

Article

The Role of Shared E-Scooter Systems in Urban Sustainability and Resilience during the Covid-19 Mobility Restrictions

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Abstract: Shared e-scooter systems were first introduced in 2017 and have since been spreading around the world as a sustainable mode of transport. The success of this mode is also due to new urban mobility strategies and plans, such as the European Sustainable and Smart Mobility Strategy, which relies on non-pollutant modes. To display the range of effects that can be achieved in urban mobility through the proper implementation of shared e-scooter systems, a systematic literature review and a case study were performed. It was found that this shared system can help cities with environmental issues, such as reducing air pollution, reducing inequality in access to transport, promoting money-saving, and improving mobility resilience. During the Covid-19 pandemic, shared e-scooters became a great asset in many cities worldwide, because they promote social distancing and help cities not to rely only on private cars to replace public transport rides, especially for short-distance trips. In the case study of Braga, it was found that the city still relies on shared e-scooter modes as a mobility option after the pandemic, also promoting special fares for people to start using the service.

Keywords: micromobility; shared e-scooters; sustainable urban mobility; covid-19; first-mile-last-mile; urban resilience



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1. Introduction

As a form of shared micromobility in cities, e-scooter sharing systems were first introduced in the United States in 2017. In Europe, these self-service and dockless rental services have been proliferating in France since the arrival of the first providers in Paris in the summer of 2018 [1]. According to Lime [2], e-scooter rides exceeded 100 million rides in 2019, and in Madrid, Prague, and Greece more than 1 million rides using e-scooters were made until 2019. In Asia, as a more recent introduction, e-scooters started to be ridden in South Korea in the second semester of 2019 [3].

This exponentially growing trend in urban mobility [4] started with the first wave of micromobility in cities, which was promoted by the expansion of bicycle infrastructures in cities and led to opportunities for the current number of dockless bicycles and e-scooters available throughout the world [5]. The e-scooters themselves have been used in cities before, as they once were an active part of transportation in the 1910s to 1940s. The revolution now seen in urban areas is enabled by smart mobility dissemination, including the ability to access shared e-scooters using personal smartphone devices and the evolution in electric batteries and smart grids [6].

This technological revolution has been responsible for changes in micromobility usage around the world. Since 2018 micromobility has experienced a switch in its main modes of transport, ranging from non-electric dockless bikes to dockless e-bikes and e-scooters, which has led to shared micromobility reaching its highest value of 84 million trips in the U.S.A. in 2018, this number being shared between e-scooters, dockless bicycles, and station-based bicycles [7].

In Europe, Paris is an example of the spread of micromobility options. After the massive operation of shared bicycles in the city, it only took one year of operation for the number of e-scooter to reach 20,000 units operated by 12 different operators [8]. In Spain, Lime [9] reported that in only one year of operation, more than 400,000 riders made more than 1.5 million trips in shared e-scooters throughout the country with an average length of 2 km per trip. In Portugal the number was a little higher, as Lime [10] reported more than 1.8 million trips taken in one year of operation in Lisbon, and these trips were being made by either residents or visitors of the city.

Moreover, the expansion of micromobility in cities is also due to new urban mobility strategies that have been implemented by governments in order to improve displacements and well-being in cities. In Europe, the sustainable and smart mobility strategy relies on non-pollutant modes of transport, such as micromobility options to significantly reduce the transport sector emissions, as well as to help increase the resilience of the sector, by ensuring that the transport system is truly resilient against future crises [11].

Yet, one major problem to expand micromobility operations, namely e-scooter sharing systems, is the lack of regulations around this “new” mode of transport. Recently, cities around the world have been working on shared e-scooter trials and pilot plans to better regulate its usage. In the United States of America, Chicago performed a shared e-scooter pilot program in 2019 to better understand how the system could be better used when implemented to boost mobility and to reduce inequality among users [12,13]. In the European context, France performed a massive e-scooter survey throughout the country to better understand how, where, and when people ride shared e-scooters [14]. In 2020 London established e-scooter trials to support a green restart of local travel and help mitigate public transport capacity due to Covid-19 pandemic restrictions [15].

The recent pandemic also helped the spread of micromobility and shared e-scooter systems. In times of social distancing, it is expected that people travel less and try to avoid crowded public transport, as well as seek more physical activity [16,17], which can be achieved with micromobility options, and active modes of transport.

Thus, this article aims at discussing how shared e-scooters are used in cities and how they can help urban mobility to achieve sustainability goals in its three pillars—environmental, social, and economic, as well as urban and transport resilience, mainly after the Covid-19 pandemic. From that perspective, this article will also discuss how shared e-scooter systems were used to help mitigate the spread of Covid-19 in different cities around the world, thus achieving more resilient urban mobility. Special focus will be given to the case study in the city of Braga, located in the north of Portugal to show how shared e-scooter systems were used before and after the pandemic. Changes that occurred in this city are related and compared with other experiences around the world to highlight the range of planning opportunities in urban mobility to build more resilient cities in the post-Covid-19 era. Finally, a discussion will be made on how to enhance the positive effects of shared e-scooters as a first-mile-last-mile transport mode, to avoid possible risks and help cities reduce crowded public transport while enabling social distancing, sustainability, and mobility resilience.

2. Worldwide Cities’ Take-Up of E-Scooter Sharing Systems

The advent of shared e-scooter schemes in 2017 made people change the way they commute in many cities around the world, such as Paris, Lisbon, Madrid, San Diego, Santa Monica, and Portland. To exemplify, in 2012 and 2013, 2% of the population over the age of 18 in metropolitan areas were members of carsharing services [18], while in less than one year of availability in some cities, e-scooter sharing has experienced an average adoption rate of 3.6% as measures by the percentage of people who have used these services [18].

In the United States of America, by August of 2020, 145 e-scooter sharing schemes were serving 69 cities across the country [19]. The number of e-scooter schemes increased through 2019 then declined almost 40% from 2019 to 2020 due to the Covid-19 pandemic restrictions. In 2018, there were 82 e-scooter systems throughout the USA, while in 2019

115 systems were seen, and in 2020 only 69 remained [19]. Some of the cities that provide e-scooters sharing systems in the U.S.A. and the companies running them can be found in Table 1.

