes can encounter high-frequency close contacts in terms of proximity with other objects.
(Moftakhar et al., 2020)	Vienna, Austria	Quantitative and descriptive analysis	ES injuries should be considered high-energy trauma affecting primarily head and upper extremity.
(Mukhtar et al., 2021)	Indianapolis, USA	Observational study of imaging exams (n = 192)	The median patient age was 28 years and 58.3% were male. The most common injuries were soft tissue and musculoskeletal in nature. ES accidents are common and frequently involve the face and extremities.
(Nellamattathil & Amber, 2020)	Washington, D.C. USA	Descriptive analysis utilizing health system's radiology database	Musculoskeletal injuries were the predominant form of scooter injury.
(Puzio et al., 2020)	Indianapolis, Indiana, USA.	Quantitative and descriptive analysis using trauma center's data	Substantial increase in the number of scooter-related injuries during the first two months of electric scooter legalization. Lack of safety equipment utilization and concomitant alcohol utilization.
(Rix et al., 2021)	Austin, Texas, USA.	Vehicle-miles-traveled base injury rate for ES and motor vehicle.	The observed VMT-based ES injury rate was approximately 175 to 200 times higher than state-wide or county-specific injury rates for motor vehicle travel.
(Sikka et al., 2019)	Washington, DC, USA.	Descriptive analysis of pedestrian injuries by e-scooters	Pedestrians injured in ES collision were mainly children and the elderly. Most injuries were mild to moderate in severity, and the most commonly injured body parts were extremities, head, face and neck. Pedestrians were more severely injured compared to ES riders.
(Smit et al., 2021)	Christchurch, New Zealand	Quantitative and descriptive analysis using ES facial injury records during a 17-month period	Most patients were male, aged between 20-39 years. A total of 30 patients with ES-related facial injuries were referred to the maxillofacial service and required a total of 23 operative procedures. The total estimated cost for the treatment of patients was $298,054 NZD.

Authors & year	Location	Methods	Key findings
(Tuncer et al., 2020)	Paris, France	Video recordings for quantitative and descriptive analysis of ES users riding behavior	ES users do not stop at red traffic lights and, in dense traffic, slow down to blend in with pedestrians and keep moving.
(Wilhelm et al., 2021)	Berlin, Germany	Naturalistic observation study (n = 2972) and a survey (n = 156)	Only one third was able to identify the braking system of the ES. Right hand and foot brake levers were used less frequently than the left one. There is a lack of knowledge about ES regulation and illegal behavior by riders.
(Yang et al., 2020)	USA	Mining news for descriptive analysis and cross tabulation analysis	169 ES involved crashes identified. Mostly due to collisions with vehicles. Most accidents occur on arterial roads and involve men.
(Haworth et al., 2021a)	Brisbane, Australia	Chi-square test and quantitative analysis	Illegal behaviors are much less common for private ES than DSES use and demonstrate a move from shared to private ES over time.
(Stigson et al., 2021)	Sweden	Descriptive statistics and Chi-square test	Most of the injuries associated with ES occurred in single crashes. The overall large proportion of injuries to the head and face.
(Gioldasis et al., 2021)	Paris, France	Logit and mixed logit specifications and a structural equation model	Empirical evidence suggests that it is more likely for young and male ES riders to develop risky behaviors. Longer trip durations seem to be associated with risk-taking behaviors.
(Kobayashi et al., 2019)	USA	Descriptive statistics, Pearson X^2 Test, test-t and Mann-Whitney test	Alcohol and illicit substance use among ES users injured was common and helmet use was extremely rare. Significant injuries, including intracranial hemorrhage and fractures requiring operative intervention, were present in over half (51%) of patients.

4.7. Policies and regulations

Several policies and measures have been proposed to regulate DSES operation and overcome the primary concerns. Rules vary by city, as Table 8 shows. Most regulations are safety-related. However, operational policies, including integrating with the current mobility network and infrastructure availability, have not been adequately addressed or implemented. Some authors argue the convenience to boost the DSES potential to reduce private car dependency and progress in multimodal integration. (Singh, 2020).

