



Vehicle-Sharing Services: An Umbrella Review

Timothée Mangeart, Virginie Boutueil

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Vehicle-sharing services: an umbrella review

Timothée Mangeart^{a,*}, Virginie Boutueil^a

^aLVMT, Ecole des Ponts ParisTech – Université Gustave Eiffel, 6-8 avenue Blaise Pascal, 77420 Marne-la-Vallée cedex 2, France

Abstract: The recent years have seen the rapid development of vehicle-sharing services and their diversification. An abundant scientific literature deal with many of these services on various aspects. However, the literature is often segmented by category of service and/or by topic. In order to make sense of the existing literature, we conduct an umbrella review – or a review of literature reviews – that covers all categories of vehicle-sharing services and all topics. We identify and present a synthesis of the results established in the scientific literature so far: on business models, users and trips, impacts, and regulation. Our non-segmented approach reveals the existence of results shared by categories of services often studied separately, but also of results that depends on other factors than the categories of services generally used. The research highlights the need for new research, in particular research that compare different vehicle-sharing services.

Keywords: vehicle-sharing; bikesharing; carsharing; scooter sharing; literature review; umbrella review

Declarations of interest: none

CRedit roles: Timothée Mangeart: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Writing. Virginie Boutueil: Conceptualization; Methodology; Project administration; Supervision; Validation.

* Corresponding author. E-mail address: timothee.mangeart@enpc.fr

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1. Introduction

The last decade has seen the emergence of a great diversity of new mobility services, fueled in part by information and communication technologies (ICT) – and singularly by the smartphone – (Aguilera and Boutueil, 2018) but also influenced by electric mobility (Ampudia-Renuncio et al., 2020). Because they can neither be considered as a form of public transit nor are they private vehicles, they have come to be known as “paratransit” (Cervero, 1997), or “shared mobility” because they provide the users with « the shared use of a vehicle, bicycle, or other low-speed mode that enables users to have short-term access to transportation modes on an “as-needed” basis » (Shaheen et al., 2015). Among all shared mobility services, this paper focuses specifically on vehicle-sharing services. Vehicle-sharing services (VSS) constitute a well-identified type of shared mobility services. They can be defined by expanding the definition of carsharing established by Ciari et al. (2014): vehicle-sharing services provide « a fleet of vehicles that can be shared by several users, who can drive it when they need it, without having to own one ». VSS can be traced back to several decades, mainly in the form of carsharing and station-based bike-sharing (Shaheen et al., 2010; Shaheen and Cohen, 2007; Huré, 2017), and recent years have seen an important development of such systems across the globe: it has been possible to identify more than a hundred vehicle-sharing platforms with more than 100,000 downloads on Google Play as of 2020, with services available on every continent (Boutueil et al., 2022).

These new services are often operated by actors that are new to the mobility sector and rely on new business models. Their rapid development has raised new issues, often specific to these new services, such as their use of the urban space and infrastructures, the safety of the users, the regulation of the offer, or their funding for instance. An abundant scientific literature has already been produced to try to make sense of these new services, and several literature reviews have been published, either holistic reviews or reviews that focus on specific issues (e.g., the “vehicle relocation problem”, the use of helmets in bikesharing services). However, even holistic reviews focus on specific VSS, often defined by the type of vehicle that is shared. To the best of our knowledge, the scientific literature has not produced any holistic literature review covering VSS as a whole yet. We intend to fill this gap by conducting a literature review in the form of an umbrella review, or a review of reviews, so as to take advantage of the already existing literature reviews by analyzing and synthesizing them.

The objective of this article is to offer a sweeping picture of the available scientific knowledge about VSS and to make sense of it beyond its fragmentation by topic and/or by VSS category. As mentioned above, VSS are defined through shared operational principles (or, from a customer point of view, similar value propositions); hence, comparing results established for different types of VSS in different contexts can bring new insights. Results that are found to apply for several categories of VSS may be tested and extended to other categories of VSS, including new and future categories. Such a generalization would make those results more resilient with regards to the frequent developments among VSS. A clear, broad picture of the scientific literature on VSS can also allow to identify new avenues for research on specific categories of VSS or reveal opportunities to conduct studies on competing, coordinated or integrated VSS offer. From a policymaking point of view, it is important to have access to high-quality syntheses of the scientific literature on the subject so as to establish clear strategies for the development of VSS and to build efficient and coherent policies accordingly.

In the first section of the paper, we present the methods used to select and analyze the publications reviewed and we propose a quantitative assessment of the comprehensiveness of the selected corpus. In the second section, we present the analysis of the corpus: first, the definition of the objects studied used by the authors; second, the results for each topic and sub-topic identified; and third, the recommendations in terms of future research and policies. The final section presents a discussion of

the results presented and suggestions for further research, as well as a brief discussion about the umbrella review method and its application to our object of study.

2. Methods

In order to make sense of the extensive scientific literature relative to VSS that has recently been produced, we conducted an umbrella review. An umbrella review is a type of literature review process that consists in reviewing other existing – and potentially competing – literature reviews on a given subject (Grant and Booth, 2009). Umbrella reviews are well adapted when the existing literature is abundant; however, they risk overlooking specific questions already tackled by the literature and established facts that have not been included in any literature review yet, such as orphan papers and recently published papers. As such, umbrella reviews cannot claim to represent a full-fledged synthesis of the literature on a given subject but only of its most advanced and mature avenues of research. This is especially true in the case of VSS studies, which is a rapidly expanding field of research. A quantitative analysis of the references of the selected articles is presented to assess the comprehensiveness of the literature indirectly reviewed through the umbrella review method.

2.1. Selection of articles and corpus creation

Relevant literature reviews on vehicle-sharing services were identified using the Scopus and Web of Science databases and searching in the titles and abstracts for the keywords “vehicle-sharing”, “carsharing”, “bike-sharing”, “scooter-sharing”, “shared mobility”, “new mobility”, “free-floating”, “micro-mobility”, “smart mobility” and their variations (e.g., public bike, car club) associated with the keywords “literature” and “review”. The research was performed in November 2021 and no restriction on the date of publication was applied. Among the results, we selected articles based on the following criteria (Figure 1):

- Peer-reviewed articles;
- Articles written in English;
- Articles that adopted literature review as their main (or one of their main) methods;
- Articles that summarized qualitative (or quantitative) results. We excluded purely quantitative scientometric analysis of the literature since the focus was on the results established by the scientific literature;
- Articles that had vehicle-sharing services as their main focus or one of their main focuses. We excluded articles dealing exclusively with shared autonomous vehicles as we decided to focus on research about mobility services that are already available to the public.

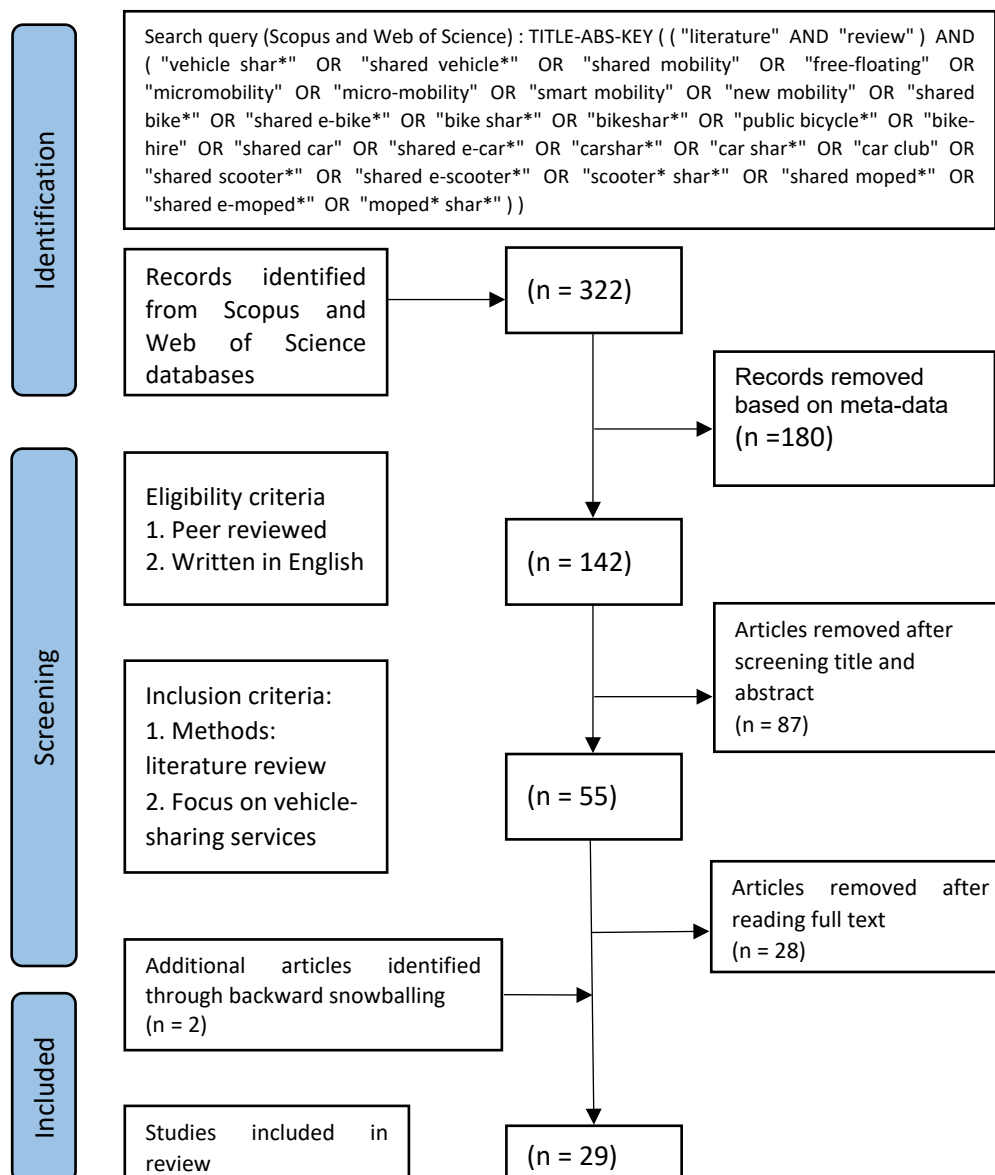


Figure 1. Selection process of the articles reviewed. PRISMA flow diagram, adapted from Page et al. (2021)

2.2. Method used to analyze the corpus

We labeled each article according to the category of vehicle sharing service (VSS) it dealt with and to the topics and sub-topics it tackled. We broke down services to 4 categories based on the type of shared vehicles: bike sharing service (BSS), carsharing services (CSS), scooter-sharing services (SSS), and moped-sharing services (MSS). Some authors used different definitions, whether broader (e.g., micromobility, shared mobility) or narrower (e.g., electric carsharing, free-floating bike sharing...). The present typology was intended to make comparisons between articles easier. Then, we determined sub-topics through a bottom-up approach: we did not use any pre-determined analysis grid and relied instead on the sections used by the authors themselves to present their results. A total of 11 sub-topics were identified; they were subsequently grouped in 4 broader topics that we established ourselves (Table 1).