Table 1. Shared e-scooter schemes in the U.S.A. by 2020.

| City | Companies Operating (by 2020) |
|--------------------|--|
| San Francisco, CA | Spin, Scoot |
| San Diego, CA | Bird, Spin, Lyft, Wheels |
| Los Angeles, CA | Bird, Jump, Lyft, Spin, Sherpa, Wheels |
| Long Beach, CA | Bird, Lime, Gruv, Razor |
| Santa Monica, CA | Bird, Lyft |
| Freemont, CA | Hopr |
| Portland, OR | Spin, Razor, Lime, Bird |
| Boise, ID | Lime, Bird, Spin |
| Bozeman, MT | Blink Rides |
| Salt Lake City, UT | Bird, Lime, Spin, Razor |
| Ogden, UT | Lime |
| Farmington, UT | Spin |
| Denver, CO | Lyft, Razor, Spin, Bird, Lime |
| Tucson, AZ | Razor (Pilot) |
| Tempe, AZ | Razor |
| Austin, TX | Bird, Lime, Spin, Wheels |
| Corpus Christ, TX | Blue Duck |
| San Antonio, TX | Bird, Razor |
| Dallas, TX | Lime, Bird, Wheels |
| Plano, TX | Boaz Bikes, Razor |
| Oklahoma City, OK | Lime |
| Stillwater, OK | Bird, Lime |
| Kansas City, KS | RideKC scooter, Bird, Spin |
| Wichita, KS | Spin, Voeride |
| Minneapolis, MN | Bird, Lyft |
| St. Paul, MN | Lime |
| Detroit, MI | Bird, Spin |
| Ann Arbor, MI | Spin |
| Lansing, MI | Gotcha |
| Nashville, TN | Lime |
| Atlanta, GA | Bird, Spin, Helbiz, Veoride |
| Tampa, FL | Spin, Bird, Lime |
| Fort Pierce, FL | Zagster |
| Orlando, FL | Wheels |
| Charlotte, NC | Bird, Lime, Spin |
| Blacksburg, VA | Spin |
| Virginia Beach, VA | Bird, Lime, Veoride, Spin |
| Washington, D.C. | Jump, Lyft, Skip, Spin |
| Baltimore, MD | Lime, Spin |
| Providence, RI | Veoride, Spin |

Source: [19].

In several European cities, an increasing amount of e-scooters and free-floating bicycle schemes were rolled out recently, as the year 2019 can be considered the year of the shared e-scooter [20]. In Brussels, for example, there are around 3000 free-floating e-scooters and bicycles, and the e-scooters are mostly used for 2 km to 3 km trips [20]. In Paris, more than 20,000 shared e-scooters [21] are rented daily for commuting during the weekday for a 19-min trip [14]. This massive adoption of shared e-scooters (as a purchase pattern) is also promoted by enlarging the access to the internet, which allows people to rent the e-scooters through mobile apps and share their experience through user-generated content (UGC) [22].

Moreover, a recent survey in Europe showed that among countries with shared e-scooter systems (Austria, Belgium, Czech Republic, Denmark, Germany, Greece, Finland,

France, Hungary, Italy, Netherlands, Norway, Poland, Portugal, Serbia, Spain, Sweden, and Switzerland) only in Denmark there are an estimated 7000 shared e-scooters (0.001 e-scooter per resident), in Norway an estimated 11,000 (0.002 e-scooter per resident) and in Sweden an estimated 17,000 (0.002 e-scooter per resident). In Germany, it is estimated that there are around 50,000 shared e-scooters (0.0006 e-scooter per resident). In other countries, only the estimate of shared e-scooters in a town or city was possible, such as Thessaloniki city (Greece) with more than 100 shared e-scooters (0.0001 e-scooter per resident), Lisbon (Portugal) with around 4000 shared e-scooters (0.008 e-scooter per resident), and Stockholm (Sweden) with around 9000 shared e-scooters (0.009 e-scooter per resident) [23]. Table 2 shows data from three different companies that provide shared e-scooter services in Europe and the cities where the offer is present.

Table 2. Shared e-scooter systems in Europe.

| E-Scooter Company | Country | Cities | |
|-------------------|----------------|---|----------|
| Bolt | Czech Republic | Boskovice, Brno, Frydek-Mistek, Mladá Boleslav, Olomouc, Pardubice, Prague | |
| | Estonia | Parnu, Talin, Tartu | |
| | France | Bordeaux | |
| | Croatia | Osijek, Rijeka | |
| | Lithuania | Kaunas, Klaipeda, Panevezys, Vilnius | |
| | Latvia | Daugavpils, Jelgava, Liepaja, Riga, Valmiera | |
| | Malta | Malta | |
| | Norway | Bergen, Fredrikstad, Lillestrom, Oslo | |
| | Poland | Bialystok, Gdansk, Gdynia, Katowice, Krakow, Lublin, Poznan, Silesia, Sopot, Trojmiasto, Warsaw, Wroclaw | |
| | Portugal | Braga, Lisbon, | |
| | Romania | Bucharest, Cluj-Napoca, Constanta, Galati, | |
| | Sweden | Gothenburg, Stockholm | |
| | Lime | Austria | Vienna |
| | | Belgium | Brussels |
| Bulgaria | | Sofia | |
| Czech Republic | | Brno, Pilsen, Prague | |
| Denmark | | Copenhagen | |
| Finland | | Helsinki | |
| France | | Lyon, Paris, Toulouse | |
| Germany | | Berlin, Bonn, Brunswick, Cologne, Dortmund, Dresden, Dusseldorf, Essen, Frankfurt, Hamburg, Hannover, Karlsruhe, Munich, Nuremberg, Ruhrpott, Stuttgart | |
| Greece | | Chania, Rethymno, Thessaloniki | |
| Hungary | | Balaton, Budapest | |
| Italy | | Milan, Rimini, Rome, Turin, Verona | |
| Norway | | Oslo | |
| Poland | | Krakow, Poznan, Tricity, Warsaw, Wroclaw | |
| Portugal | | Lisbon | |
| Romania | | Bucharest, Cluj-Napoca | |
| Spain | | Barcelona, Madrid, Malaga, Seville | |
| Sweden | | Gothenburg, Malmo, Stockholm | |
| United Kingdom | | London, Milton Keynes | |

Table 2. Cont.

| E-Scooter Company | Country | Cities |
|-------------------|-------------|--|
| Bird | Austria | Vienna |
| | Belgium | Antwerp, Brussels |
| | France | Bordeaux, Bretigny-sur-Orge, Marseille, Orange, Villemonble, Viry-Chatillon |
| | Germany | Berlin, Chemnitz, Cologne, Darmstadt, Dortmund, Dusseldorf, Erfurt, Frankfurt, Gelsenkirchen, Gottingen, Hamburg, Hannover, Heidelberg, Heilbronn, Karlsruhe, Kassel, Ludwigshafen, Munich, Neckarsulm, Neu-Ulm, Oldenburg, Pforzheim, Regensburg, Reutlingen, Rostock, Troisdorf, Ulm, Wurzburg |
| | Italy | Aprilia, Firenze, Milano, Palermo, Pesaro, Rimini, Rome, Torino, Verona, Viareggio |
| | Norway | Bergen, Oslo |
| | Portugal | Braga, Lisbon, Porto |
| | Spain | Madrid, Malaga, Terragona, Zaragoza |
| | Sweden | Gothenburg, Stockholm |
| | Switzerland | Basel, Winterthur, Zurich |
| | UK | Canterbury, Redditch |

Source: [24–26].