Studies on this topic have sought to make recommendations to municipalities and public institutions, seeking to improve safety, accessibility and exploit the potential of DSES use are in Table 9. In this review, we did not find recommendations related to insurance coverage for users.

Table 8. DSES regulations summary. (Table view)

City	Where is it allowed to ride			Helmet required	Minimum age	Driver's license	Speed limit
	Roadway	Bike lane	Sidewalks				(km/h)
Santa Monica	Yes (b)	Yes (a)	No	No	16	Yes	24.14
Miami	Yes	Yes	Yes	No	18	No	24.14
Detroit	Yes (b)	No	Yes	Yes (g)	12	–	40.23

City	Where is it allowed to ride			Helmet required	Minimum age	Driver's license	Speed limit
	Roadway	Bike lane	Sidewalks				(km/h)
Austin	Yes (b) (c)	Yes	Yes	Yes (f)	16	No	32.19
Calgary	No	Yes	Yes	Yes (f)	16	No	24
Paris	Yes (d)	Yes	Yes	No	12	No	25
Madrid	Yes	Yes	No	No	15	No	20
Auckland	Yes	Yes	Yes	No	16	–	16
Santiago	Yes €	Yes	No	Yes	14	No	25
Bogotá	Yes €	Yes	No	Yes	14	No	20
Buenos Aires	Yes €	Yes	No	–	16	No	25

Note: (a) Except in beach bicycle paths. (b) Only if the road speed limit is under 40.23 km/h. (c) Only if the road has 4 lanes or less. (d) Only if the road speed limit is under 50 km/h. (e)Only if there is not a bicycle lane. (f) Under 18 years old. (g) Under 19 years old. *Source:* Municipal Transportation Departments official rules and regulations.

Table 9. DSES policies and regulations papers review. (Table view)

Authors & year	Location	Methods	Key findings
(Anderson-Hall et al., 2019)	USA	Manual review of policies, programs, and regulations	Summary of fares, regulations, vehicle specifications of ES.
(Gössling, 2020)	Brisbane, Christchurch, Copenhagen, Dallas, Los Angeles, Málaga, Paris, Stockholm, Vienna, Zurich.	Mining news (n = 173)	Recommendations: establishing maximum speeds, mandatory use of bicycle infrastructure, and dedicated parking, as well as limiting the number of licensed operators.
(Ma, Yang, Ma, et al., 2021)	USA	Manual review of E-Scooter user guidelines	Municipalities should introduce guidelines for parking, riding, sharing road space and speed limits driven by quantitative performance metrics.
(Moran et al., 2020)	Vienna, Austria	Spatial analysis	The public sector should define the areas of operation, the number of operators and guarantee that this service is offered to peripheral areas.
(Reck et al., 2021)	Zurich, Switzerland	Modal choice model estimation	Mode choice is dominated by distance and time of day. Docked modes are preferred for commuting. Docking infrastructure for currently dockless modes could be vital for bolstering micromobility as an attractive alternative to private cars.
(Moran, 2021)	San Francisco, USA	Spatial analysis and regulatory review	ES operators were present in the city's dense zone. Many areas with lower density and primarily residential did not have access to these shared vehicles. The regulatory approach does not challenge the preference of operators in centering geofences in dense zones.

Authors & year	Location	Methods	Key findings
(Riggs et al., 2021)	USA	Reviewing regulations and policies	Policies have the potential to constrain or accelerate the market adoption of ES and that very few communities are designing and adopting environmental strategies to regulate ES use.

4.8. Covid-19 impacts on DSES

DSES has not been an exception to the SARS-CoV-2 (Covid-19) impacts. Most companies suffered a significant decrease in their operations. Micromobility Industries (2020) compared the percentage variation of app usage per company, showing the quarantine effect clearly (Figure 6). The impact has been different among companies, i.e., while Tier, Bird or Voi recovered quickly after April, Grin (Grow Mobility) stopped its operation, probably because of the lengthy lockdowns in South America.

