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Article

Lessons from Implementing a Metropolitan Electric Bike Sharing System

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Abstract: Electrically assisted bicycles are anticipated to become an effective tool to limit not only the use of cars in cities but also their negative impact on health, the environment, and passenger transportation in cities. In this paper, we examine the effects of implementing the first fully electric bike (e-bike) sharing system in the Metropolitan Area of Gdańsk–Gdynia–Sopot in Northern Poland, where no other bike sharing system had been introduced before. The aims of this article were to determine the impact of the new e-bike sharing system on the modal choice of citizens, identify barriers to its usage, and find differences between the usage of the system in the core of the metropolitan area and in the suburbs. We used two primary data sets: the survey data collected using the computer-assisted personal interviewing technique (CAPI technique) and the data automatically acquired from the website that monitored the system activities. We performed the analysis by using nonparametric tests and correspondence analysis. We found no evidence suggesting that e-bike sharing can replace large number of private car trips, but we found it likely to be competitive to carsharing, moped, and taxi services. E-bike sharing competes also with public transportation services, but it is also used as the first/last mile of the transportation supplementing public transport system. The major barrier to using this system in central cities of the metropolitan area was the lack of available public bikes, and possession of private bicycles, whereas for residents of the suburbs, the obstacles were the need to transport children, the high price of the bicycle rental/subscription, and the long distance to the docking stations.

Keywords: electric bike sharing; e-bikes; electromobility development policy; public bicycle system

1. Introduction

Transportation systems in cities are constantly burdened with problems related to the externalities of petroleum fuel usage. The sustainable development of smart and electric mobility can support overcoming the problems related to the use of cars—traffic congestion, air pollution, urban noise, and diseases [1]. One of the remedies to these problems is supporting cycling and every other type of micromobility by providing infrastructure that ensures safety. Another is introducing sharing systems that increase the accessibility of these vehicles. In cities around the world, different types of bike-sharing systems (BSSs) have become very popular in the last few years. Additionally, the popularity of electric scooters, electric bikes (e-bikes), or even electric cargo bikes is growing. Micromobility is an integral part of urban transport systems [2]. Electrically assisted vehicles are more competitive with a private car than conventional bicycles [3]. E-bikes replacing cars can also contribute to the reduction of energy consumption, air pollution, and noise [4]. Thus, combining the idea of shared mobility with e-bikes could be an effective solution to accelerate the transformation of passengers' travel modes into more green and sustainable ones [5]. Our investigation fits into these new mobility [6] and sustainable accessibility [7] approaches.

The aim of the article was to investigate the effects of introducing a fully e-bike sharing system in the largest metropolitan area in the north of Poland—the Metropolitan Area Gdańsk–Gdynia–Sopot (MAGGS). We explore its effects on the choices of citizens in the light of the transportation policies of the metropolitan authorities. To identify barriers to e-bike sharing instead of other means of transportation, we use the Kruskal–Wallis test to juxtapose the obstacles influencing the decision to ride a bike with frequency using the public bike system called "Mevo". Knowledge about these effects and barriers is fundamental for designing an e-bike sharing system that would allow for a stronger shift toward more sustainable forms of transportation.

We also investigate the differences between the usage of a bike-sharing system within the core (the three agglomerated central cities) and the peripheral municipalities (the suburban and commuting area).

The decline in bicycle trips with increased distance from the city center has been observed in many cities [8–10]. As electric bicycles encourage longer distance trips [11], the introduction of e-bike sharing to the metropolitan suburbs could encourage some of the residents to cycle. In this article, we investigate the barriers to e-bike sharing for the residents of the peripheral municipalities in comparison to those perceived as important by the people living in the core cities of the MAGGS metropolitan area.

2. Literature Review

We focused our literature review in three basic areas: the influence of the use of electrically assisted bicycles (e-bikes) on citizens transport behavior and modal choice, the effects of implementation of e-bike sharing systems, and the barriers to electric and conventional bike sharing and their role in commuting areas.