The data from Table 2 shows that more than 18 countries in Europe offer a shared e-scooter service, and this service reaches both big and small size cities in different countries. The establishment of shared e-scooter services in Europe is already solid, and the success of its usage reflects the need for more sustainable and efficient modes of transport to enable commuters to choose something different from private vehicles and sometimes crowded and inefficient public transport.

3. Theoretical Framework

3.1. City Resilience

According to [27], “city resilience focuses on increasing—or at least securing—the performance of urban systems in the face of multiple hazards in crises, rather than preventing or solely mitigating the loss of assets due to a specific event”. When applied to transportation systems, resilience can be seen as the ability to resist, reduce, and absorb the impacts of disturbance, maintaining an acceptable level of service, and restoring the regular and balanced operation within a reasonable time and cost [28].

One major step towards a more sustainable, resilient, and human-centric mobility system will depend a great deal on whether stakeholders act according to the opportunities they have. Among them, it is possible to point out city governments and transport authorities, which can act on the system by regulating each of its components, as well as enabling other system actors to move things forward coherently and effectively, in a way to invest in physical and digital mobility infrastructures [29].

Recently, what brought disturbance to life in cities and consequently to urban mobility was the Covid-19 pandemic. The lockdown policies around the world, which included border closures and travel bans, public activity restrictions, and school and business closures [30] changed how people circulate in the matter of travel-distance and mode of transport, which translates into some behavioral trends, such as the fear of infection in public transport and shared mobility, as well as the adoption of healthier mobility modes (e.g., walking, cycling, e-scooters). Although, this issue has not been openly discussed in recent literature.

To envision urban mobility to be ready, or at least more resistant to current and future disturbances, shared e-scooters can help cities achieve resilient principles [27,31], such as (i) reflectiveness, as they can contribute to the constant evolution of mobility systems; (ii) robustness, as they can be conceived to maintain their function despite hazards and dysfunctions; (iii) redundancy, as they can save efficiency to accommodate disturbances; (iv) flexibility, as they can adapt in cities depending on the circumstances; (v) resourcefulness,

as the usage of the system can be modified according to needs; (vi) inclusiveness, as they can promote mobility for a more diverse public; and (vii) integrated, as they can be aligned with other city systems to promote consistency in decision-making.

Besides, the Covid-19 pandemic enabled a set of actions by authorities to reset mobility in order to achieve its sustainability and resilience. Special attention was given to investments in physical mobility infrastructure, which includes extensive cycling-network extension to boost active travel (e.g., walking and cycling) and mobility devices (e.g., e-scooters); also the introduction of incentives to encourage adoption of soft and shared mobility modes, such as e-bikes and e-scooters [29].

Thus, it can be seen throughout literature that sustainable and resilient cities for the future need to invest in modes such as e-scooters and shared e-scooters in order to improve mobility as well as provide a better quality of life for the residents. One proof was the measures taken during the Covid-19 pandemic, which culminated in a series of actions towards active, electric, and shared mobility.

3.2. Sustainable and Smart Mobility

In a world where shared systems have been used for a long time, especially shared bicycles and more recently shared e-scooters, the use of technology to collect data that includes temporal and spatial patterns can help understand people's behavior and the impacts and limitations of these solutions to promote urban sustainability [32]. Besides, if all elements associated with urban mobility are connected and integrated, much better decisions can be taken on a real-time basis [33].

In addition, urban mobility is a key factor behind the smart and sustainable development of cities, which translates into a heavy investment in transportation infrastructure as an approach to ensure smart and affordable means of transport to citizens [34]. In recent years, technology has played an important role in promoting more sustainable transport modes (e.g., public transport and active modes), as smart mobility aims to offer a seamless mobility experience, which is flexible, integrated, safe, on-demand, and convenient [35].

Some of the attributes related to smart mobility are flexibility (allowing users to choose multiple modes through smart and dynamic navigation), efficiency (provision of efficient mobility options), integration (end-to-end route plans independent of transport modes), sustainability (promotion of cleaner and sustainable operations), security and safety (efficient data sharing and connectivity models to ensure road safety), social benefits (provision of equal opportunities to use public transport), automation (facilitates automation in all processes), connectivity (all entities in the network are connected), accessibility (affordable to all), and user experience (efficient processes to ensure better experience) [34].

Those attributes are added to some implications of smart mobility, which are closely related to the usage of shared and electric micromobility (e.g., shared e-scooter systems). Some of these implications are the shift towards a shared experience instead of ownership of vehicles, for example, which is added to the new user-generated and user-centered real-time data that can impact users' purchase patterns [22], along with 'intelligent' infrastructure that includes connected vehicles, and the electrification of vehicles (usage of batteries) [36].

Making smart mobility sustainable remains a common challenge across cities [37]. Sustainable urban mobility plans can be implemented through a collaborative and integrated approach by focusing on people's needs [38]

4. Methodology

This research systematically analyses the scientific literature available regarding shared micromobility, shared e-scooter systems, their role, and presence in smart, sustainable, and resilient mobility solutions for cities, along with its usage during the Covid-19 pandemic. Thus, the literature available about the subject is composed of scientific journal publications, company reports, government reports, and manuals edited by urban mobility experts. The procedure to collect the literature was composed of four different phases [31], which started with a comprehensive gathering of literature using relevant databases, such

as Web of Science (SCOPUS), Google Scholar, and Web of Knowledge (Clarivate Analytics). Furthermore, Google was also used as it is a source of abounding technical documents from research companies and reliable transportation entities, such as the Shared-Use Mobility Center, Arcadis, and Populus.

Phase 2 started with the application of general keywords for research, such as “Micromobility”, “Shared micromobility”, “E-scooters”, “Shared e-scooters”, “Sustainability and micromobility”, “Smart and sustainable cities”, “Urban resilience”, “Resilience in urban mobility and transport”, and “Micromobility and Covid-19 pandemic”. Most of the articles available about the subject, mainly about e-scooters, were published in the last five years, and the ones selected were published in journals indexed in Clarivate Analytics and/or Scopus, once these databases include works that go under more rigorous revision processes. In addition, reports and documents from established entities were selected.