2.3. Corpus description

The selection process resulted in a selection of 29 articles. Among them, 8 deal with 2 or more categories of VSS. In total, 19 deal with BSS, 13 with CSS, 8 with SSS, and 1 with MSS. 6 articles also include results on other mobility services or vehicles, such as ride-hailing or private micromobility. Each topic is covered for each category of VSS by at least one literature review from the selected corpus, except for MSS for which the only review we identified covers one sub-topic only, namely design and operation (Table 1).

19 of the 29 articles reviewed were published in 2020 or later, whereas only 3 were published before 2018. This confirms that VSS are a recent focus of the scientific literature. The top 3 journals are *Sustainability* (6 articles), *Transport Reviews* (5 articles) and *Sustainable Cities and Society* (2 articles); no other journal has more than 1 article in the selected corpus.

The scientific literature on VSS is overwhelmingly concentrated on services in North America, China, and Europe. There are also mentions of services in Oceania, Asia and South America. Africa is virtually absent. 6 of the 29 articles indicate a geographic focus as an element of their method for selecting the reviewed articles. It has been possible to assess the geographic focus of 12 other articles of the selected corpus either because the authors present an analysis of the location of the articles they reviewed (8), or because there were multiple studies for which the location was mentioned (4). Among the 11 articles for which it was not possible to assess the geographic focus, 7 deal entirely or mainly with modeling issues (which are not necessarily location-specific). In total, 4 articles of our corpus focus on North America, 2 on Asia and 1 on Europe, and 11 cover 2 or more world regions, either by design or as a result of the scientific literature reviewed (Annex 1).

Topics and sub-topics / Category of VSS	BSS	CSS	SSS	MSS	Total
Total	19	13	8	1	29
<i>Business models, design and operations</i>	13	10	3	1	19
History and business models	7	7	2	0	12
Design and operation	8	7	1	1	12
<i>Users and trip analysis</i>	7	6	5	0	14
Users' profiles	6	5	4	0	11
Motivations to membership and usage	7	5	4	0	12
Trips analysis	7	5	5	0	13
<i>Impacts</i>	8	4	2	0	12
Impacts on other modes of transport	6	4	1	0	9
Environmental impact	3	2	2	0	5
Public health, safety, physical activity, and well-being	8	1	2	0	9
Accessibility and social equity	3	3	1	0	5
Economic impact of VSS	2	0	0	0	2
<i>Regulation</i>	6	2	3	0	9

Table 1. Topics and sub-topics covered by the selected corpus for each VSS category

2.4. Comprehensiveness of the corpus: a quantitative analysis

The point of choosing the umbrella review methods is to indirectly review a greater number of publications than would have been possible with a regular literature review. This section is dedicated to assessing to what extent the selected corpus meets this objective. In order to do so, we compared two sets of articles:

- The “primary references” set contains the references of the 29 articles of the corpus selected for the umbrella review. They were obtained thanks to the “view references” tool available in Scopus. This set contains 2041 references.
- The “general corpus” set contains references obtained through Scopus with a query adapted from the query used to identify the literature reviews: the same keywords were used, bar “literature” and “review”, and the same parameters were used. This set contains 7244 references.

A first analysis revealed that the two sets share 672 articles in common. At first glance, this can be disappointing as this means that less than 10% of the general corpus has been indirectly reviewed through the umbrella review method. Several observations tend to qualify this finding. First, the keywords used to create the “general corpus” were broad – as shown by the high exclusion rate presented earlier – and many articles of the database may in fact not be relevant for the present study. Secondly, the umbrella review method is by construction unable to take into account the most recent literature, which is all the more significant as the VSS field of study is rapidly growing (Figure 2). 1328 articles of the “general corpus” set (18%) were published in 2021 or 2022, against only 37 articles of the “primary references” set (2%). For the 2010-2020 time period, the number of “primary references” included in the “general corpus” set is 624, against 4264 articles published in the same time window for the “general corpus” set, or a more satisfying 15% rate. Thirdly, insofar as the number of citations is a relevant indicator for quality, the articles of the “primary references” set have a better quality overall than the articles of the “general corpus” set. 517 of the 672 articles included in both set of articles, or 77%, have been cited more than 10 times (and 104 or 16% have been cited more than 100 times), against 2988 or 41% for the “general corpus” set (348 or 5% have been cited more than 100 times). Another way to put it is that 517 of the 2988 most quoted articles (or 17%) of the “general corpus” set have been indirectly reviewed through the umbrella review.

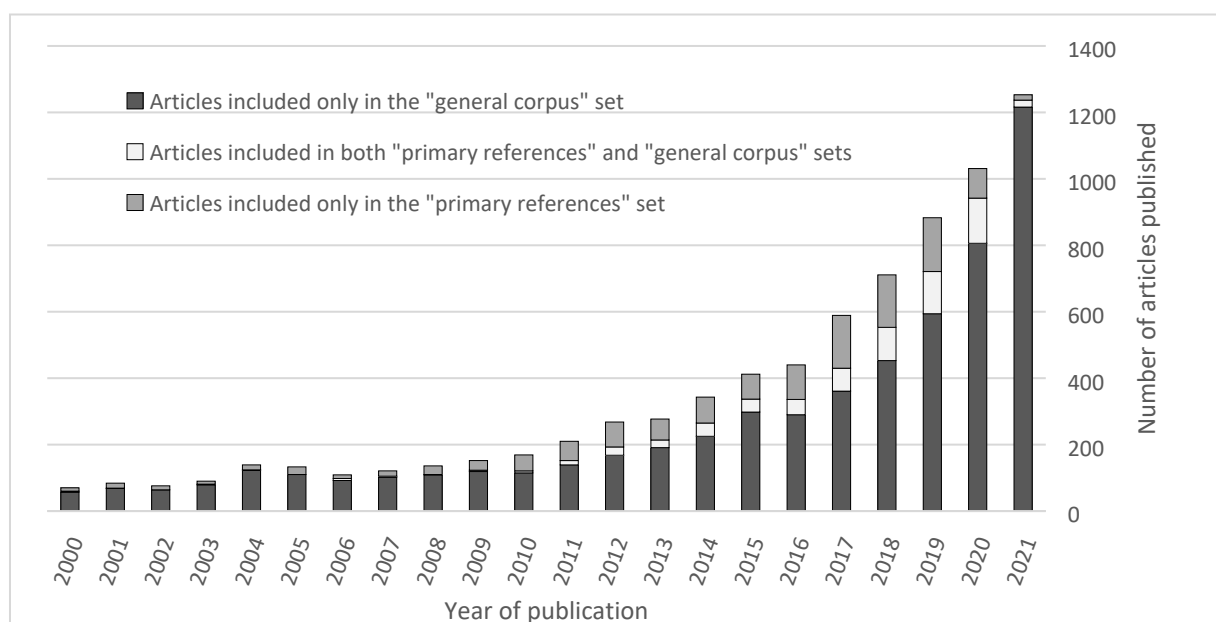


Figure 2. Number of articles published each year in the two sets of articles described for the 2000-2021 period

Of the 2041 articles of the “primary references” set identified thanks to Scopus, 1369 (67%) were not included in the “general corpus” set (or at least it was not possible to identify a match based on the data automatically retrieved through Scopus). Two reasons may explain this. First, the literature reviews of the selected corpus quote articles that are not related to VSS: they may be articles used to

justify the methods used, or articles covering broader subjects to introduce a concept for example. Second, several primary references may be gray literature (or non-peer-reviewed literature). This would be consistent with two facts: 353 of the 1369 articles (26%) were not quoted (they would be gray or non-peer-reviewed literature); and 408 of the 1369 articles (30%) were quoted more than 100 times (they would be methodological or theoretical articles).

Among the 2041 articles of “primary references” set, 415 (20%) have been included by two or more of the literature reviews of the selected corpus, and 1641 (80%) have been reviewed only once. The top 3 articles most quoted by the literature reviews of the selected corpus are Fishman et al. (2013), DeMaio (2009), and Nair and Miller-Hooks (2011) ; they were quoted by 9, 9, and 8 literature reviews of the selected corpus respectively.

3. Analysis of the corpus

This section is organized in three parts. First, we compare the definitions and typologies used by each article to define the category of services studied. Second, we present the results established for each of the 11 identified topics. Finally, we sum up the avenues for further research put forward in each article.

3.1. Definitions and typologies used in the corpus

All the papers included in this study focus on one or several categories of vehicle-sharing services. Although not every article features a clear definition of their object of study, all the definitions put forward have in common the idea of a shared fleet of vehicles that users can rent for a trip or a short period of time on an as-needed basis.

21 out of 29 articles included in the review focus on one specific type of shared vehicle, whether bike, car or scooter, with only 8 articles focusing on two or more types of shared vehicle.

In his literature review, Fishman (2016) defines bike sharing systems (BSS, or bike-share programs, BSPs), as “the provision of bikes, which can be picked up and dropped off at self-serving docking stations.” However, this definition does not include dockless BSS. Teixeira et al. (2021) included dockless BSS in their review and extended the definition to include both categories of BSS: “BSS consists in the short-term renting of bicycles distributed across a network of stations (docked systems) or predefined operational areas (dockless systems), typically in an urban setting, enabling low-cost point-to-point trips”.

Some articles of the corpus focus on specific sub-categories of carsharing services (CSS) according to their operation model (one-way, two-way, free-floating) (e.g. Jorge and Correia, 2013) or to their market model (B2C, B2B, Peer-to-peer...) (e.g. Kent, 2014). Nansubuga and Kowalkowski (2021) further clarify the distinction between CSS and car rental established by prior research: “Unlike traditional car rental and leasing, carsharing relies on platform mediation to identify appropriate matches between provider resources and users and to facilitate exchange (Eckhardt et al., 2019). While car rentals require a contractual agreement each time one rents a car, carsharing typically requires a membership and subscription.”

Scooter-sharing services (SSS) suffer from a “terminological clash” (Bozzi and Aguilera, 2021): standing scooters, or kick scooters, are “electrically powered vehicles with a handlebar, deck, and wheels. They are light (less than 35 kg), travel at a relatively low speed (about 25 km/h), and usually carry only one person (the driver)” (Bozzi and Aguilera, 2021). Indeed, “e-scooters should not be confused with small, electric motorbikes on which the rider sits and are also sometimes called electric scooters”, best referred to as mopeds (Button et al., 2020).

Ataç et al. (2021) are the only authors of the selected corpus to make no distinction between the types of vehicle in the fleet and to consider vehicle sharing services (VSS) as a whole. Machado et al. (2018) grouped bike-sharing services and carsharing services in the “shared mobility” category together with ridesharing (carpooling, vanpooling) and on-demand ride services (ridesourcing, ridesplitting). Santos (2018) noted that the “shared mobility” concept he has used is a “loose concept” – just like the “shared economy” concept to which it refers. Santos (2018) defines it as “the sharing of a vehicle instead of ownership, and the use of technology to connect users and providers”, adding the criterion of the technology to prior definitions.