E-bikes enable users to cycle more often and for longer distances [12–15], and also to carry more cargo [13]. Several studies indicate that e-bikes make riding a bicycle possible for the elderly and even those who have physical limitations [12,16–18]. They also allow riding up hills with relative ease, meaning people able to reach their destination less sweaty and tired [12,15]. E-bike users in Shanghai and Kunming, China, were found to travel more than conventional bicycle users; they would also travel more by bus if they were not in possession of e-bikes [19]. One of the studies among e-bike users in the Netherlands revealed that 40% of electric bicycle trips would have been made in a car if an e-bike had not been available [20]. Another Dutch study showed that e-bike ownership reduced car trips, but it also indicated that e-bike owners used public transport less [21]. A survey among 5500 Norwegian car owners highlighted that those who cycled the least were most interested in buying an e-bike. According to Fyhri et al., this, in turn, could result in a shift from cars to bikes [22]. Fyhri and Fearnley described an experiment in which a random group of people was provided e-bikes for a limited time. Their study showed that e-bike possession increases bicycle use in everyday trips and that number of trips per day and total distance travelled is higher on e-bikes than on conventional bikes. [23]. Astegiano et al. revealed that on the distances between 3 and 50 km, e-bikes can compete not only with conventional bikes and bike sharing but also with cars, buses, trams, metro, car sharing, and even rail transportation [24]. Carins et al. also proved that e-bike users with loaned e-vehicles travel less as car drivers but also use buses and walk less [25]. The research conducted by Sun et al. showed that e-bike adoption results in a significant reduction in conventional bike usage and a less meaningful reduction in car usage [1]. Similar dependencies were also revealed by Jones et al. [26], Cherry et al. [27], and Bourne et al. [28]. Furthermore, Fyhri and Sundfør argued that those who purchase e-bike increase their daily bicycle use in the long term—the observed changes are not just a novelty effect [29].

E-bike sharing systems are still a novelty, but several studies about their use have been already published. In 2010, Shaheen et al. suggested that electric bicycles could become an important feature of the next generation of BSSs [30]. Thomas et al. discussed the technical problems connected with charging an e-bike sharing fleet [31]. One of the first fully electric bike sharing systems was implemented in 2014 in Copenhagen, where the bicycles were equipped with tablets for login for pickup, information, and navigation with GPS. Initially the Municipality of Copenhagen suggested 20% of the bicycles to be electric, but the operator that won the tender preferred all bicycles being electric due to logistical issues [32]. The study of a free-floating e-bike sharing system in Zurich, Switzerland, revealed that e-bike sharing can become a serious competitor for public transportation and taxi services [33]. An analysis of the trip data from the first fully electric BSS in in Park City, Utah, revealed that its usage depends on population density, proximity to public transit centers, recreational centers, and bike trails, and temperature and wind speed. The topography of Park City is similar to that of the MAGGS metropolitan area, as it is hilly with large differences in elevation between the different parts of the city. Despite that, the average recorded trip distance in Park City was about 8 km, which is much longer than the average distance of a conventional BSS [34]. In a study about Beijing, China, Campbell et al. revealed that users of an electric BSS travel longer distances, are more resilient to high temperatures and poor air quality than users of a conventional BSS, but both are prone to precipitation [35]. In a recently published study by Chen et al., they proved that charging e-bikes (typically in the charging stations) can cause travelers long delays and that quick-charging technology and reservation policy could widely improve an electric BSS [36]. The main advantages of an electric BSS are greater speed and range, better accessibility for different social groups in comparison to the conventional BSS, and environmentally friendlier in comparison to cars. Higher costs for maintaining the fleet and infrastructure stand as the main drawbacks of an electric BSS [37].

Although barriers to e-bike sharing have not yet been fully explored, there are several studies about barriers to the conventional BSS. E. Fishman et al. identified accessibility (e.g., sign-up process, docking stations, and mandatory helmet legislation), safety (e.g., bicycle infrastructure, driver behavior, and motor vehicle speed), and weather and topography (e.g., heat, rain, and hills) as most of the important factors affecting the usage of a BSS in Brisbane, Australia [38]. In another paper, E. Fishman recognized a long commute distance to be the major barrier for people who were not BSS users in Brisbane [39]. Similar conclusions were reached by El-Assi et al. in a Toronto, Canada, study, where intersection density, spatial dispersion of docking stations, bike infrastructure (bike lane, paths, etc.), and temperature were found to be crucial for bike-sharing ridership [40]. Another study in Seattle, USA, confirmed that roadway design, elevation, and weather conditions may become crucial barriers for a BSS [41]. A study based in New York, USA, also showed that that bad weather and infrastructure unfavorable for cycling affect BSS usage [42]. Through a survey done in Drama, Greece, Nikitas showed that similar factors (lack of cycling infrastructure, limited road safety, and unfavorable weather conditions) constitute barriers for BSS usage in small cities [43]. Another study focused on e-bikes shows that the main barriers to e-bike usage are the weight of the vehicle, battery life, e-bike cost, social stigma, and poor cycling infrastructure [26].