Next, phase 3 was composed of the snowballing technique to incorporate additional literature that was identified in the citations made in each publication previously incorporated [39]. After these 3 phases, more than 90 scientific articles, governmental reports, and company reports were obtained. To conclude the research process, phase 4 was performed, which represented a narrowing of the relevant literature found in phase 3, which resulted in a total of more than 80 documents that were used for this paper. Yet, these documents were studied and analyzed in-depth, especially regarding the matter of main characteristics of shared micromobility/e-scooters, the sustainability-related opportunities when implementing shared micromobility systems in urban environments, and its impacts and usage during the Covid-19 pandemic.

This information was retrieved in order to explain how shared e-scooter systems can be used as an asset in cities to promote sustainability (environmentally, socially, and economically), and resilience, mainly after the Covid-19 pandemic, which can be described as a disturbance for the way mobility is planned to accommodate citizens.

In addition, a case study was performed to analyze the measures taken around the world to promote shared e-scooters as a means to boost urban mobility, sustainability, resilience, and prevent the spread of the Covid-19 pandemic, namely for home-work commuters. Moreover, information from shared e-scooter usage in the city of Braga was obtained from the Municipality of Braga in order to illustrate and understand how the service was used before the pandemic and what happened to it when the pandemic started.

5. Literature Review: Impacts of E-Scooter Sharing Systems on Sustainability

Shared e-scooter systems gained popularity as an environmentally friendly transport [40], as its usage can result in several benefits, such as the increase of community cohesion, possible reduction of traffic congestion (for short-distance trips), and lower emission levels, therefore contributing to improving air quality [41]. On the other hand, the current lifespan of e-scooters raised concerns about their direct environmental benefits [42], but a more recent study emphasizing the increase of the lifespan of e-scooters by 9.5 months can be an asset to make them a green choice for urban mobility [43], which can be translated into a higher mileage achieved by each e-scooter, which could represent a drop of up to 76% of their carbon footprint [44].

Besides, shared e-scooters systems, as an electric-powered mode of transport, can help to reduce the emission of pollutant gases to the atmosphere if they are used to replace fossil-fuelled vehicle trips [45]. Data from Lime [46] shows that only in Paris, in more than one year, e-scooter rides replaced 1.2 million motor vehicle trips and kept more than 330 tonnes of CO₂ from being emitted into the atmosphere. However, the use of shared e-scooters can generate three different activities that pollute the environment, such as the pickup and drop-off of charged e-scooters by fossil-fuelled vehicles, the displacement of e-scooters by pollutant vehicles when some repair is needed, and battery charging when the required electricity is generated by polluting resources [47]. However, these pollutant trips generated by the e-scooter services can be replaced by greener options if proper planning strategies and policies [48] are applied by municipalities and the companies that

provide the service, as well as the energy to charge the batteries of the e-scooters can come from renewable sources to enhance the sustainability of this mode of transport, such as solar-powered charging systems [49].

In addition, the global warming impacts associated with the use of shared e-scooters are highly associated with the materials used, the manufacturing procedure, and the automotive use for e-scooter collection and charging [42]. To help increase the sustainability ratio of this mode of transport some strategies need to be taken, such as increasing the lifespan of e-scooters, the reduction of collection and redistribution of e-scooters by using more efficient vehicles, as well as making less frequent battery charges [42,50].

As a result of these actions, in Munich, Germany, shared e-scooters are seen as a benefit to the environment, as they have low energy consumption, produce less noise and fewer air pollutants, as well as helping overcome congested, exhausted riddled streets and over-crowded parking spaces by substituting cars. The data from the pilot program performed in Munich shows that shared e-scooters could cover up to 60% of daily trips by replacing cars, especially the ones for commuting and leisure purposes, also, up to 50% of all trips in Munich are suitable to be made by an e-scooter [51].

In addition, despite the possible complaints from dwellers about pedestrian safety and the impact of the emerging shared e-scooters on urban public spaces in Europe. They are believed to help cities ease problems with traffic, emission, and parking [52,53]. A survey conducted in Brussels showed that 25% of the respondents said that one of the reasons for them to use shared e-scooters was to lower the air pollution in the city [43], which can translate into a positive effect on human footprint, especially if shared e-scooter trips replace private car trips [54]. Besides, the use of both e-bikes and e-scooters in urban logistics to replace traditional combustion engine vehicles has been demonstrated to have environmental and social effectiveness [55].

If considering the social benefits of shared e-scooter usage, it could reduce the gender gap in transport use, as women can feel safer on e-scooters because they are smaller in comparison to other transport modes [56] and are more easily ridden on sidewalks; along with the possibility of wearing skirts and dresses that make it easier to stand on an e-scooter than on a bicycle; women are also more distance-sensitive and are less likely to bike long distances, and both e-bikes and e-scooters enable everyone to travel greater distances easily [57].

Furthermore, new micromobility solutions such as shared e-scooters can help cities to develop policies to incentivize the equitable placement of micro-vehicles [58,59]. One possibility could be the creation of programs and policies to distribute shared e-scooter in cities considering undeserved developments and focus on portions of the city with the highest social impact [60]. Lee et al. [61] also points out that low-income people prefer shared e-scooter services for first-mile and last-mile trips, but governments should take special action on promoting a policy reducing the fares of shared e-scooters, as well as fare integration systems allowing for multiple modes of public transport.

For economic purposes, shared e-scooters' main motivation for usage can be seen as travel time savings followed by playfulness and money savings [62], as they are cheaper than hailing a ride-share vehicle [63]. For urban drivers on short-distance trips, shared e-scooters would be a more cost-effective alternative to car ownership [64].

Table 3 shows a collection of references where the three aspects of sustainability in shared e-scooter usage are approached as a means to shed light on how this service can be used in urban environments to achieve more sustainable mobility for all.