Several articles of the corpus defined their object of study as “shared micromobility”, or sometimes simply as “micromobility” even though they focused on shared vehicles and devices. Button et al. (2020) remarked that there was no agreed definition of micromobility, and their paper is the only one of the selected corpus to exclude bicycle from the micromobility category. In most cases, the authors defined micromobility by the speed (less than 45 kmph) and weight of the vehicles (less than 350 kg, less than 500 kg). Liao and Correia (2020) added the criterion of the distance traveled: less than 15 kilometers. Micromobility generally included both scooters and bicycles, whether electric or human powered, as well as other vehicles such as – depending on the authors – skateboards, gyroboards, hoverboards, segways, e-skateboards, one-wheeled balancing boards, unicycles, pedelecs, e-mopeds or four-wheeled electric micro-vehicles. Among all these vehicles, only e-scooter, e-bicycle, bicycle and e-moped sharing services are studied in the selected corpus.

3.2. Research topics presented in the corpus and main associated results

In this section, we summarized the results presented in the corpus for each of the 11 identified sub-topics.

3.2.1. Business models, design and operation: understanding the development of a recent and diversified category of mobility services

19 of the 29 articles in the selected corpus deal with the business models, design features and operational issues of VSS, including 9 that focus mainly or exclusively on those topics. In particular, 6 literature reviews included in the corpus focus specifically on the modeling literature. The 19 articles reviewed in this section cover BSS, CSS and SSS.

3.2.1.1. *History of VSS and variety of their business models*

3.2.1.1.1. *Carsharing services: a pioneering and diversified category of VSS*

The Sefage cooperative that started its operation in 1948 in Switzerland is identified as the first carsharing service, with similar services being operated in Europe in the following decades (Shaheen et al., 1999). However, the development of commercial CSS is much more recent and dates to the end of the 2000s or the beginning of the 2010s, affecting Europe, but also North America and Asia (Nansubuga and Kowalkowski, 2021; Golalikhani et al., 2021; Calderón and Miller, 2020).

It appeared from the literature that two different criteria were used to categorize the business models of CSS. These criteria could be used separately, or they could be combined.

- *Market model.* CSS businesses can sell their services directly to consumers (B2C model), or to other businesses (B2B model); they can be platforms that allow car owners to rent their car directly (P2P model); or they can be cooperative/non-profit networks (Coop model) limited to a defined group of users (Nansubuga and Kowalkowski, 2021; Golalikhani et al., 2021). Machado et al. (2018) have distinguished general carsharing from personal vehicle sharing

(PVS) where privately-owned vehicles are shared, either through P2P platforms or via fractional ownership, a specific form of cooperative where only members of the cooperative can access the service. Calderón and Miller (2020) have noted that P2P CSS are “operationally different” from other CSS from a modeling point of view since the person who share their car is a different agent from the person who rents it (they are not peers).

- *Operation model.* CSS can be segregated according to their operation model. The scientific literature distinguishes three operation models (Golalikhani et al., 2021; Ferrero et al., 2018; Calderón and Miller, 2020; Machado et al., 2018):
 - Two-way CSS: vehicles are parked at designated stations and must be returned to their pickup stations.
 - One-way CSS: vehicles are parked at designated stations but can be returned to any other station within the operation area.
 - Free-floating CSS: there are no designated stations and vehicles can be picked-up and returned anywhere within the operation area.

However, the authors noted that other factors affect the business models of CSS, such as the pricing strategy, the incentives and penalties for certain customer behaviors, the registration process, the reservation process, the parking policy, the incorporation of technologies (user interface, methods for accessing the vehicles), the fleet characteristics (fleet size, types of vehicles, type of energy used by the vehicles) or the type of organization (company, non-profit) that operates the CSS (Nansubunga and Kowalkowski, 2021; Golalikhani et al., 2021; Ferrero et al., 2018). These factors can be combined to define different categories of CSS business models (see e.g., Shaheen and Cohen, 2013; Remane et al., 2016). Furthermore, Nansubunga et al. (2021) noted that “service providers offer carsharing services for different reasons. Among profit-driven ventures, pure B2C and B2B service providers are motivated mainly by the desire to make a profit on their services, while car manufacturers offer carsharing services mainly to expand their market and to explore untapped niches (Bellos et al., 2017; Perboli et al., 2018)” (Nansubunga et al. 2021).

3.2.1.1.2. *Bike-sharing services: A debated generational divide*

In their comprehensive scientometric analysis of the BSS literature, Si et al. (2019) underlined the centrality of the work of Shaheen et al., whose 2010 article (Shaheen et al., 2010) was the most cited among Si et al.’s pool of articles. In this study, Shaheen et al. (2010) defined 4 “generations” of BSS (Table 2). “White Bikes”, launched by the political movement Provo in Amsterdam in 1967, is recorded as the first bikesharing service and representative of the 1st generation (Shaheen et al., 2010). A few similar services were offered in the following decades. The first coin-deposit BSS (2nd generation) was launched in Copenhagen in 1991. 3rd generation BSS, which included smart cards to unlock the bicycle, soon followed, e.g., in Copenhagen (1995) and Rennes (1998). At the time of writing, Shaheen et al. (2010) anticipated a 4th generation that would be more flexible thanks to a greater use of technologies. For Nath and Rambha (2019), “the fourth-generation bikes came into existence in 2005 with the Velo’v program in France”. Thus, Nath and Rambha (2019) and Si et al. (2019) suggested adding a 5th generation to take into account the then new free-floating BSS (e.g., Ofo, Mobike) (Si et al., 2019). However, Hirsh et al. (2019) and Roukouni and Correia (2020) considered that free-floating BSS are in fact the 4th generation anticipated by Shaheen et al. (2010). Zheng and Li (2020), for their part, chose to use the concept of “categories of activities” that can largely be intersected with the “generations” (Table 2). Calderón and Miller (2020), although having published their article in 2020, described only one category of BSS: one-way, station-based BSS “where users can retrieve bicycles in any dock and return them to any other dock within the service area”, which could correspond to the 3rd and 4th generation of BSS, and which was indeed virtually the only existing BSS during the 2010-2016 period.

Finally, Roukouni and Correia (2020) were the only authors of the corpus to include personal vehicle-sharing (PVS) and bike-lease systems as other models of bikesharing.

“Generation”	“Category of activity”	Main characteristics	Examples	Source
	(1) Bike rental	Staffed stations, two-ways service		Zheng and Li, 2020
1- White bike	(2) White bikes	No station, free (no lock)	Witte Fietsen, 1965 (Amsterdam) ; Vélos jaunes, 1976 (La Rochelle)	(2010)Shaheen et al., 2010 Zheng and Li, 2020
2- Coin deposit system	(3) Coin deposit BSS	Stations, lock, no smart system	Bycyklen, 1991 (Copenhagen)	Shaheen et al., 2010 Zheng and Li, 2020
3- IT-based system	(4) Automated station BSS	Stations, smart lock system, membership	Vélo à la carte, 1998 (Rennes)	Shaheen et al., 2010 Zheng and Li, 2020
4- 4 th generation		Stations, smart lock system, smart kiosks membership, electric bikes, public transit integration	Vélib’ 2007 (Paris)	Shaheen et al., 2010 Zheng and Li, 2020
5- Free-floating BSS	(5) Dockless BSS	Dockless, smart lock system, data driven, commercial	Ofo, 2014 (Peking University) Mobike, 2016 (Shanghai)	Si et al., 2019 Zheng and Li, 2020

Table 2: “Generations” and “Categories of activity” of BSS, adapted from Shaheen et al. (2010), Si et al. (2019) and Zheng and Li (2020)

Although the categorization of BSS is debated, the authors agree on the use of operational (docks) and technological elements (smart locks, electric motors) as the relevant criteria on which to base their categories.

3.2.1.1.3. Scooter-sharing services: the latest VSS development

Both Button et al. (2020) and Dias et al. (2021) identified the Bird scooter-sharing service launched in 2017 in Santa Monica, California (USA) as the first scooter-sharing service. Button et al. (2020) advanced two arguments to identify scooter-sharing services (SSS) as an improvement on BSS and their continuation: they were launched in California soon after the first free-floating bikesharing services in 2013 (5th generation, Table 2), and they address the same market as bikesharing services (the authors thus rejected their qualification as a “disruptive innovation” based on Bower and Christensen (1995) definition). Button et al. (2020) also identified an evolution among SSS: operators were beginning to rely on models dedicated to sharing (as opposed to dedicated to private use) so as to make the maintenance easier, to improve the safety when used, and to increase the range of the scooter. This is an example of the existence of strong links between different categories of VSS.

3.2.1.2. Design and operation of VSS: a problem thoroughly studied by the modeling literature

The technical characteristics of VSS bring new design and operation issues with a “much higher level of detail than conventional transportation modes” (Calderón and Miller, 2020). Ataç et al. (2021), Bahadori et al. (2021), Nath and Rambha (2019), and Illgen and Höck (2019) have classified the different issues as *strategic*, *tactical*, and *operational* according to the time horizon in which these issues can be dealt with, corresponding roughly to one year, one month, and one day respectively (Golalikhani et al., 2021 only distinguished between strategic and operational issues). Issues at different time horizons can interact.

In total, we identified 6 literature reviews that focused specifically on the design and operation issues of VSS, and 6 additional reviews that included at least some references to the design and operation issues of VSS. These were exclusively prescriptive research (i.e., research on what ought to be done, as opposed to descriptive research that analyses what is actually being done), often based on modeling techniques. Since these researches use a broad definition of VSS and VSS-related issues based on basic operational features shared by all types of vehicles, the design and operation issues of VSS could be studied independently of the category of VSS (CSS, BSS, SSS, MSS), and several authors tackled several VSS categories at the same time (e.g., Ataç et al., 2021; Calderón and Miller, 2020; Laporte et al., 2018). However, some design and operation issues only apply to certain categories of VSS. For instance, most station-related issues are not relevant to free-floating VSS, including SSS. They may however be useful for semi-floating VSS, where free-floating vehicles are to be stationed within designated parking spots. Relocation operations are not needed for two-way services, as vehicles will always be returned to their original location by the users. Vehicle charging issues are only relevant to electric VSS (fossil-fuel VSS have their own operational constraints).

An overview of those literature reviews allowed to list the main topics a VSS operator can be confronted with when planning and designing its service, as identified by the scientific literature:

- Station-related design issues (strategic level): locations of stations – including the “buffer zone” of each station (Eren and Uz, 2020) –, station capacity, and total number of stations. Bahadori et al. (2021) also explored methods to determine where to add new stations within an existing network of vehicle-sharing stations.
- Vehicle-related design and operation issues, including fleet sizing and management (tactical level). For one-way VSS, after determining the optimal fleet size and its features (motorization of the vehicles, unlocking technologies, vehicle reservation options), relocation operations need to be carried out to correct the imbalance in the vehicle distribution across the operation area due to the use of vehicles by customers: this is the vehicle relocation problem. There are three broad types of relocation strategies (Nansubuga and Kowalkowski, 2021; Cao et al., 2021; Ataç et al., 2021):
 - User-based relocation: the user themselves are incentivized to reposition the vehicles in the desired locations, mainly through price incentives.
 - Operator-based relocation: dedicated teams drive the vehicles back to the desired location to maintain the balance. Operator-based relocation strategies can be either static, if the operations are held while the system is inactive (at pre-defined times, during off-peak hours), or dynamic, if the relocation is done in real-time. Nath and Rambha (2019) propose another division of operator-based relocation strategies: offline and online. Offline relocation refers to strategies that rely on pre-generated relocation patterns, while online relocation refers to strategies that use real-time data about usage and stock imbalance to determine which rebalancing operations should be performed.
 - Hybrid relocation: a mix of user-based and operator-based relocation strategies.