Little research has been published on the subject of bike sharing in suburban areas [44]. Wang et al. found the BBS and buses are competing modes of transport in suburban areas but not in city centers [45]. A study in Shenzhen, China, revealed that the BSS is used both for a short-distance commute and long-distance journeys (as first/last mile transportation), whereas in the peripheral districts, a BSS serves mainly to get access to public transit. Shared bicycles were also found to be used less frequently in the peripheral district [46]. Another study in Shanghai, China, in the suburban area, showed that the BBS "expands the rail transit coverage areas and provides travel services to areas with less accessibility to public transit" [47]. Zuev et al. highlighted how e-bikes helps new migrants to Chinese cities to commute from distant suburban areas to city centers, and that without e-bikes, Chinese "residential areas would remain ghost-towns" [48]. Bruzzone et al. analyzed the possibility of using e-bike sharing and demand-responsive transport systems in the suburban areas of Velenje, Slovenia. They concluded that implementation of such a system "would increase the number of settlements with daily and frequent access to the train and bus stations and to public functions downtown" [49]. In the recently published article about Polish BSSs and their role in connecting cities with the surrounding areas, Wolny-Kucińska found these systems are becoming an important link in multimodal transportation between cities and suburban areas [44].

In the recent publication by Bourne et al. the authors identify research gaps in e-cycling literature. The article calls for research that would "evaluate whether e-bike sharing systems impact alternative travel behavior" [28]. Our study contributes to that research area as one of the first publications on e-bike sharing tackling the problem of modal choice of citizens, and barriers to the usage of such a system. We also focus on the differences between the usage of the system in metropolitan and suburban areas, which was previously not investigated in context of shared e-bikes.

3. Metropolitan Transportation Policies and Mevo System Characteristics

3.1. The Transportation Policy of MAGGS as a Framework to Implement the Public Bike System

The MAGGS is in Northern Poland on the southern coast of the Baltic Sea. Its area is 6.7 thousand square meters, and the number of inhabitants exceeds 1.5 million. It has a significant position in the European settlement network. European Special Policy Observatory Network's typology of functional urban areas determined based on four characteristics—size, competitiveness, availability, and knowledge resources—locates MAGGS in the highest class: European metropolitan growth areas [50].

The MAGGS operate in the legal form of association established in 2011. It was an essential step in the integration activities that lasted almost from the beginning of the 1990s [51]. The rise of the association was the reaction of local governments to a lack of legislative action regulating cooperation in metropolitan areas. The main goal of MAGGS is to improve quality of life. Activities focus on two fields: strengthening economic competitiveness to other metropolitan areas and initiating, supporting, and coordinating the development of public services of metropolitan importance. An essential aspect of the association's activities is the development of public transport. The members are 56 local administrative units (Figure 1)—formerly UE NUTS level 4 and 5 [52]. These territorial units have diversified spatial organization. The core formed by Gdańsk, Gdynia, and Sopot has the character of a large city. The high density of population (1819 people/km^2 in 2019), buildings and technical infrastructure such as the bicycle path network (69 km/100 km^2) distinguish this area from surroundings. The next 11 municipalities that joined the bicycle shared system development program (referred to as the periphery) are towns or suburbs. Population (236 people/km^2) and bicycle routes (16 km/100 km^2) density is much lower. Therefore, the basic conditions for the development of BSS varied significantly.

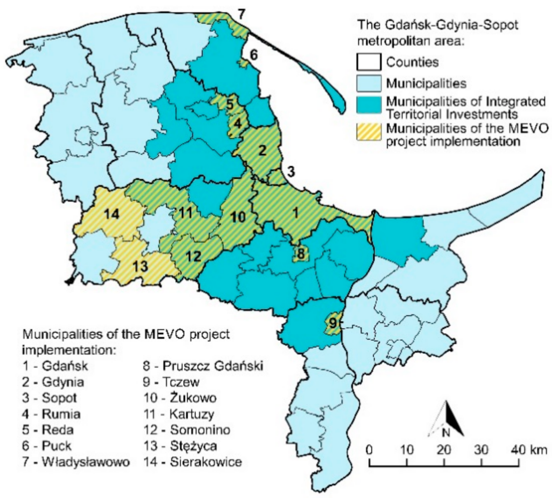

Figure 1. Administrative division of the Metropolitan Area Gdańsk–Gdynia–Sopot (MAGGS) and the range of the metropolitan public bike system project. Source: Author's own elaboration.