Table 3. Sustainability in shared e-scooter usage.

| Reference | Sustainability Aspect | | | | Methodology | | | |
|--------------------------------|-----------------------|--------|----------|-----------------------|-------------|--------|------------------------|----------------|
| | Environmental | Social | Economic | Discussion/ Review | LCA | Survey | Geospatial Analysis | Pilot Study |
| Chang et al., 2016 | x | | | | x | | | |
| Clewlou et al., 2018 | | x | | | | | x | |
| Populus, 2018 | | x | | | | | x | |
| Zagorskas and Burinskien, 2019 | x | | | x | | | | |
| Smith and Schwieterman, 2019 | x | | x | | | | x | |
| Hollingsworth et al., 2019 | x | | | | x | | | |
| Schellong et al., 2019 | | | x | x | | | | |
| Hardt and Bogenberger, 2019 | x | | | | | | | x |
| Fong and Mcdermott, 2019 | x | | | x | | | | |
| Moreau et al., 2020 | x | | | | x | | | |
| Gössling, 2020 | x | | x | x | | | | |
| Caspi et al., 2020 | | x | | | | | x | |
| Holm Moller and Simlett, 2020 | x | | | x | | | | |
| Bortoli, 2020 | x | | | | x | x | | |
| Christoforou et al., 2021 | x | | x | | | x | | |
| Hosseinzadeh et al., 2021 | | x | | x | | | | |
| Lee et al., 2021 | | x | | | | x | | |
| Almanaa et al., 2021 | | x | x | | | x | | |

Table 3 shows that the environmental effects of shared e-scooter usage are still the main subject of research in the recent literature, whereas its social and economic effects are still understudied. On the other hand, geospatial analysis, Life Cycle Assessment (LCA), and discussions/revisions are the main methods used to describe the impact of shared e-scooters on cities. These are behavioral and attitudinal studies that are quite needed to deepen the studies on this matter. Table 4 shows the main terms of research used to find available literature to compound Table 3.

Table 4. Terms of research used in Scopus and Web of Science (WoS).

| Keywords/Query | Scopus | WoS |
|--|--------|-----|
| (e-scooter) | 233 | 168 |
| (e-scooter) AND (life cycle assessment) | 9 | 7 |
| (e-scooter) AND (urban sustainability) | 8 | 8 |
| (e-scooter) AND (sustainable transport) | 17 | 14 |
| (e-scooter) AND (field test) | 5 | 3 |
| (e-scooter) AND (environmental assessment) | 13 | 8 |
| (e-scooter) AND (spatial analyses) | 12 | 10 |

Table 4 shows the different subjects searched to compound the studies of the impacts of sharing e-scooters systems in sustainability with different methodologies (discussion, LCA, survey, spatial analyses, pilot studies). The methodology used [65] comes to demonstrate that even if the number of papers about e-scooters and shared e-scooters in both platforms (Scopus and WoS) is growing over the years (when comparing the number of publications by year from 2016 until 2021), the ones focusing on sustainability impacts are still low.

6. Case Study

6.1. Impacts of COVID-19 on Urban Mobility and the Role of Shared E-Scooters

An initial investigation of the spread of the Covid-19 found that most cases are transmitted in an area or group where a large number of people gather in closed or crowded settings [66]. People started avoiding the use of crowded public transport in many cities around the world in an attempt to stop the spread of the Covid-19 [16], which culminated in historic low passenger demand for public transport use [17].

To bypass the shift from public transport to individual vehicles, cities around the world joined forces to invest in infrastructure to increase micromobility usage, especially to address daily mobility needs among commuters. Many countries have adopted policies, including financial support, for the relaunch of transport through more sustainable modes, which included an investment of €100 million in Italy to incentivize the transition to sustainable solutions, such as electric vehicles, e-bikes, and e-scooters, as well as the possibility for e-scooters to become part of the public transport offer [67].

To boost micromobility usage during the pandemic of Covid-19, Rotterdam, Netherlands, partnered with micromobility providers, such as Donkey Republic, Felyx, Check, Go Sharing, and Rotterdam Ahoy to ensure that 1500 shared bicycles and more than 1500 shared e-scooters are available in more than 25 public transit hubs throughout the city [68].

Milano, Italy invested in the Lazzaretto and Isola pilot projects to create more protected and accessible roads for everyone, offer new public spaces for adults and children, and encourage travel by foot/bicycle/e-scooter for urban displacements through a diversified, complementary, and alternative offer to public transport and private car. The municipality aims to free up public space through temporary pedestrianization of some roads, the widening of sidewalks, connections with existing cycle paths, implementation of new tactical urban planning intervention, and laying of outdoor areas [69].

In Rome, drastic measures were taken by the capital municipality in order to reduce dependence on personal automobiles. E-scooter operators such as Bird took a leading role in supporting this effort by promoting micromobility as an everyday alternative to cars that also allow for social distancing [70].

The e-scooter provider Lyft, with its program Lyftup started offering free 30-min rides for first respondents, the transit workforce, and healthcare providers in Denver, Colorado; Los Angeles, California; the Washington, D. C. area; San Diego, California and Santa Monica, California. This program is in addition to bicycle share programs offering free membership for critical workers on networks that Lyft operates including City Bike (New York), Divvy (Chicago), Bluebikes (Boston area), and Bay Wheels (SF Bay Area) [71]. In Europe, the shared e-scooter company Bird equipped Red Cross volunteers with a donated fleet of Bird e-scooters to enable easier transportation around urban neighborhoods [72] so they could provide healthcare assistant to those in need.

Other than that, to evaluate and study the resilience of alternative mobility systems such as public transport, bicycles, and e-scooters during the Covid-19 pandemic, shared micromobility companies such as Bird, Spin, Biketown Spin, and TriMet are sharing their survey data on riders' habits, preferences, and attitudes towards various shared transport modes with researchers [73]. Preliminary data from this study shows that almost 90% of respondents said they do not avoid taking shared e-scooter trips because of Covid-19, also, almost 20% of respondents said they replaced public transport trips with e-scooters trips during the pandemic [74].

Despite the shutdown of the shared e-scooter services in some cities around the world, this mode could be used to promote well-being and sustainable and safe transportation for people who need it the most when the pandemic started. This leads to the advantages of having shared systems in cities to help decrease the need for "traditional" transport modes [75], such as vehicles, and public transport, which became an unsafe option during the Covid-19 pandemic. In many cities, shared e-scooter services also played an important role in not letting people rely only on cars to avoid public transport, and consequently

increasing urban mobility and environmental problems related to the massive usage of private vehicles.

6.2. Insights from the E-Scooter Sharing System in the City of Braga

Considering what was shown in Section 6.1 about the diverse usage of shared e-scooter to fight the spread of the Covid-19 pandemic, e.g., replacing crowded public transport and being an alternative to car use, the city of Braga, in Portugal, was used as a case study to highlight the impacts of the pandemic in a city where the service of shared e-scooter was already established. In this section, it will be discussed how the service was offered before the pandemic and what happened to shared e-scooters after mobility in the city was reduced and somewhat forbidden, in order to stop the spread of the virus, and how shared e-scooters came back to the city with a hope to offer sustainable mobility for all.