- Long- and mid-term demand forecasting, including to inform fleet sizing (strategic and tactical level) (Ataç et al., 2021).
- Short term demand forecasting, including to inform vehicle relocation operations (operational level). It can be either dynamic (in real-time) or static (based on pre-generated patterns) (Ataç et al., 2021).
- The pricing strategy, that has an influence on overall demand and on demand forecasting (tactical level). It can be used as a tool in user-based relocation strategies, as mentioned above (operational level) (Ataç et al., 2021; Nansubuga and Kowalkowski, 2021; Laporte et al., 2018).
- Staff- and maintenance-related issues, including the number of staff, the maintenance and charging strategy, and the routing of relocation and maintenance teams (operational level) (Ataç et al., 2021; Nansubuga and Kowalkowski, 2021).

The description and comparison of the different algorithms used to optimize the design and operation of VSS and how the different issues presented above interact is out of the scope of this article. For detailed literature reviews that focus on this subject, see Ataç et al. (2021), Bahadori et al. (2021) (focused on the station location problem both at the strategic and tactical levels), Vallez et al. (2021) (focused on the operational vehicle relocation problem), Illgen et al. (2019), Nath and Rambha (2019), and Laporte et al. (2018).

3.2.1.3. Intermediary discussion

The literature on the development of VSS is much structured by the type of vehicles that are shared. The criteria used to characterize VSS are often the same irrespective of the category of VSS: mainly the operation models (station-based/free-floating, 1-way/2-way) and the market model (B2C, B2G2C, P2P...), and to a lesser extent the type of motorization used (electric VSS). These criteria are also the most relevant for design and operation issues. The justification for the segmentation of the approach on VSS by category (BSS, CSS, SSS, MSS) are limited, in particular when the market trends seem to go towards the integration of the sharing of different vehicles by a single platform or operator. Concepts such as “shared micromobility”, which regroups BSS, SSS and MSS are an acknowledgement of their similarities from an operational point of view, although in our opinion there are no strong arguments to isolate CSS. Besides, the notion of “generations” of VSS may be outdated: VSS with different characteristics may coexist on the long term, as is already the case in many cities where public station-based BSS coexist with free-floating e-BSS and free-floating CSS coexist with 2-way CSS. Other features may be more important to discriminate between VSS categories, and the determining features on which to base categories depend on the point of view: for instance, public space management authorities may discriminate based on parking features, which may not be the most important feature for would-be users for instance (they would be more interested at features such as the number of seats for instance). The question of whether these different VSS correspond to different uses or users is explored in section 2.

The abundant and very detailed modeling literature on design and operation issues raises questions about the actual implementation and use of those models by VSS operators. Besides, the prescriptive, modeling literature appeared rather isolated from the descriptive literature, which may limit its reach.

3.2.2. Vehicle-sharing services’ users and trips

On the demand side, 14 articles from the selected corpus study the profiles of VSS users, the success factors of the services, and the characteristics of the trips that are made using VSS. Most of those 14 articles study all of the 3 aspects mentioned. Our corpus allows to make a cross-analysis of the results on those subjects for BSS, CSS and SSS (MSS are not dealt with).

3.2.2.1. Similar profiles of VSS users across studies

A broad consensus emerged from the articles reviewed: the users of VSS, be it BSS, SSS or CSS, tend to be young (20 to 40 years old approximately), and male, they tend to display higher income and education than the average, and they tend to live in a smaller household than the average (Bozzi and Aguilera, 2021; Nansubuga and Kowalkowski, 2021; Chen et al., 2020; Eren and Uz, 2020; Zheng and Li, 2020; Machado et al., 2018; Fishman, 2016). However, the literature we retrieved was concentrated on Europe and North America, and to a lesser extent China. As a consequence, it is difficult to assess to what extent those results are valid in other contexts. Zheng and Li (2020) pointed to a difference in China where BSS users may have lower financial income compared to the general population, contrarily to BSS users in Western countries, though they share the other socio-demographic characteristics detailed above. Similarly, Nansubuga and Kowalkowski (2021) explained that in developing economies, unlike what was observed in Europe and North America, carsharing is not used predominantly by highly educated people.

Regarding gender, although there are more male among VSS users, VSS may still reduce the gender gap compared to the private use of the same types of vehicles, in particular for BSS (Fishman, 2016) and SSS (Button et al., 2020); Bozzi et al. (2021) put forward the hypothesis that SSS “attract new users among people who are not able (or are reluctant) to make physical effort.” Female users also have different usage patterns than male users: they take longer trips, less often for commuting and more often for leisure (Elmashhara et al., 2022; Fishman, 2016). In the US, people from ethnic minorities and “those living in more deprived areas” also use VSS less regularly than others (Elmashhara et al., 2022; Bozzi and Aguilera, 2021).

Golalikhani et al. (2021), Nansubuga and Kowalkowski (2021) and Liao and Correia (2020) quoted studies that show that customers with lower incomes may be more willing to join CSS or BSS. A reason may be that early adopters tend to have higher incomes, whereas people with lower income join VSS at a later stage of service development (Liao and Correia, 2020).

Other characteristics of the users have been studied. The evidence about the link between vehicle ownership and the use of VSS is mixed. Surveys in North America found a negative correlation between car ownership and CSS use (Golalikhani et al., 2021) while models have diverging results (Ferrero et al., 2018; Golalikhani et al., 2021). For BSS and SSS use, the correlation with car ownership is positive according to surveys but negative according to models (Elmashhara et al., 2022; Eren and Uz, 2020). However, it seems clear that BSS and CSS users have a better opinion of public transport, walking and cycling than non-users (Elmashhara et al., 2022; Liao and Correia, 2020).

Finally, several authors have looked at the link between where people live and where services are available as an explanatory factor for VSS use. Living close to a VSS station increases the probability to be a user of the service (Golalikhani et al., 2021; Nansubuga and Kowalkowski, 2021; Fishman, 2016).

3.2.2.2. The use of VSS can be explained by individual reasons, the characteristics of the services and the characteristics of the places where they are located

3.2.2.2.1. Individual reasons to use VSS are very diverse

The articles in the corpus quote several individual reasons to use VSS. Users that are concerned with the environment are more prone to use VSS according to studies based on revealed preferences of CSS users (willingness to pay, Ferrero et al., 2018), on questionnaire or qualitative interviews with CSS users (Golalikhani et al., 2021; Nansubuga and Kowalkowski, 2021) and BSS users (Zheng and Li, 2020), or on means-end chain analysis of CSS users (a quantitative analysis of data collected through qualitative

interviews) (Machado et al., 2018). The price of the service was quoted as a reason to use VSS by Ferrero et al. (2018) for CSS users and by Zheng and Li (2020) and Dibaj et al. (2021) for BSS and SSS users. After his review of BSS studies, Fishman (2016) concluded that the price of the service was only relevant for less affluent users. Other reasons were quoted: the convenience that stems from using a VSS compared to other transportation options (Nansubuga and Kowalkowski, 2021; Zheng and Li, 2020 ; Ferrero et al., 2018; Fishman, 2016), a “cycling lifestyle” (Zheng and Li, 2020), and “familiarity with technological devices” in general (Nansubuga and Kowalkowski, 2021 ; Machado et al., 2018). However, Liao and Correia (2020) noted that the reasons to use VSS may be different depending on the service category, as shown by a comparison between BSS users and e-BSS users: e-BSS users are more interested in bike-related technologies but have “lower subjective norms” toward in cycling in general, while the opposite is true for regular BSS users. Safety is often quoted as a reason not to use BSS or SSS (Bozzi and Aguilera, 2021; Eren and Uz, 2020; Zheng and Li, 2020; Fishman, 2016).

3.2.2.2. *What operational features make a VSS more attractive to its potential users?*

The operational features of VSS impact their success. The availability of vehicles is an important success factor for VSS (Nansubuga and Kowalkowski, 2021; Illgen and Höck, 2019 ; Ferrero et al., 2018), and so is the ease to park a vehicle (Golalikhani et al., 2021), the ease to use the service and the vehicle, including the accessibility with a public transport smartcard (Nansubuga and Kowalkowski, 2021; Eren and Uz, 2020), and the possibility to sign up for the service on the spot (Fishman, 2016). However, in most cases, a smartphone is needed to access VSS, and this creates a barrier for people who do not own one (Zheng and Li, 2020).

Electric bikes may allow to increase the use of BSS in hilly terrain compared to non-electric bikes (Eren and Uz, 2020). Liao and Correia (2020) noted that the scientific literature has produced mixed evidence as to whether electric cars are more or less attractive to users than combustion-engine cars in CSS: this may be due to an evolution of the perception of the different motorizations over time.

Finally, there is a consensus that mandatory helmet regulations adversely affect BSS usage (Elmashhara et al., 2022; Eren and Uz, 2020; Fishman, 2016).

3.2.2.3. *VSS success is affected by their urban setting*

There is a consensus in the papers reviewed that CSS and BSS demand is higher in dense cities and in high-density neighborhoods (Golalikhani et al., 2021; Nansubuga and Kowalkowski, 2021; Zheng and Li, 2020; Eren and Uz, 2020; Ferrero et al., 2018). More specifically, Eren and Uz (2020), Chen et al. (2020) and Bozzi and Aguilera (2021) concluded that commercial and recreational areas attract more demand for BSS and SSS than other areas (residential, office). Liao and Correia (2020) and Golalikhani et al. (2021) found on the contrary that CSS are used more in residential and office areas rather than commercial and recreational areas.

All VSS are positively affected by the proximity of public transport hubs (Bozzi and Aguilera, 2021; Nansubuga and Kowalkowski, 2021; Golalikhani et al., 2021; Eren and Uz, 2020; Liao and Correia, 2020; Ferrero et al., 2018). BSS and SSS benefit from good cycling infrastructures (Bozzi and Aguilera, 2021; Eren and Uz, 2020; Fishman, 2016), and CSS benefit from scarcity of parking spaces for privately owned vehicles (Nansubuga and Kowalkowski, 2021).

Steep slopes are detrimental to BSS and SSS use, even though the effect is smaller for electric BSS than for regular BSS as mentioned earlier (Bozzi and Aguilera, 2021; Eren and Uz, 2020).

3.2.2.3. *Pattern analysis: what are VSS used for and when?*

3.2.2.3.1. Purpose and length of the trips

Trip purposes vary according to the characteristics of the service, the users' profiles and the local context. Trips linked to leisure and special events represent a more important share of trips for SSS than for other mobility options, in particular when compared to BSS (Bozzi and Aguilera, 2021; Dibaj et al., 2021; Button et al., 2020) and "visitors seem to represent a significant proportion of [SSS] users" (Bozzi and Aguilera, 2021). Commute was quoted by several authors as another important purpose for VSS users (e.g., Elmashhara et al., 2022; Button et al., 2020), but Fishman (2016) and Nansubuga and Kowalkowski (2021) found that this is only the case for long-term users in the case of BSS and CSS. Nansubuga and Kowalkowski (2021) also found that using CSS to commute is more frequent in the case of B2B services than in the case of other market models of CSS, and that high-income users use CSS for business purposes while lower-income users rely on CSS for non-regular trips. Machado et al. (2018) found that one-way CSS is more often used to commute than two-way CSS, whereas two-way CSS is more often used to go shopping than one-way CSS. Finally, data collected by Chen et al. (2020) showed that younger users commute more with BSS than other age groups, whereas older users use BSS to go shopping more than other age groups.