The main directions of MAGGS's development policy until 2030 supports [53] the development of the public bicycle system in two ways: (i) improvement of internal transport accessibility and improvement of the public transport network and (ii) improvement of management and prioritization of metropolitan public multimodal transport, and active mobility [53].

The general strategic directions were specified in the document of the transport and mobility strategy [54]. This strategy outlines two kinds of activities to promote the bicycle as a means of urban transport. The first involves increasing the share of bicycle travel through the development of a network of bicycle routes and the construction of transport integration nodes. The second focuses on creating a public space attractive to active mobility and on creating favorable conditions for the use of a bicycle in intermodal passenger chains. This type of activity requires the development of a coherent organization and a tariff system for metropolitan bicycles [54]. Actions for the development of sustainable transport, including bicycle transport, should be seen in the context of the high level of individual motorization in large Polish cities. The number of vehicles per 1000 inhabitants in the core of the metropolitan area ranges from 761 to 936 [55]—nearly two times higher than in many European cities [56]. The widespread use of cars is not only a response to the shortcomings of public transport but also an important element of social life [57].

MAGGS's ability to implement a metropolitan public bicycle system would be minimal if not for integrated territorial investments (ITIs). This instrument allocates part of the funds of regional operational programs for 2014–2020 for the development of functional urban areas. The ITI agreement also includes some local communities belonging to MAGGS (30 local administrative units). In 2015, MAGGS became the institution responsible for preparing the strategy and supervising its implementation [58]. One of the proposed three basic projects is the construction of integration nodes with access routes. In addition to the construction of at least 27 interchange nodes or park and ride facilities, the creation of a public bicycle system should facilitate access to the planned integration nodes. The strategic document did not prejudge the nature of this system, stating only that in small towns or villages, it would operate as a central bicycle rental facility located at an interchange node [58]. However, such formulation suggests that the designed system does not have to be homogeneous. The adopted solutions should consider the significant variability of local conditions, especially in the urban core and suburban functional areas associated with it.

This political framework programming the shape and functions of the bike-sharing system in MAGGS seems to be coherent and consistent with the paradigm of sustainable urban mobility [59]. In particular, they support the change in the division of transport tasks in favor of collective transport and pedestrian and bicycle transport. However, Duffhues and Bertolini [60] suggested that the implementation gap may occur between the stage of formulating strategic goals and the stage of their operationalization in the form of specific projects. It turns out that as a result of sectoral divergences of interests and patterns of action, operationalization of common goals leads to a loss of coherence and a fragmentation of effects. As further analysis shows, this problem also occurred with the implementation of the BSS in MAGGS. In the case of post-socialist cities, the complexity of the transport policy may deepen the gap. Adapting the concept of the "three-stage urban transport policy development cycle" (stage one: accommodating traffic growth; stage three: encouraging modal shift; and stage three: promoting livable cities) [61] to the conditions of these cities clearly show that in post-socialist cities, these phases do not form a cycle but occur almost simultaneously. The transport policy is an attempt at infrastructural "catching up" or reconciling the interests of the automobility system lobby [57] while striving to establish patterns of sustainable mobility. Therefore, implementing the BSS may be accompanied by projects that hinder the use of such a system. Paradoxically, a significant obstacle in the implementation of the BSS may be easy access to financing sources, which gives rise to a temptation to implement large-scale urban development projects. Such projects, due to their scale strictly, focus on fragmented problem solving [62], pushing the effects for the entire transport system into the background. The analyzed example seems to confirm the accuracy of this statement, which is discussed later in the article.