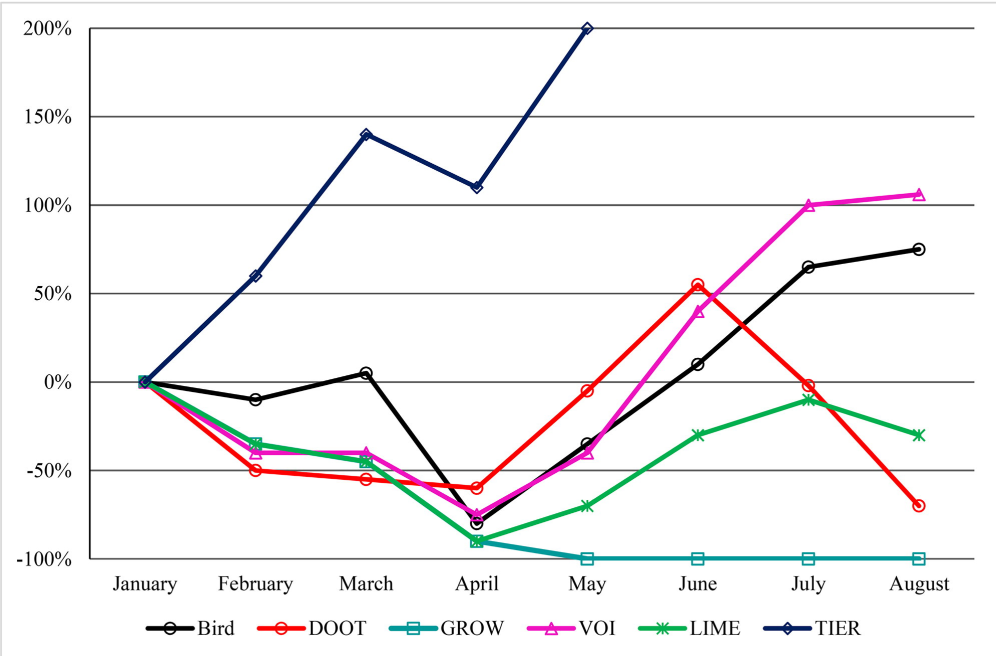

Figure 6. Covid-19 impact on DSES companies Source: Micromobility Industries (2020).

In Bogotá, Grin (Grow mobility) and Movo were among the leading DSES companies. Nevertheless, the pandemic forced them to modify their operational scheme. Firstly, they rented the vehicles by the month, but it did not work. After that, they ended up selling their vehicles by August 2020 (Caracol Radio, 2020). A similar situation happened in Buenos Aires, where companies reduced their fleet or suspended operations (La Nación, 2020). However, in a study conducted in Riyadh, Saudi Arabia half of respondents believed that Covid-19 would not affect their willingness to ride e-scooters (Almannaa et al., 2021).

5. Discussion

The review shows that e-scooters are used mainly for short trips (between 1 and 2 km). They compete primarily with active modes (cycling and walking), which reduces its environmental benefits. However, it has the potential to be used as a feeder (last/first mile) of public transportation systems. In this regard, possibilities are opened up for specific studies on the impact that this policy may have.

The profile of the users leans toward young men with medium and high incomes. However, there are still critical gaps in the acceptance of the technology and user behavior. The adaptation and application of psychological theories (e.g. Theory of Planned Behavior and the Technology Acceptance Model) to assess users behavior emerge as research areas of interest. Studying perceptions of risk, comfort and convenience, pro-environmental attitudes, and mimetic behavior could also be incorporated into the analysis.

The net environmental impact remains a topic of discussion. Although DSES are zero-emission vehicles, the logistics costs of distribution, the short life cycle and final disposal, coupled with the fact that the demand comes mainly from active modes, raises doubts about their sustainability as a mode of transport. Further analysis, in different contexts, on this topic is of particular interest, particularly in cities with high levels of pollution.

Deaths and injuries in crashes involving e-scooters remain a major concern. The impact, effectiveness and acceptance of policies and regulations in the use of the DSES have not been studied in depth. Furthermore, little has been explored on applying statistical models and data mining techniques to study the environmental, vehicle and human factors influencing the frequency and severity of crashes involving e-scooters.

The impact of the SARS-CoV-2 (Covid-19) pandemic has been mixed. In some cities, the demand fell sharply, while in others, the impact was minor. Uncertainty exists about post-pandemic e-scooter use. Social distancing recommendations have favored individual modes of transport. However, it is not clear whether this trend will persist over time. The intention of using DSES in post-pandemic scenarios is worth studying.