There is a broad consensus among the papers reviewed that BSS and SSS trips are short: in general, VSS are used for trips of less than 15 minutes and less than 2 miles (Bozzi and Aguilera, 2021; Dibaj et al., 2021; Button et al., 2020; Chen et al., 2020; Machado et al., 2018; Hirsch et al., 2019).

3.2.2.3.2. Impacts of time and weather on travel behavior

All the data presented in the papers reviewed showed that CSS and SSS use is higher at weekends and during holidays (Bozzi and Aguilera, 2021; Dibaj et al., 2021; Nansubuga and Kowalkowski, 2021; Golalikhani et al., 2021; Button et al., 2020). Nansubuga and Kowalkowski (2021) noted that this creates an opportunity to maximize utilization by attracting organizations to use CSS on weekdays during working hours. During weekdays, SSS are used more in the afternoon than in the morning (Bozzi and Aguilera, 2021; Dibaj et al., 2021; Button et al., 2020), with the hourly distribution showing "a long afternoon plateau" (Bozzi and Aguilera, 2021). BSS, however, "display a two-peak pattern, during morning and evening commuting times" (Bozzi and Aguilera, 2021). VSS use during nighttime is not covered by our corpus.

Rain, snow and low temperature have each been found to adversely affect SSS and BSS demand (Bozzi and Aguilera, 2021; Liao and Correia, 2020; Zheng and Li, 2020; Eren and Uz, 2020; Fishman, 2016). However, Fishman (2016) noted that "inclement weather is much more likely to impact on casual users than members with a commuting function". This means that in Northern countries, these services are less used during wintertime (Elmashhara et al., 2022; Bozzi and Aguilera, 2021; Eren and Uz, 2020), and "several BSP [station-based BSS] close during wintertime due to low demand" (Eren and Uz, 2020). CSS may also be impacted by bad weather (Golalikhani et al., 2021) and low temperatures "probably because the driving range of EVs is lower when it is cold" (Liao and Correia, 2020).

3.2.2.4. Intermediary discussion

It appears from the literature that the sociodemographic characteristics of the users are well identified and not dependent on the type of vehicle used. Their reasons to use the service, however, are diverse. Through the design of their service, VSS operators can attract more users by addressing the barriers to use the service. Providing an integrated or coordinated offer of different VSS options (in terms of categories of VSS) may help address the different motivations of their potential users. One paradox is that safety concerns limit the use of BSS and SSS, while mandatory helmet use also reduces the attractiveness of these services. Resorting to measures outside of the VSS such as limiting the speed of

motorized vehicles or providing adapted infrastructure may be a way to overcome this paradox, which cannot be solved by VSS operators alone. Another result is that the land use characteristics that favor high use of VSS are different for CSS than for BSS and SSS, and different VSS are used for different purposes. This result suggests that an integrated or coordinated offer of different categories of VSS (or competing offers) can be deployed complementarily in different neighborhoods and to meet different demands.

Comparisons between different VSS in a single urban area, or at least in very similar contexts, may help understand the different use of VSS that are observed by identifying explaining factors. Longitudinal studies of VSS users may allow to precise the profile and the reasons to use the service of early VSS adopters versus users that adopt the service at a later stage and explain the diversity of results found in the scientific literature.

3.2.3. Impacts of vehicle-sharing services: general trends and context dependencies

The articles included in the corpus discuss 5 categories of impacts that VSS can have: impacts on the use of other modes of transport; impacts on climate and the environment; impacts on public health, safety, physical activity and well-being; impacts on accessibility and social equity; and economic impacts (a slightly different division of the various impacts of VSS is proposed by Roukouni and Correia, 2020). In total, 12 of the 29 literature reviews included in the corpus deal with one or several of the 5 categories of impact identified through the umbrella review. The 4 first categories of impacts are each covered by the corpus for 2 or 3 categories of VSS (MSS are not covered for any impacts); economic impacts are covered only for BSS.

3.2.3.1. VSS impacts on mobility behaviors and the use of other modes of transport are very context-specific

The literature on the impacts of VSS on mobility behaviors and the use of other mobility services is abundant. However, our corpus of literature reviews does not include any information specific to SSS or MSS, probably due to their too recent implementation. In this section, we synthesized the results presented in the selected corpus in terms of: impact on car use, car ownership and congestion; impact on public transit use; impact on use of active modes (cycling, walking); impact on use of other modes; and reported modal shifts. It has to be noted that the impacts can vary greatly from one city to another and from one service to another, so it is difficult to draw definitive conclusions about the impacts of VSS on the use of other modes of transport.

3.2.3.1.1. Impacts on car use, car ownership and congestion

The impacts of VSS on car have been explored on two levels: the use of a car, measured in vehicle-kilometer traveled (VKT), and the car ownership rate. The articles of the corpus that looked at the impact of either CSS or BSS on VKT all concluded that these services lead to a reduction in the total distance traveled by car (either by shared car or by private car) (Teixeira et al., 2021; Golalikhani et al., 2021; Liao and Correia, 2020; Zheng and Li, 2020; Santos, 2018; Fishman, 2016; Kent, 2014). However, the actual number of kilometers saved varies greatly from one study to another. In particular, different VSS have different impacts on VKT reduction: shared cargo-bikes and e-bikes replace more trips by car than regular shared bikes (Teixiera et al., 2021; Liao and Correia, 2020); frequent users of BSS seem to reduce their use of car more than casual users (Teixiera et al., 2021); electric CSS lead to a greater reduction in VKT than gasoline CSS (Liao and Correia, 2020). Based on several works by Cervero (2003, 2004, 2007), Kent (2014) also explained that CSS may increase VKT in the short run as the early adopters may be non-car owners but reduce overall VKT after a few years when car-owners – who are generally not early adopters – start joining the scheme. High rates of car-to-VSS modal shifts in Chinese

cities may be explained by the profile of the users: Teixeira (2020) has observed that in China, BSS users have a higher rate of car ownership than non-users. Besides, Fishman et al. (2014) made the hypothesis that cities with high modal shares for car have higher car replacing rates.

The rate of car ownership can be impacted by VSS in two ways: households selling a car they own, or households postponing/cancelling a purchase they would have made without the introduction of VSS. Here again, the authors of the corpus are unanimous about the fact that CSS reduce the rate of car ownership (we found no mention of the impact of BSS on car ownership). However, CSS “mostly replace a second or third car” according to a survey in the Netherlands conducted by Nijland et van Meerkerk (2017) and cited by Santos (2018). Different studies show opposite results about the differentiated impact of e-CSS versus regular CSS (Liao and Correia, 2020). However, it seems that round-trip CSS does have a greater potential to reduce the rate of car ownership than free-floating CSS (Golalikhani et al., 2021).

According to Zheng and Li (2020), BSS also have a positive impact on road congestion, with a lesser impact when cities are smaller or wealthier.

3.2.3.1.2. Impacts of VSS on the use of public transit

The impact of VSS on the use of public transit (PT) is mixed: VSS can act both as a complement to PT (feeder), or as a substitute to PT (rival).

BSS is often cheaper and faster – or at least not slower – than PT (Teixeira et al., 2021; Zheng and Li, 2020). At the same time, the proximity to a PT hub is a factor of higher usage of a BSS (Teixeira et al., 2021; Eren and Uz, 2020), and several surveys among BSS users have confirmed that a high proportion of BSS users combine both modes (Teixeira et al., 2021; Hirsh et al., 2019). Moreover, Saberi et al. (2018) cited by Teixeira (2021) observed that a subway strike in London led to a major increase in both the number and the length of trips made with the BSS. According to Teixeira et al. (2021), “bikesharing acts as a substitute mode [to PT] in high density areas due to being faster and cheaper than PT (which also tends to be overcrowded), while complementing PT in peripheric and low-density areas by acting as a first and last mile connector, increasing the catchment areas of less developed PT networks”. An illustration of this is offered by Shaheen et al. (2012) observation (cited by Zheng and Li, 2020): “the commuting distance of BSS users is usually shorter than that of the general population, but those with relatively long commute times are more likely to increase their use of other public transportation methods”. Finally, studies in Montreal and Lyon showed that BSS users are highly multimodal: BSS is often not their preferred mode, even for high-frequency users (Teixeira et al., 2021).

The impact of CSS is mixed and appears to depend on the features of the service. Golalikhani et al. (2021) cited an article by Chicco et al. (2020) where the use of PT is found to be positively affected by the use of round-trip CSS but negatively affected by the use of free-floating CSS. Non-electric CSS may cause a greater reduction in PT use than e-CSS based on a study of five North-American cities (Martin and Shaheen, 2016 quoted by Liao and Correia, 2020). Nansubuga and Kowalkowski (2021) explained that CSS users combine CSS trips with other modes including PT, but also use CSS as a substitute to PT.

3.2.3.1.3. Impacts of VSS on walking and cycling

Several studies in Dublin, Montreal and London cited by Teixeira et al. (2021) showed that BSS attracts users that did not cycle before, that it leads to the purchase of private bikes, but also that it makes car drivers more cautious about bike riders on the road. Kent (2014) found 3 surveys and 1 observation about the impact of CSS on walking and cycling: they all concluded to an increase in these modes,

ranging from +8% to +54%. Eren and Uz (2020) mentioned the doubling of the modal share of cycling after the introduction of BSS in China.

3.2.3.1.4. Competition among VSS and with other shared mobility services

VSS can impact the use of other VSS. Hirsh et al. (2019) mentioned the competition between free-floating B2C BSS and station-based B2G2C BSS, in particular when free-floating bikes are positioned next to bike stations. Liao and Correia (2020) observed the quasi-disappearance of free-floating BSS after the introduction of SSS “as a result of their providers switching focus toward the more promising e-scooters” in the US. The launch of an e-bike sharing service by Uber also led to a 10% reduction of the ride-hailing trips booked through its platform (Liao and Correia, 2020). The existence of potential synergies between different categories of VSS is not studied by the literature reviewed.

3.2.3.1.5. Reported modal shifts to VSS

Teixeira et al. (2021) tried to quantify and to compare the reported modal shifts to BSS of 13 services in different cities in North America, Europe, China and Australia by expanding the work done by Fishman (2014) in 5 cities. The variations from one service to another are significant, but the authors found that most trips with a BSS replaced a trip formerly made with PT (mean: 35%, [interquartile range: 20-26%]), followed by walking (33%, [20-54%]), car (10%, [1-23%]), private bike (8%, [4-12%]), taxi (4%, [3-6%]), and with 4% of new trips [1-10%]. This is consistent with the statement by Liao and Correia (2020) that “the replacement of active modes is around 40–50% in total across several studies”.