6.2.1. Background Information

Braga is a municipality located in the North of Portugal in the sub-region of Cávado with more than 180,000 inhabitants in an area of 183 km², which represents a population density of 989.6 inhabitants per km² (data from 2011 [76]), distributed in 37 parishes.

Within the city, 175,231 commuting trips are generated daily, 84% of them being within the municipality, which represents a total of 147,248 trips that are mostly made by active individuals (66.7%), followed by trips made by students, which represent 33.3% of the displacements [77]. The most common modes of transportation used in these trips are cars, followed by walking, and bus [78]. This tendency to use individual vehicles has been growing in Braga if compared to data from the 2001 Census, and a decrease in trips by foot and by public transport have been noticed as well [79]. More than 65% of these trips are made in less than 15 min [77], which could be easily done by walking or a micromobility option, such as shared e-scooters.

The city has been working in the last few years to promote more active modes by expanding its pedestrian zone and the bicycle network. The pedestrian zones have been created since 1995 with the pedestrianization of the main streets of the city center, including the area of the Republic square and Souto street [80], and nowadays it counts more than 20,000 m² of area exclusively for pedestrian use [81]. The local government has been also assuming the need for better bicycle mobility infrastructure to achieve the sustainable mobility goals from the National Strategy for Active Mobility, which culminated in the creation of 22 km of cycling routes along with parking facilities to promote multimodality [82].

6.2.2. Shared E-Scooter Systems in Braga

The e-scooter sharing system started its operation in Braga on 19 August of 2019 with only one company providing the service. The former Circ (now Bird) started its operation with about 80 e-scooters distributed around the city center with expected expansion in the short term. In the following months of the same year, two other companies started to provide the same service; Hive and Frog. These e-scooters from the 3 companies were available in 22 different parking spaces allocated within the city center area [83]. These parking spots were converted from car parking spaces to accommodate bicycles and e-scooters (Figure 1), which contributes to a more efficient public space usage once the same space that only accommodated one car now can contain at least 10 different e-scooters.

Although riders do not need to park their shared e-scooters in the parking spots, it is considered a great asset to decrease the number of e-scooters parked on sidewalks blocking the walkways. Besides the parking spots, the City of Braga also created a “red zone”—that can be seen in the company app—where the maximum speed of the e-scooter must be reduced, and the wheels are blocked when the rider reaches a “no-circulation zone”. These areas were created to increase the safety of the e-scooter user and the pedestrians circulating in the area. This “no-circulation” zone covers some important streets of the city, such as Dom Diogo de Sousa Street, Souto street, Dom Paio Mendes Street, Dom Gonçalo Pereira Street, Rossio da Sé, Misericórdia Street, Eça de Queirós Street, Dr. Justino Cuz Street,

Francisco Sanches Street, Janes Street, S. Marcos Street, Liberdade Avenue, and Dr. Gonalo Sampaio Street. The map in Figure 2 covers the city of Braga with the “red zones” printed in “red” and the 22 e-scooter parking spots in green.



Figure 1. E-scooter parking spot converted from a car parking spot in Braga.

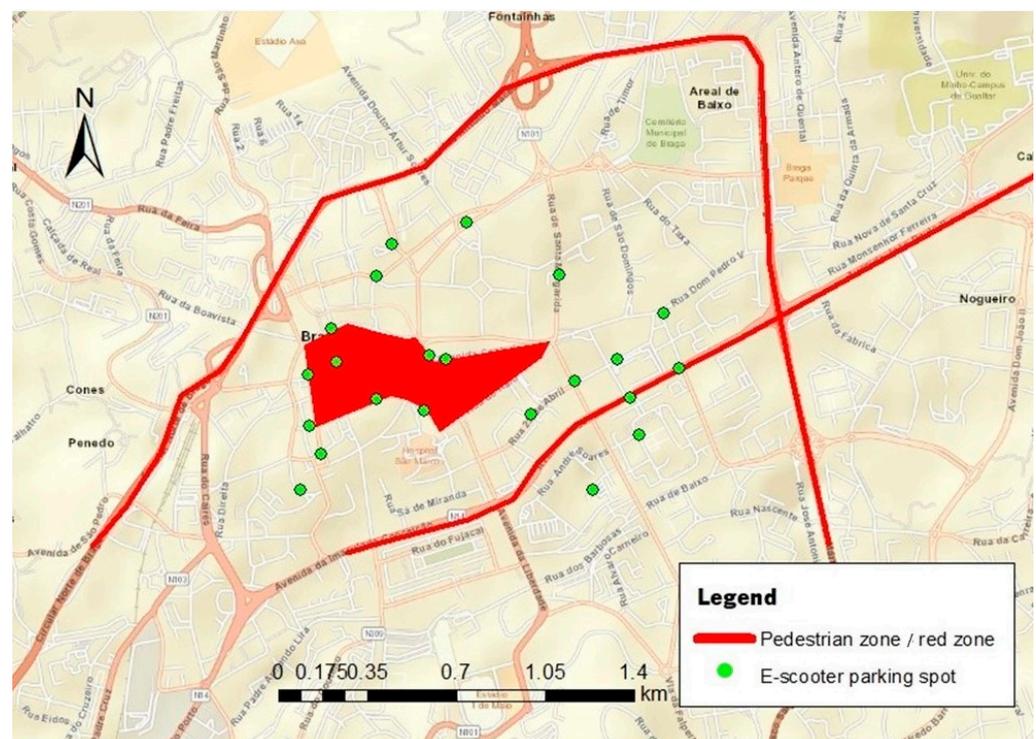


Figure 2. Red zones and e-scooter parking spots in Braga.

The three companies (Circ/Bird, Hive, and Frog) that offered the service in Braga before the pandemic let their applications allow users to unlock and ride their e-scooters throughout the city. In the app, users can find the location of the specific parking spots for e-scooters, besides the exact location of the available e-scooters for rent. It is important to

point out that only the Hive app shows the “red zone” in the city center (represented by the red spots in the walk-only zone of the city center), and the specific zone that the riders can travel within Braga boundaries.

The prices charged for the rides depended on each e-scooter provider. Bird (former Circ) and Hive charged €1.00 to unlock the e-scooter and more €0.15 for each minute traveled, but Bird also provided some different charging options, such as €6.00 per 1 h traveled, €10.00 for 2 h traveled, and €25.00 for 24 h possibility of taking the e-scooters for rides. Frog, on the other hand, did not charge users to unlock e-scooters, but charges €0.25 for each minute traveled.