A topic of discussion is whether e-scooters should benefit from the facilities offered to active modes, for instance, on using dedicated infrastructure and accessing exclusive areas for pedestrians and cyclists. Monitoring and evaluation of pilot programs can shed light on this.

6. Conclusions

The number of research papers about these vehicles is growing. Since the beginning of 2021, as previously shown, most papers are related to user and trips characteristics, followed by safety papers (the majority from health journals), while papers related to environmental impact and policies are few, showing a necessity to conduct more studies on these topics. This systematic review of DSES and ES shows that, although this is a relatively novel mode of transport, it has proved to be the most successful electric micromobility system to date, according to their growth in use and acceptance, surpassing all other EM initiatives with 86 million trips in 2019 (pre-pandemic).

However, being dockless makes it an expensive mode of transport (because of operational costs). Hence, it does not favor transport equity and could widen social and territorial inequalities (STI). Also, there are gender, income, and age gaps among users. They are mostly young male adults with a high income (or above the average), in most cities DSES are limited to certain areas, so its limited coverage affects user accessibility. Given that users are increasingly buying their e-scooters, providing charging stations inside public transport facilities could favor their integration.

Regarding DSES sustainability, their environmentally friendly label needs to be analyzed according to the city context and characteristics, identifying which modes they are replacing, their distribution and collection logistics, and the vehicle's service.

On the other hand, the review shows that, contrary to the premise of DSES capability to improve urban mobility issues such as congestion by attracting private car users, they come mainly from public transport, walking, and cycling. From our perspective, one of the biggest potential contributions from DSES to urban mobility is the possibility to be integrated not only with public transport but with ride-hailing services (given the willingness its users to use ES (Almannaa et al., 2021)) as a crucial step to eliminate MaaS implementation barriers (Butler et al., 2021).

Being dockless has proven to be the reason why these systems succeed. However, in high-density areas with high traffic and pedestrian volumes, designated parking areas should be implemented to avoid public space invasion, blocked paths and conflicts with other road users, offering a "semi-dockless" service, (Zou et al., 2020) as DSES share public space with other transport modes. Moreover, DSES accidents are mainly falling and collisions with fixed objects. DSES accidents are usually mild; however, they primarily affect the head and face. Another safety-related issue is improper use (e.g., more than one person on a vehicle or riding while intoxicated).

Authorities must design appropriate policies and requirements for both companies and users to be fulfilled before operating or riding these vehicles. The number of individual collisions and falls is much higher than in bicycles, perhaps because of its limited maneuverability and the fact that users do not need any skill to ride, making them prone to quickly lose control (it is much easier to fall from a scooter than from a bicycle). Wearing a helmet and implementing speed limits while restricting riding them on the sidewalk should be explicitly analyzed in future research, as well as vehicle safety elements such as turning and braking lights, and rearview mirrors. DSES need to have a standardized regulation of its operation internationally, such as private cars, and with this, being able to report crashes adequately to create specific databases.

As cars did many years ago, DSES have the potential to reshape cities, their operation could modify land use and travel patterns, helping achieve the 15–minute cities goal, which is on the agenda of many cities worldwide.

Further research is still needed on this topic. Assessing the impact of regulatory policies on travel behavior; determining variables influencing DSES choice; conducting elasticities analysis regarding distance and costs; conducting specific studies on crashes related to frequency and severity; designing integration with public transport systems within the MaaS concept; as well as considering the influence of attitudes and perception on user behavior could become helpful tools for policy-makers. Also, there are no specific infrastructure design guides for this type of vehicle and successfully integrating them with the existing urban infrastructure.

Notes

1. Whose objective is to provide a standardized way for municipalities or other regulatory agencies to collect ingest, compare and analyze data from mobility service providers focused on dockless e-scooters, bicycles, mopeds and carshare.
2. Image created by the authors using Inkscape software
3. OECD series correspond to constant prices USD exchange rates.

Disclosure statement

The authors reported no potential conflict of interest.

Funding

The Universidad Militar Nueva Granada funded this article through research grant number INV-ING-3187.

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