3.2.3.2. The uncertain environmental impacts of VSS calls for more reliable data and method for their evaluation

The environmental impact of VSS is mainly appraised through the GHG emissions they induce and the GHG emissions they prevent. Some authors also consider the environmental impact of the batteries used by electric VSS.

The overall environmental impact of VSS is highly dependent on the modes for which they substitute (Teixeira et al., 2021; Zheng and Li, 2020; Liao and Correia, 2020). As was exposed in the previous section, the impacts of VSS on other modes can vary greatly from one service to another and from one city to another. For this reason, several authors of the corpus are doubtful about results showing extremely positive environmental impact of BSS, criticizing methods that rely on unverified assumptions (of modal shifts for instance) or non-transparent datasets (Teixeira et al., 2021; Zheng and Li, 2020). In some cases, taking into account the emissions of maintenance operations seem to result in an overall negative environmental impact: “in London, one kilometer of shared bike travel would generate 2.2 km of car travel by redistribution trucks” (Fishman, 2014, cited by Zheng and Li, 2020 and by Teixeira et al., 2021). There is no consensus either about the positive impact of CSS in terms of GHG emissions (Golalikhani et al., 2020; Liao and Correia, 2020). A study of CSS-induced car ownership- and use-reduction even counterintuitively found that electric CSS have a lesser positive impact than combustion-engine CSS since they replace fewer cars (Martin and Shaheen, 2016, cited by Liao and Correia, 2020).

Life-cycle assessments (LCA) of VSS are still rare. According to the ones reviewed by Bozzi and Aguilera (2021), SSS have a greater environmental impact than all other modes (including private scooters) except for cars. The impact of BSS and SSS are significantly affected by the lifespan of the vehicles and the techniques and vehicles used for the relocation and maintenance of the fleet, with rapid improvements from the operators on those subjects (Bozzi and Aguilera, 2021; Teixeira et al., 2021). As underlined by Teixeira et al. (2021), it seems important to establish shared methods based on

reliable data to evaluate the global impact (including LCA) of VSS on the environment. This would also help to identify and tackle the main sources of impacts and make the service evolve accordingly.

Apart from GHG emissions, VSS induce other types of pollution. In particular, “widespread use of lithium batteries can potentially lead to extra pollution during lithium mining” (Liao and Correia, 2020). The batteries of shared electric vehicles, managed by the operators, may be better handled than the batteries of private electric vehicles (Liao and Correia, 2020).

3.2.3.3. Public health: benefits of increased physical activity may outweigh the crash risks (even with low helmet-wearing rates)

Most of the BSS-focused literature reviews and some SSS-focused literature of the corpus include a section on the impacts on public health, safety, physical activity, or well-being. CSS-focused studies do not include those impacts. The authors predominantly focus on direct impacts in the form of injuries and death induced by the use of BSS or SSS, and on the related issue of helmet-wearing, but some authors also underline the more long-term benefits that stem from increased physical activity and from the well-being associated with BSS and SSS.

Chen et al. (2021) identified two epidemiological studies on injuries among BSS users, both of which reveal greater rates of injuries compared to private bike users. Bozzi and Aguilera (2021) looked at the relatively abundant academic literature on injuries linked to SSS: the victims are predominantly young men – “a demographic group with a statistically proven propensity for risky behavior” (Bozzi and Aguilera, 2021) – which is consistent to users’ demographics. Victims also include non-users (10% of the total number of victims according to Trivedi et al., 2019). However, e-scooter and bike trips are “less likely to result in a traffic fatality than a car or motorcycle trip”, and e-scooters trips are “no more likely to result in a road traffic death than a bicycle trip, although the risk of hospital admission may be higher for e-scooters” (Bozzi and Aguilera, 2021). Based on the “2018 E-Scooter findings report” of the Portland Bureau of Transportation (PBOT, 2019), Liao and Correia (2019) concluded that SSS “may still result in a net reduction of injuries since it replaces many car trips which are related to a higher number of injuries and fatalities”. Furthermore, Bozzi and Aguilera (2021) have shown that it is mostly non-users who feel unsafe about SSS: safety may improve as other users of the urban space get accustomed to it.

Several authors focused specifically on helmet wearing in both BSS and SSS, which can reduce injuries and deaths (Bonyun et al., 2012 cited by Eren and Uz, 2020). The meta-analysis of 11 studies in North America conducted by Chen et al. (2021) revealed that “the unhelmeted rate varied from 36.0 to 88.9% in bike share users. And the unhelmeted rate ranged from 9.0 to 40.49% in private bike users as reported in five studies.” Bozzi and Aguilera (2021) also found low rates of protective gear wearing among SSS users. BSS long-term subscribers, week-end users and female users are more likely to wear a helmet (Fishman, 2016; Eren and Uz, 2020).

Another factor to take into account when evaluating the impact of VSS on safety and health is the induced physical activity, which can result in overall gains in terms of lifetime expectancy. The three BSS comparative risk assessment studies reviewed by Teixeira et al. (2021), based on physical activity, exposure to pollution and traffic crashes, all concluded in a net positive impact of BSS in most contexts. The positive impact of e-BSS is lower since they induce less physical activity (Zheng and Li, 2020). Hirsh et al. (2019) noted that in the U.S. only a small proportion of residents use bikeshare, resulting in little impact on physical activity in the broader population, but BSS users also have a wider benefic impact since they reduce the overall pollution in the city (Zheng and Li, 2020). The impact of SSS on physical activity “is still disputed in academic and non-academic work” as revealed by the literature review conducted by Bozzi and Aguilera (2021). Indeed, SSS burn less energy than active modes and might

replace them; however, some argues that the development of SSS promotes an environment and a culture favorable to actives modes (see e.g., Glenn et al., 2020).

Finally, identifying a gap in the literature, Chen et al. (2020) questioned the subjective well-being that results from the use of dockless BSS: cycling is known to have high satisfaction rate among users, and dockless BSS provides further convenience linked to the absence of responsibility of owning a bike, but unavailability of bikes and bad parking practices may reduce the overall satisfaction with the service.

3.2.3.4. Do VSS increase accessibility for everybody?

VSS increase the diversity of mobility services offer and can thus potentially contribute to increasing accessibility, defined from a user's perspective as "the extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s) at various times of the day" (Geurs and van Wee, 2004). However, some features of VSS can limit their ability to increase the accessibility for every neighborhood and for all the population.

When they complement PT – either spatially or temporally (VSS generally run 24/7) – VSS increase the accessibility by increasing the reach of their users compared to walking (Liao and Correia, 2020; Chen et al., 2020). CSS may be an affordable alternative to owning a car (Golalikhani et al., 2021; Kent, 2014). BSS have prompted hopes about greater accessibility compared to station-based BSS since they do not require specific infrastructure, and simply because their deployment increases the total number of shared bikes (Chen et al., 2020; Hirsh et al., 2019). However, the business models of free-floating operators also mean that BSS are increasingly funded by venture capital, which leads to operating zones being concentrated in the most profitable areas while excluding spaces such as suburbs or peripheral areas (Chen et al., 2020). When they are offered in marginalized areas, BSS are used by the residents of those areas provided the price of the trip remains limited (Chen et al., 2020).

Barriers to BSS use include cost and pricing structure, lack of awareness about how to use bikeshare, and limited access to credit cards or smartphones (Hirsh et al., 2019). Some disabled persons are excluded from BSS by the nature of these services; they are also disproportionately affected by bad parking of free-floating BSS and SSS.

Finally, the improper parking of shared scooters and bicycles can be a nuisance for pedestrians and other users of the sidewalk and the curb space (Liao and Correia, 2020; Hirsh et al., 2019). On the contrary, CSS can decrease the need for parking space compared to private cars (Golalikhani et al., 2021).

3.2.3.5. Economic impacts of VSS

Few studies focus on the economic impacts of VSS. Economic gains of BSS are primarily linked to the time saved according to Eren and Uz (2020). Apart from the economic valuation of other impacts mentioned before, such as reduced pollution or impacts on other modes of transports, BSS may increase local house prices and retail sales (Teixeira et al., 2021).

3.2.3.6. Intermediary discussion

The literature has identified a large array of impacts that VSS can have, both positive and negative. Most of them are heavily influenced by where the modal shift to VSS originates from (which mode, if any, VSS users use less due to VSS availability). Going further requires a more thorough identification of the specific characteristics of VSS linked to a given impact, which are not necessarily the type of vehicle shared. Indeed, different VSS can have very different impacts according to how they are designed and where they are implemented for example. More precise data would allow to select more

effectively the category of VSS to implement in a given context to meet a pre-identified need, and to identify what innovations are needed to limit some identified negative impacts. Besides, a more comprehensive quantification of the different categories of impact would make it easier to compare the positive and negative impacts of VSS. The literature reviewed suggests that such evaluations would probably be more appropriately conducted at the local level given the important variability from one context to another, but the development of rigorous methods that can be applied in different contexts can help (Roukouni and Correia, 2020).

Finally, other categories of impacts not covered by this umbrella review may be explored, in particular long-term and indirect effects. For instance, we mentioned above the impacts of land use and urban characteristics on VSS use, but the reverse may be studied: how do VSS affect the urban landscape and the infrastructure? Identifying the different categories of impacts of VSS, including outside of the impacts traditionally studied when it comes to mobility services such as the propensity of VSS users to buy a vehicle they have tried in a shared fleet, may also enhance our understanding of the strategies of the different actors involved in the development of VSS.

Another avenue for further research is the impact of an integrated or coordinated (or competing) offer of different categories of VSS in a single area. If VSS really do complement each other, the presence of a diversified offer may increase their impact as it becomes easier and more relevant to rely on them for a wider array of trips. It is possible that such an integration, coordination, or competition of different VSS may increase their capacity to reduce car purchase and/or use, promoting walk for short trips, or increase the accessibility overall. Such a study of a integrated, coordinated or competing offer of VSS is all the more relevant as many cities currently do host several VSS, and individual VSS operators themselves increasingly offer different categories of VSS to their customers.

3.2.4. Regulation of vehicle sharing services: what can local authorities do and what should they do?

9 articles of the corpus deal with VSS regulation, and most of them are focused on BSS or SSS. They all stress that the first difficulty the authorities were confronted with was the novelty of the services and of the issues they raised (Teixeira et al., 2021; Bozzi and Aguilera, 2021; Cao et al., 2021; Roukouni and Correia, 2020; Button et al., 2020). The regulation process may be hampered if there is a lack of clarity about which government or agency should be in charge of the issue, as was the case in Shanghai for example – but the introduction of VSS can also be an incentive to bring about more cooperation between different authorities (Cao et al., 2021). Button et al. (2020) explained that this led SSS companies to adopt a “wait-and-see” approach (or rather a “do first, ask latter” approach): “rather than seek permission to provide services and to conform to regulations pertaining to similar industries, [SSS companies] entered markets and waited for the authorities to respond”.