6.2.3. Shared E-Scooter Usage in Braga before Covid-19 Pandemic

As Bird (former Circ) was the company that had more time to run the service in the city, most of the data available are from this service (Table 5). The Bird sharing system started in August of 2019 with 46 e-scooters—a different number from what was stated by the Municipality—and increased the number of e-scooters to reach a peak of 174 e-scooters by October of 2019. These e-scooters made an average of 4000 trips per month, and according to the data retrieved, from August to October e-scooters made more than one trip per day, and in November and December the average number of trips per e-scooter decreased to 0.8, which can be justified as in these months the temperature decreases, the days are shorter, and it starts raining more often in Braga. In addition, the weekends, and hours between 5 p.m. and 7 p.m. were the periods when e-scooters were more solicited, which can represent that e-scooters are more used for leisure activities [84].

Table 5. Bird e-scooter usage data in Braga in 2019.

| Metric | August | September | October | November | December |
|--------------------------------|--------|-----------|----------|----------|----------|
| Number of e-scooters | 46 | 110 | 174 | 103 | 98 |
| Number of trips per month | 1746 | 7159 | 6843 | 2439 | 2549 |
| Number of trips per e-scooter | 1.26 | 2.17 | 1.31 | 0.8 | 0.8 |
| Number of trips (average/day) | 58 | 239 | 228 | 81 | 82 |
| Number of km traveled | 4624 | 14,924 | 11,770 | 4004 | 4076 |
| Most solicited weekday | Sunday | Sunday | Saturday | Saturday | Tuesday |
| Most solicited hour of the day | 6 p.m. | 5 p.m. | 7 p.m. | 6 p.m. | 5 p.m. |

Source: [84].

At the end of the five months of Bird shared e-scooters in Braga, they have made more than 20,000 trips and traveled more than 40,000 km. According to data from the company, more than 95% of the users in Braga are from Portugal, and they take trips mostly during the evening, between 5 p.m. and 6 p.m. These trips usually start in the city center of Braga and end in the same region. Therefore, during September and October, most of the trips started and finished in the city center of Braga. On the other hand, in October people took e-scooters from the city center to travel to other areas of the city. During the last two months of the year (November and December of 2019) people stopped a pattern that had been seen in late September and October, which was the possibility of taking e-scooters from the city center to travel to further places. This can be justified by the decrease in the number of trips and the weather conditions since people do not tend to use shared e-scooters to travel further distances in bad weather.

6.2.4. Impacts of the Covid-19 Pandemic on Shared E-Scooter Usage in Braga

With the spread of the Covid-19 in Europe, Portugal started a lockdown on 18 March 2020. Among the measures taken by the government, dwellers could only circulate on the streets for very few reasons, including grocery shopping, health care, assisting vulnerable people, and exercising [85].

In Braga, with the state of lockdown, the shared e-scooters service was suspended until people could walk freely on the streets, which happened at the beginning of 2021. Since then, three different companies have resumed their services to the population. Starting in April of 2020, the city offered about 500 shared e-scooters by the companies Frog, Bird, and Bolt. For the service to be resumed some measures were taken to try to reduce the negative impact of this mode of transport in the city, such as the control of the speed, as e-scooters cannot run at speeds higher than 25 km/h in order not to disturb and to harm people's accessibility to public spaces. In addition, e-scooters must be allocated in specific parking spots distributed along within the city, where companies need to ensure their correct parking [86].

Besides, to increase usage of this mode of transport in the city companies started offering reductions in pricing. Bolt offered the service with a free e-scooter unlock and only 0.05€ per minute traveled (Figure 3). Bird, on the other hand, started providing 15-min trips for only 1€ (Figure 3), along with the offering of some trip packs to be used for one month or 90 days with price reduction.

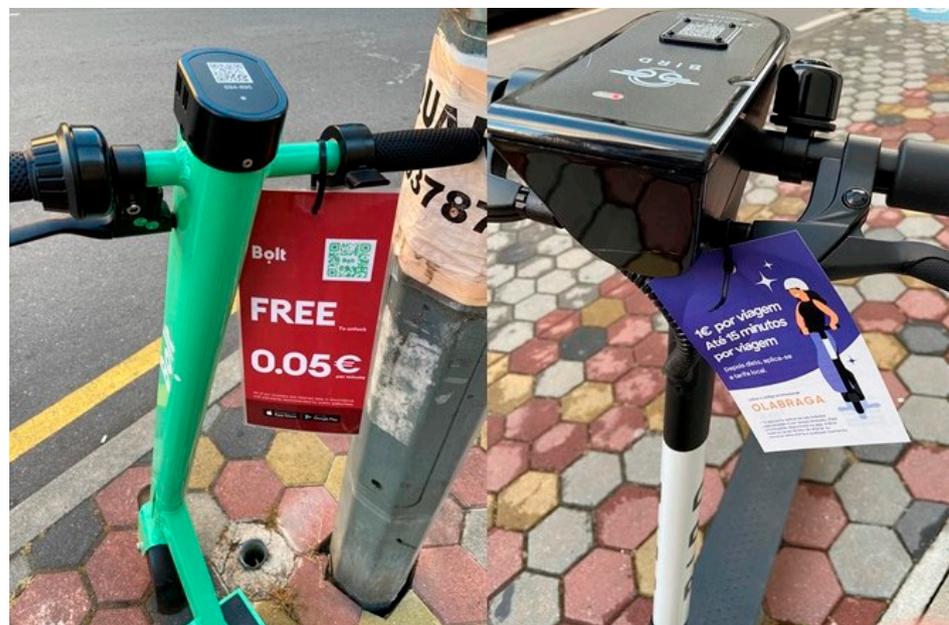


Figure 3. Bolt and Bird price reduction to increase e-scooter usage.

In addition, to boost e-scooter usage by young adults that attend the University of Minho and high schools within the central area of Braga, more parking spots were created to allocate the 500 e-scooters that were available (Figure 4).

It is possible to infer now that the Municipality of Braga invested in resuming shared e-scooter systems focusing on providing the service near places where younger people are able to rent them. As an example, the new parking spots created near the University of Minho campus, located on the right-upper part of Figure 4, are now part of more than 40 different parking spots in the central area of Braga that were created after the pandemic. This parking measure enables users to have more options to park shared e-scooters and avoids them leaving those vehicles on sidewalks obstructing people's right of way. Moreover, it contributes to helping the city to achieve higher mobility standards that can secure a more sustainable and resilient urban environment.