3.2. The Implementation of the Public E-Bike System in MAGGS—From Bold Plans to a Spectacular (Temporary?) Collapse

The development of a conceptual study [63] preceded the implementation of the BSS at MAGGS (mid-2016). The proposed territorial scope of the system was divided into two areas and was served by different subsystems. In ten communes with a high population density, the study recommended the implementation of the fourth-generation area system (smart bikes instead of smart docks and bicycle parking places instead of a smart docks). In 14 communes—mainly suburban areas with a low population density hybridized type of system was proposed (bicycle collection and return at a station or anywhere in the area paying an additional fee). These solutions are modeled on the call a bike system associated with Deutsche Bahn. The authors of the study estimated the demand for bicycles in the entire system at about 3.7 thousand. They recognized that the maintenance of a system of this size is within the financial capabilities of the entities participating in the project (including support from EU funds). They also recommended a combined business model. The expenses for the construction and implementation of the system should come from EU funding. Local governments should be the owners of infrastructure and the bicycle fleet. The day-to-day operation could be outsourced [63]. This study mentions the potential dissemination of e-bikes in public systems. However, their use has not been recommended, except for possible long-term rental, which would be a side function of the system.

Fourteen communes participated in the development of the system the development of the system. Until March 2018, the MAGGS task force carried out the preparation of the tender specifications. The idea of equipping some bicycles with an integrated electric motor used to assist propulsion emerged this time as a solution to the region's topography—numerous and steep slopes make it difficult and sometimes even impossible for the average bike user (Figure 2). The primary conditions of the announced tender were delivering a minimum of 3866 bicycles, including at least 10% electric, and maintaining the system using the designed network of 660 docking stations. The tender criteria were price, the share of e-bikes and the number of bikes exceeding the minimum required [64]. The terms of the tender were significantly different from the study proposals. The critical change was the requirement to provide e-bikes. It was also important that there was no requirement to differentiate the system depending on the geographical conditions of the area. When designing the network of stations, the MAGGS task force essentially determined the uniformity of the system. As already mentioned, two subsystems adapted to the different local conditions were proposed. At this point, there was an implementation gap. The established parameters of the system significantly differed from the strategic goal—ensuring accessibility to the intermodal nodes.

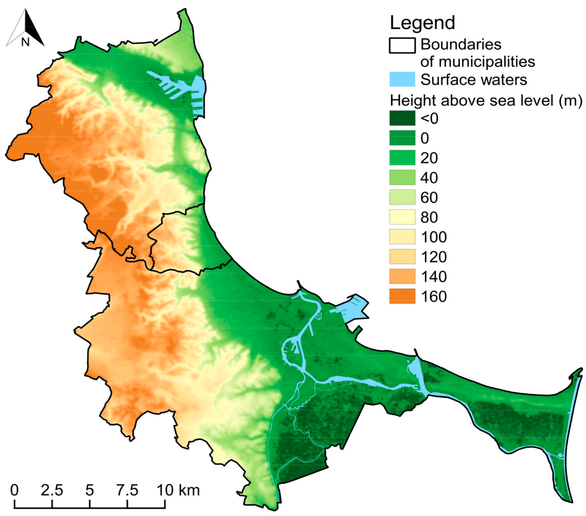

Figure 2. Relief of the core of the metropolitan area—municipalities of Gdańsk, Gdynia, and Sopot. Source: Author's own elaboration.

Three entities entered the tender. The daughter company of the well-known European operator Nextbike won. It offered 4080 bicycles—all with electric power assistance—and at a competitive price: PLN 40.3 million with a contract period of 6.5 years. According to the contract, the implementation was to take place in two stages. The first would cover 30% of the fleet, and the second would cover the rest. The launch of the first stage was delayed for almost four months (until the end of March 2019), as the system did not undergo further readiness tests. After just two days of operation, it turned out that the operator did not have the ability to operate the system properly. First, the operator was unable to keep up with the replacement of discharged batteries, although that was not the only problem. By the end of October 2019, the operator did not meet their obligations, as they neither completed the system nor implemented the second stage of the project (i.e., they did not deliver most of the bicycles). These flaws became the reason for the termination of the contract [64].

Seven months of the system's operation proved the legitimacy of the public bicycle system at MAGGS. High trips per day per bike ratio reaching 12 (as the average in Polish systems is between 5 and 6) [64] should be treated with caution. The reason was apparent, as two-thirds of the bikes provided were missing. This shortage meant that in some low-density units, only a few were available.