The reasons for a transport authority to implement a BSS or a SSS are diverse and depend on the local context and strategies: improving first- and last-mile connections, enhancing the public transit offer, reducing GHG emissions, attracting tourists, increasing bike use (Zheng and Li, 2020), providing a new mobility solution after the coronavirus pandemic (Bozzi and Aguilera, 2021), reducing the dependence on automobile, limiting congestion and improving mobility in lower-income areas without putting a strain on public finances (Button et al., 2020). However, Santos (2018) pointed out that “there are no clear-cut benefits to society in terms of substantial congestion or CO₂ emissions reductions” that would justify (local) government involvement in implementing CSS. Roukouni and Correia (2020) listed the different methods available to make a choice as to whether to implement a VSS or not: transport modeling, data analysis, mobility surveys, stated preference surveys, benchmarking. In particular, they quoted the Shared Mobility Benefits Calculator designed by the Shared-Use Mobility Center to

estimate the GHG emissions reduction resulting from the implementation of various shared mobility services in U.S. cities.

Santos (2018) listed three categories of regulatory tools that can be leveraged by local authorities to encourage shared mobility: command-and-control tools; financial tools; and in-kind advantages.

- Command-and-control tools include regulations such as technical requirements on vehicles, operational standards, permits, restrictions on circulation, fleet caps, outright bans. Concerning fleet caps, Button et al. (2020) suggested that a fixed fleet cap imposed by “bureaucratic managers (...) deciding what the consumers want rather than market forces” may have limited efficiency compared to market-based regulation such as auctions. Fleet caps generally do not evolve over time. They may make companies unable to minimize costs.
- Financial tools mainly include subsidies. They are particularly useful to ensure the service continuity, in an industry where aggressive business practice creates high uncertainties that limit the possibility of these services to really have an impact on behaviors (Button et al., 2020; Hirsh et al., 2019). However, subsidizing VSS risks jeopardizing public transit (Santos, 2018) or pre-existing VSS services such as station-based BSS (Hirsh et al., 2019) by making them less attractive.
- In-kind advantages mainly refer to access to the urban space, and specifically parking spaces (Roukouni and Correia, 2020; Santos, 2018). Concerning scooters, it is still unclear which are the best circulation policies in terms of lane of safety for road users (Bozzi and Aguilera, 2021; Button et al., 2020).

VSS companies themselves have a responsibility in governing their own services (Cao et al., 2021). Their scope of action includes awareness campaigns, feedback collection and establishing reward and punishment mechanisms (Cao et al., 2021), including “out of system” fees when bikes are parked outside the service area (Hirsh et al., 2019).

Finally, several authors discussed the question of data-sharing between users, VSS operators and local governments. Indeed, trips data can be valuable for mobility planning and the integration of mobility services (Bozzi and Aguilera, 2021; Cao et al., 2021; Chen et al., 2020). Button et al. (2020) also quoted the example of the SSS operator Bird, which introduced a platform aiming at “appeasing authorities by allowing them to designate no-ride and no-park zones, set speed limits, and display safety messages on scooter dashboards.” If data from free-floating VSS may “more accurately reflect travel demands” (Chen et al., 2020), “the for-profit model of free-floating systems complicates data sharing logistics” (Hirsh et al., 2019). Data provided by operators “have to be interpreted carefully because they often lack independence and they also might not provide thorough information about their methodological approach” (Roukouni and Correia, 2020). More generally, the production of mobility data by private operators raises the question of the capacity of local authorities to exercise a public governance of mobility. Data-sharing also raises privacy issues (Bozzi and Aguilera, 2021) – in the case of track records for instance – which local governments tried to mitigate through mandatory “opt-in” clause or third-party contracting (Hirsh et al., 2019). The safety of the collected and stored data should also be questioned.

3.3. Synthesis of further research proposed in the corpus and recommendations made

3.3.1. Further research proposed in the corpus

Writing on CSS in 2018, Ferrero et al. (2018) considered that the abundant scientific literature was disproportionate considering the limited number of CSS. The scientific literature on VSS has grown even more since then (Elmashhara et al., 2022, Teixeira et al., 2021), but despite its volume several

authors deem the scientific literature on VSS insufficient, be it due to the lack of high-quality studies (Teixeira et al., 2021) or to the plurality of concepts used to describe a single phenomenon (Elmashhara et al., 2022). More generally, there are numerous questions that are yet to be tackled by the scientific literature on VSS (Elmashhara et al., 2022; Teixeira et al., 2021; Liao and Correia, 2020).

In terms of business models, the authors recommend studying different pricing and marketing strategies and their optimization (Ataç et al., 2021; Hirsh et al., 2019; Ferrero et al., 2018). The question of the ability of the models offered by the scientific literature to accurately represent VSS remains open (Calderón and Miller, 2020; Golalikhani et al., 2020; Jorge and Correia, 2013). In particular, most authors having tackled this subject identify the demand modeling as a necessary area of further research (Ataç et al., 2021; Vallez et al., 2021; Eren and Uz, 2020; Nath and Rambha, 2019; Illgen et al., 2019), implying the need to include the results of descriptive research in particular on potential users and modal shifts. The vehicle relocation problem, extensively reviewed by Illgen et al. (2019), is another opportunity for further research, in particular user-based relocation (Cao et al., 2021; Vallez et al., 2021; Hirsh et al., 2019; Fishman, 2016): here again, it would be useful to rely on descriptive research of actual relocation operations.

Most studies on BSS, SSS and MSSS users to date identified by Elmashhara et al. (2022) up to August 2020 have taken the form of surveys, most of them one-off self-reported surveys. Alternative methods include longitudinal surveys, interviews, vehicle counts (Teixeira et al., 2021), or personas (Dibaj et al., 2021). Researchers could also exploit the available data on VSS trips more (Vallez et al., 2021) (but, as mentioned above, the production of data by private operators make its sharing and use by researchers harder). These methods could allow for a sharper understanding of VSS uses and users, in particular when it comes to better understanding the values and cultural norms related to the use of VSS, addressing the intention-behavior gap, analyzing temporal dynamics of VSS use, assessing the relation between the number of available VSS and the user experience, or understanding the reasons for the gender-gap in VSS use (Elmashhara et al., 2022; Bozzi and Aguilera, 2021; Teixeira et al., 2021; Dibaj et al., 2021; Liao and Correia, 2020; Hirsh et al., 2019). Studies should also look at non-users (Fishman, 2016), but also at negative attitude towards VSS, boycott and uncivilized actions (Elmashhara et al., 2022; Hirsh et al., 2019). Drops-out are not specifically mentioned by the articles of the corpus but they may be another interesting population to look at.

The research topics proposed by the authors of the selected corpus in terms of impacts of VSS correspond approximately to the subtopics identified by our umbrella review. However, the authors have proposed new ways to look at those impacts. In particular, they stress the need to look at long-term and indirect impacts. Hirsh et al. (2019) have proposed to look at the unintended effects on access to healthcare facilities for people relying on VSS and Bozzi and Aguilera (2021) proposed to look at long-term indirect health effects of SSS (lifestyle, exposure to pollution). Vallez et al. (2021) proposed to include the environmental impact of rebalancing strategies in models and impact studies. Liao and Correia (2020) and Bozzi and Aguilera (2021) suggested looking at the effect of VSS on purchase of new vehicles (e.g., a SSS user buying a private scooter). In terms of impact on the urban environment, Hirsh et al. (2019) proposed to explore the relationship between VSS and the creation of new infrastructure, Zheng and Li (2020) proposed to compare the spatial impact of BSS compared to bike rental, and Dibaj et al. (2021) proposed to look at VSS impacts in terms of conflicts between different users and in terms of evolution of the public “sense of place” citing a risk of its “degradation” (in 2014, Kent (2014) deemed that CSS could increase the sense of belonging through collaboration and the sharing of a common fleet of vehicles).

Cao et al. (2021) and Hirsh et al. (2019) have identified the governance of VSS as an area for further research. In particular, Santos (2018) asked whether local governments should subsidize VSS and Hirsh

et al. (2019) if public-private partnerships could replace “venture capital dependency” (Hirsh et al., 2019). For Roukouni and Correia (2020), there lacks a comprehensive evaluation framework of VSS for local government to use. Cao et al. (2021) mentioned the unsettled economic debate over the classification of BSS as “quasi-public goods”: quasi-public goods are either non-exclusive or non-competitive (as opposed to public goods that have both attributes). Other policies are considered for further research including helmet use for BSS users, data-sharing, and geofencing (Chen et al., 2021; Hirsh et al., 2019). VSS integration with PT, which is the focus of the literature review conducted by Oeschger et al. (2020), is identified as an area for further research by several authors, including the technological integration and the physical coordination (Elmashhara et al., 2022; Oeschger et al., 2020; Roukouni and Correia, 2020; Hirsh et al., 2019; Machado et al., 2018). Competition between VSS has not been very much studied (Ataç et al., 2021), and Hirsh et al. (2019) and Liao and Correia (2020) have suggested exploring the implications of the presence of multiple VSS operators (integrated, coordinated or competing VSS), both within cities and between cities, from the point of view of the user, including fare integration.

As mentioned earlier, VSS studies are concentrated on North America, Europe and China. Several authors identify the need for enhancing the global geographic coverage of VSS studies (Elmashhara et al., 2022; Bozzi et al., 2021; Liao and Correia, 2020; Hirsh et al., 2019). Writing in 2016, Fishman (2016) noted that “no country has the bikeshare scale of China, yet research activity does not reflect this”. Writing 5 years later, Cao et al. (2021) found few studies of free-floating BSS outside China. A diversity of geographic coverage at the local scale is also important: VSS in suburban and rural context could also be explored (Bozzi et al., 2021). Studying a greater diversity of contexts would allow to identify more factors of VSS development.

Studies should also cover a wider array of services and compare VSS between each other and with other mobility services. According to the date of publications, authors identified different services of interest not yet studied by the scientific literature they reviewed: one-way CSS (Roukouni and Correia, 2020), dockless BSS (Teixeira et al., 2020; Vallez et al., 2021; Chen et al., 2021; Chen et al., 2020;), or more generally VSS other than CSS or BSS (Ataç et al., 2021). Several authors recommended making comparison between different subcategories of VSS: impacts of electric CSS vs. conventional CSS (Illgen et al., 2019), sustainability and users’ profiles of free-floating vs. station-based BSS (Vallez et al., 2021), determinants of use of SSS vs. BSS (Elmashhara et al., 2022). However, Liao and Correia (2020) noted that “the difference between free-floating and station-based may not be so obvious in the future: virtual stations can be created with geofencing, and both the size and location of stations can be easily adjusted based on need, which results in an organized yet flexible system, combining the strengths of both free-floating and station-based systems”. Indeed, looking at current services can help identify trends of future VSS developments (Golalikhani et al., 2021; Hirsh et al., 2019), for instance in terms of parking possibilities (“semi-floating”, control devices) or in terms of types of shared vehicles.