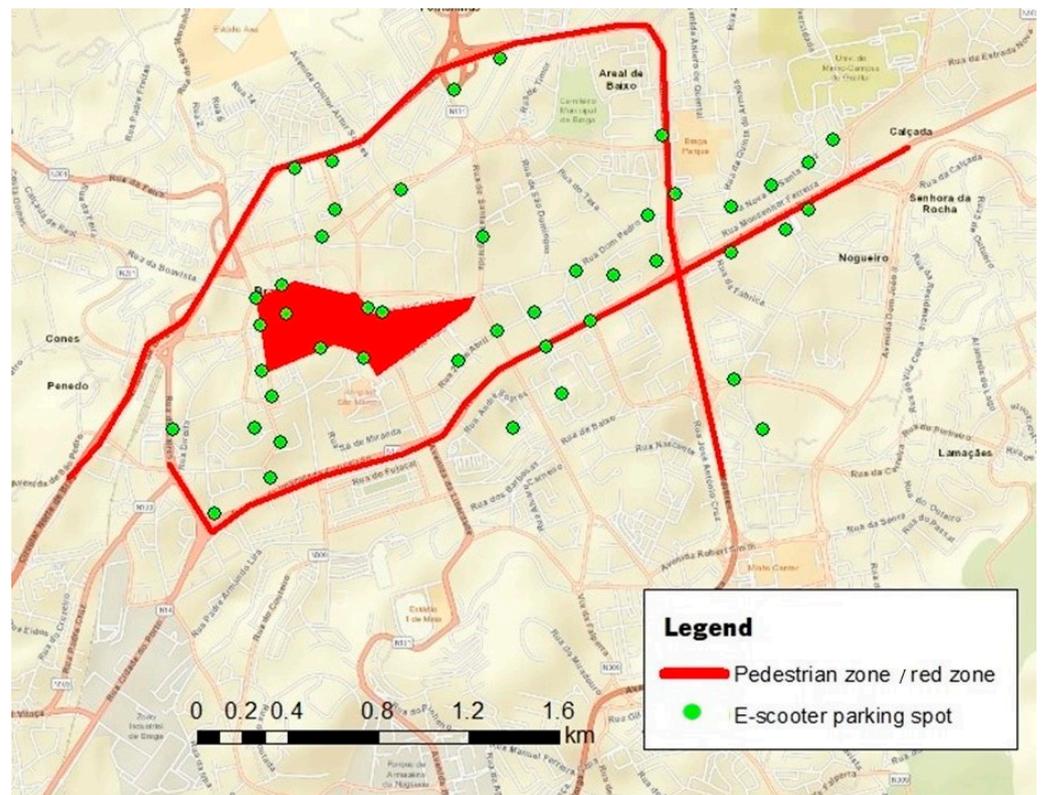


Figure 4. E-scooter parking spots after the pandemic.

7. Discussion and Conclusions

Shared e-scooter systems debuted in the summer of 2017 in the United States of America, and since then have been proliferating around the world, with the first appearance in Europe in 2018, in Paris [1], and in Portugal in October of 2018 [87]. This mode of transport faced a quick acceptance by users all around the world, and the rates of usage were reported to be higher than shared bicycles when implemented.

As a hope to ease traffic congestion, decrease air pollution, increase community relationships, and contribute to a more resilient urban mobility, shared e-scooters were adopted in cities, sometimes without any planning or policies to regulate their usage [52], which brought some problems for dwellers, such as accidents involving pedestrians and interruption in people's right of way on sidewalks [88–90]. However, the benefits of a proper introduction of this mode can bring the negative impacts down. As an electric-powered micro vehicle, e-scooters do not create air pollution by the trips made. On the other hand, the process of e-scooter manufacturing and the vehicular trips needed to replace e-scooters in cities and the charging of the batteries added to the short lifetime of the e-scooters itself can bring the positive environmental impacts to be reduced. However, recent research and improvements in e-scooter logistics and life cycle show that with small changes in these aspects, shared e-scooter systems in cities are a great asset to promote sustainable urban mobility.

Besides the positive environmental impacts caused by shared e-scooter usage in cities, it can still contribute to reducing transport social inequalities, mainly when comparing men's and women's participation in urban displacements. Shared e-scooters have proven that their usage can bring more women to use different transport modes. In addition, this mode can contribute to a higher distribution of transport accessibility to remote areas in different cities and is considered a mode of transport that can reach further areas and convince more people to use them.

Money savings can also occur when riding a shared e-scooters. People surveyed said they use this mode because of the savings they can make, and also because this mode can be considered a cheaper way to commute when comparing car-sharing and owning a car.

Unfortunately, with the spread of Covid-19, many cities around the world stopped offering this service to their residents. However, good practices could be felt in other cities, which enhanced shared e-scooters' role as a transport mode to promote sustainable urban mobility. Examples in various cities (Rome, Rotterdam, Milano, Braga, and the USA) show that this micromobility option can be used to avoid public transport trips and also stop the problem of modal shift from public transport to private cars in a pandemic world where social distancing and avoidance of public transport is the rule. In addition, cities can promote shared e-scooters combined with walking to enhance their trip length by implementing e-scooter parking spots within a walking distance from people's residences.

To corroborate with the worldwide trend of investing in micromobility options in cities, namely, to stop the spread of private cars to avoid public transport, the city of Braga was used as one illustrative case study example. The city already had a shared e-scooter system established before the pandemic, although, with the circulation restrictions approved by the government, the service was temporarily suspended. After a couple of months, three different companies started offering the service, and in order to stimulate people's usage, some incentives were offered, such as price reductions. This allowed more than 500 shared e-scooters to invade the streets of Braga, along with dedicated parking spots and municipality supervision to ensure the proper parking of the e-scooters to minimize disruption in peoples' ways on sidewalks and transit disturbances.

The comeback of the e-scooters to Braga brought back the possibility of the city to promote a more sustainable and connected mode of transport that could help the city to be more resilient to future disturbances, as what happened with the Covid-19 pandemic, when people were afraid of using 'traditional' public transport modes for displacements. The technology and connectivity of the e-scooter sharing systems can help not only Braga, but other cities around the world to better understand user needs and patterns to better plan cities' urban mobility that are smarter, more sustainable, and resilient.

Overall, the lessons learned in the case study show that the implementation of shared e-scooter systems in cities can be seen as a great asset to help decrease the burden of massive car usage in cities, promote more efficient use of public space and contribute to a resilient mobility system, namely through increasing its redundancy and inclusiveness.

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