3.3.2. Recommendations made by the authors of the corpus

Several authors of the selected corpus made recommendations directed towards policymakers for a greater development of VSS. From a modeling perspective, Calderón and Miller (2020) underlined that VSS should be adequately represented as “a combination of operational tasks”. From a regulation point of view, authors recommended new frameworks too, adapted to the specific characteristics of these services (Bozzi and Aguilera, 2021; Cao et al., 2021). For free-floating BSS in particular, Cao et al. (2021) underlines that regulation by local governments in China should cover industry access and withdrawal rules, protection of user deposits, and data sharing. Policymakers also need to develop evaluation frameworks and metrics (Cao et al., 2020; Roukouni and Correia, 2020). Teixeira et al. (2021) recommended supporting BSS’s improvement with regard to the modal shift they induce: even

though the modal shift resulting from BSS may be small, it cannot be disregarded as modal shifts are difficult to make happen overall. Oeschger et al. (2021) mentioned the need to take into account equal access to all population groups when planning for VSS. Several authors stressed the need for a collaborative governance of VSS including different stakeholders, including users (Oeschger et al., 2021; Nansubuga and Kowalkowski, 2021; Bozzi and Aguilera, 2021; Cao et al., 2021). In particular, VSS should be integrated or coordinated between them and with PT (e.g., BSS and CSS, BSS and SSS etc.) (Oeschger et al., 2021; Nansubuga and Kowalkowski, 2021; Liao and Correia, 2020). VSS can be used as a complement to PT in less dense areas, and as a way to reduce congestion in denser areas (Roukouni and Correia, 2020). The business models of CSS must be planned according to the local context (Nansubuga and Kowalkowski, 2021). Integration of VSS and PT can be realized through mobility hubs (“one-stop location that makes available a wide range of mobility modes”) or MaaS platforms for example (Liao and Correia, 2020). However, public support of CSS should not make provoke a modal shift that would jeopardize PT (Nansubuga and Kowalkowski, 2021). To promote BSS and SSS, the authors insist on the importance of the infrastructure and the built environment (Bozzi and Aguilera, 2021, Oeschger et al., 2021). Other promotion tools include users’ trainings and educational campaigns (Oeschger et al., 2021). Policymakers should also take advantage from the data generated by VSS and exploit it (Nansubuga and Kowalkowski, 2021; Fishman, 2016), and Fishman proposed in 2016 to create an “international bikeshare research and data centre” (Fishman, 2016).

In terms of innovation, Fishman saw in 2016 the spread of GPS as a way to make BSS dock-free and to use geo-fencing tools. He also proposed to share electric bicycles to create e-BSS (Fishman, 2016).

4. Discussion and conclusion

The review of 29 literature reviews covering all categories of vehicle-sharing services (VSS) and with no restriction in terms of topics allowed us to present a synthesis of the scientific literature on vehicle-sharing. As mentioned in introduction, the chosen method leaves out, by design, the most recent findings and the subjects that have not been covered by a literature review yet. Was it too early to conduct an umbrella review on this subject? We may not have been able to identify many strong, established results, but we have revealed limits in how the research on this subject is conducted and provided insights on how to better design future studies. Besides, since our review included several holistic reviews, we can say that we identified all the majors VSS-related topics covered by the literature.

One result of the umbrella review is the virtual absence of results concerning moped-sharing services (MSS), and the relatively few results concerning scooter-sharing services (SSS). Another is the concentration of the studies on North America, Europe, and to a lesser extent China and Asia. Besides, we verified the fragmentation of the literature by type of shared vehicles – sometimes grouping several types of vehicles together, such as with articles focused on “(shared) micromobility”, but rarely grouping all of them with the concept of “vehicle-sharing services” – or by other criterion (e.g., operation model).

Our cross analysis of VSS based on different types of vehicles proved valuable as it allowed to establish several results that apply to VSS in general:

- The general users’ profiles of all VSS seems to be the same.
- The uses of a VSS and the reasons for its use are very diverse, and the type of vehicle that is shared may not always be the most important factor.
- VSS can be complimentary between them and with the existing alternatives to private car driving such as public transit.
- The various impacts of VSS are heavily dependent of the modal shifts they induce.

- The impacts on the environment of VSS are most probably always lesser than that of private car driving.
- Local authorities are in the process of establishing policies in relation to VSS.

Overall, the knowledge related to VSS needs to be established more firmly. In particular, the articles reviewed only seldom mention the geographic context in which the studied VSS are deployed, whether in term of global geographic location (continent, country) or in term of urban context (e.g., urban, suburban, exurban).

Another direction that should be explored to make knowledge on VSS more precise is to design studies (on impacts, uses etc.) that do not necessarily discriminate VSS by the type of vehicle that are shared but that rely on more complex categories of VSS. Those categories could be based on a combination of criteria that include the business model, the operation model, or maybe the source of energy of the vehicles or the type of organization that operates the service. Another useful lead for further research may be to study the relation between the profiles of the users of a service and its impacts: do younger VSS users VSS own or use car less than other users? do less affluent users use VSS more or less regularly than richer users? are some VSS users using regularly multiple VSS? in what context and for what purposes are BSS more attractive than SSS? These sort of questions that combines elements from business, users', and impacts analysis could be based on comparison of several services in the same or in similar contexts. Furthermore, more studies on the regulation of VSS, its modalities and its effects, need to be pursued. A literature review on this specific subject may be useful as we have not found any to include in our umbrella review.

Improving the knowledge related to VSS is important for local authorities to develop a coherent mobility strategy. One way local authorities may improve their VSS-related strategy is to adopt a framework that encompasses all VSS together rather than addressing each VSS on its own. Indeed, as our umbrella review revealed, a scientific literature too segmented by VSS category risks overlooking the potential similarities between different categories (establishing the same result twice) and the potential combined effects of an integrated, coordinated or competing offer of different categories of VSS.

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6. Appendix: Presentation of the articles in the selected corpus

Authors	Title	Publication Year	Number of articles reviewed	Regional focus	VSS categories studied					Topics				Additional description
					BSS	CSS	SSS	MSS	Others	Business models, design and operations	Users and trip analysis	Impacts	Regulation	
Ataç, S.; Obrenović, N.; Bierlaire, M.	Vehicle sharing systems: A review and a holistic management framework	2021	63	NA	x	x	x	x	x	x				Modeling
Bahadori, M.S.; Gonçalves, A.B.; Moura, F.	A systematic review of station location techniques for bicycle-sharing systems planning and operation	2021	24	Global	x					x				Modeling (station location problem)
Bozzi, A.D.; Aguilera, A.	Shared e-scooters: A review of uses, health and environmental impacts, and policy implications of a new micro-mobility service	2021	70	Global			x				x	x	x	
Button, Kenneth; Frye, Hailey; Reaves, David	Economic regulation and E-scooter networks in the USA	2020	19**	North America***			x			x	x		x	Economics
Calderón, F.; Miller, E.J.	A literature review of mobility services: definitions, modelling state-of-the-art, and key considerations for a conceptual modelling framework	2020	72*	NA	x	x			x	x				Modeling

Cao, J.; Prior, J.; Moutou, C.	The governance of dockless bike-sharing schemes: A systemic review of peer-reviewed academic journal papers between 2016 and 2019	2021	95	China***	x					x			x	
Chen, S.; Cui, H.; Tang, M.; Wang, Y.; Zhang, M.; Bai, Y.; Song, B.; Shen, Z.; Gu, D.; Yin, Z.; Liu, G.	The Injuries and Helmet Use in Bike Share Programs: A Systematic Review	2021	13	Global	x							x		Focus on safety and helmet use
Chen, Z.; van Lierop, D.; Ettema, D.	Dockless bike-sharing systems: what are the implications?	2020	77*	North America***	x						x	x	x	Focus on individuals' user experiences
Dibaj, S.; Hosseinzadeh, A.; Mladenović, M.N.; Kluger, R.	Where have shared e-scooters taken us so far? A review of mobility patterns, usage frequency, and personas	2021	25	North America (Europe)			x				x			
Elmashhara, M.G.; Silva, J.; Sá, E.; Carvalho, A.; Rezazadeh, A.	Factors influencing user behaviour in micromobility sharing systems: A systematic literature review and research directions	2022	203	Global	x		x				x			
Eren, E.; Uz, V.E.	A review on bike-sharing: The factors affecting bike-sharing demand	2020	155*	Global	x					x	x	x		Factors affecting demand of station-based systems

Ferrero, F.; Perboli, G.; Rosano, M.; Vesco, A.	Car-sharing services: An annotated review	2018	137	NA		x				x	x			Scientometric analysis
Fishman, E.	Bikeshare: A Review of Recent Literature	2016	80*	Global***	x					x	x	x		
Golalikhani, M.; Oliveira, B.B.; Carravilla, M.A.; Oliveira, J.F.; Antunes, A.P.	Carsharing: A review of academic literature and business practices toward an integrated decision-support framework	2021	130	NA		x				x	x	x		Focus on commercial (B2C) services
Hirsch, J.A.; Stratton-Rayner, J.; Winters, M.; Stehlin, J.; Hosford, K.; Mooney, S.J.	Roadmap for free-floating bikeshare research and practice in North America	2019	93*	North America***	x					x		x		Free-floating BSS
Illgen, S.; Höck, M.	Literature review of the vehicle relocation problem in one-way car sharing networks	2019	35	NA		x				x	x			Modeling (vehicle relocation problem)
Jorge, D.; Correia, G.	Carsharing systems demand estimation and defined operations: A literature review	2013	26	NA		x				x				Modeling
Kent, J.L.	Carsharing as active transport: What are the potential health benefits?	2014	7	North America		x						x		
Laporte, Gilbert; Meunier, Frédéric; Wolfier Calvo, Roberto	Shared mobility systems: an updated survey	2018	74*	NA	x	x				x				Modeling

Liao, F.; Correia, G.	Electric carsharing and micromobility: A literature review on their usage pattern, demand, and potential impacts	2020	64*	Global	x	x	x				x	x		Focus on electric mobility. Focus on users and usage.
Machado, C.A.S.; Hue, N.P.M.S.; Berssaneti, F.T.; Quintanilha, J.A.	An overview of shared mobility	2018	113*	NA	x	x			x	x	x			
Nansubuga, B.; Kowalkowski, C.	Carsharing: a systematic literature review and research agenda	2021	279	NA		x				x	x			Includes focuses on P2P services
Nath, R.B.; Rambha, T.	Modelling Methods for Planning and Operation of Bike-Sharing Systems	2019	156*	NA	x					x				Modeling
Oeschger, Giulia; Carroll, Páraig; Caulfield, Brian	Micromobility and public transport integration: The current state of knowledge	2020	48	Global	x		x		x					Integration with PT, synthesis of research agendas
Roukouni, A.; Correia, G.H.A.	Evaluation methods for the impacts of shared mobility: Classification and critical review	2020	132*	Europe	x	x	x		x	x			x	Identification of research topics
Santos, G.	Sustainability and shared mobility models	2018	78*	NA		x			x			x	x	
Teixeira, J.F.; Silva, C.; Moura e Sá, F.	Empirical evidence on the impacts of bikesharing: a literature review	2021	77	Global	x							x	x	Oriented towards impacts and benefits of BSS

Vallez, C.M.; Castro, M.; Contreras, D.	Challenges and opportunities in dock-based bike-sharing rebalancing: A systematic review	2021	75*	Global	x					x				Scientometric analysis Modeling (vehicle relocation problem)
Zheng, L.; Li, Y.	The development, characteristics and impact of bike-sharing systems: A literature review	2020	55*	Asia***	x					x	x	x	x	
Total					19	13	8	1	6	19	14	12	9	

* When the authors did not state the number of articles reviewed, we used the total number of references of the article as a proxy

** For this narrative review, we counted the number of references that were directly focused on VSS

***Articles for which the regional focus is part of the method rather than the result of the selection of the articles reviewed