The lack of insight into the operator's financial results made it impossible to answer unequivocally about the reasons for the inability to ensure the functioning of the system. The analysis of known circumstances allowed us to assume, however, that the costs of its maintenance, particularly the availability of bicycles with charged batteries, were too high considering the total revenue. This revenue consisted of public support resulting from the tender, revenues from user fees (only PLN 10 for a monthly subscription, allowing daily use of the bike for 90 min), and other sources, mainly advertising [63]. The experience of other BSSs shows that the profitability of operators is often questionable [65] and raises many financial sustainability concerns [66].

After the termination of the contract with the operator of Mevo, work is now underway to reactivate the system, which takes place in two ways. First, there is a technical and competitive dialogue with potential contractors and second, consultations with residents. The restart of the system is not expected until September 2021, at the earliest [64], after nearly a two year break.

4. Materials and Methods

This article used two kinds of data to achieve its aims: survey data, which were collected during the time period when the Mevo system was operational, and the data automatically acquired from the website monitoring system activities. The survey data were collected between 21 August and 27 September 2019. The MRC consulting company carried out the data collection on a random sample of 633 MAGGS residents form 14 municipalities that decided to join the Mevo BSS: Gdańsk, Gdynia, Sopot, Żukowo, Reda, Pruszcz Gdański, Tczew, Sierakowice, Rumia, Somonino, Stężyca, Kartuzy, Puck, and Władysławowo. The data was collected using the computer-assisted personal interviewing technique (CAPI). The scientific aim of the survey was to verify what was the impact of the implementation of the Mevo system on the modal choice of citizens. It was also to identify the differences between perceived barriers to the usage of the Mevo system between core cities of MAGGS and its peripheries. This study's questionnaire design was based on the similar surveys conducted by Nikitas [67], Sanders et al. [68], and Du and Cheng [69], and on interviews with users of Mevo. Prior to distributing the sampling frame, a pilot study was undertaken on 17 people. The sociodemographic characteristics of the sample are presented in Table 1.

The research sample was well balanced in terms of gender; however, in terms of age, the 25–39 group predominated. The respondents were classified according to the place of residence to the MAGGS core—Gdansk, Gdynia, or Sopot. This group accounted for over three-quarters of all respondents. Other respondents lived on the periphery of the metropolitan area. The research sample is representative of the population in terms of the place of residence. This is especially important because one of the aims of the article is to investigate the differences between the usage of a BSS within the core and the peripheral municipalities.

Table 1. The sociodemographic structure of the sample.

Variable	Response Categories	Percentage of Responses
Gender	Male	47.55
	Female	52.45
Age	<25	13.43
	25–39	56.40
	40–55	26.22
	>55	3.95
Place of residence	MAGGS core	76.94
	MAGGS periphery	23.54
Net monthly income	No income	6.32
	1–1500 PLN	7.90
	1501–3000 PLN	24.96
	3001–4500 PLN	28.12
	4501–6000 PLN	12.95
	>6000 PLN	12.32
	No response	7.42

Source: Author's own elaboration.

The second dataset was automatically downloaded from the website https://mevowatchdog.pl/ [70], which was dedicated to investigating the Mevo system's activities. The data included the number of bicycles available, the changes of position of every bicycle, the number of batteries needing recharging, and the battery replacements. The data also included separate datasets for each of the 14 municipalities and was downloaded from the website to the dedicated server every two hours from 28 April 2019 to 29 October 2019.

In this article, we used two nonparametric tests, namely the Mann–Whitney test [71] and the Kruskal–Wallis test [72]. These tests were used to assess the impact of different obstacles on the use of the Mevo electric public bike and to assess the attitudes of the respondents living in the MAGGS core and in its periphery. We did not use parametric tests because the variables measured on the ordinal scale (1–10) were analyzed.

To define some policy-sensitive respondent profiles on the basis of the questions listed in Table 2, we conducted a correspondence analysis. The main strength of correspondence analysis is its ability to represent categorical variables. Moreover, it does not assume any underlying theoretical distribution. Therefore, this is a method in which the data are not subjected to any restrictive assumptions [73]. In this article, we present the outcome of the analysis, which was carried out with the Statistica 13 package. The technical background of correspondence analysis can be found in [74]. The survey contained a larger set of questions, but in this article, we used a subset, for which the results were significant.

Table 2. Questions used in the correspondence analysis and the structure of the responses.

Question	Response Categories	Percentage of Responses
Place of residence	MAGGS core	76.94
	MAGGS periphery	23.54
Frequency of using Mevo public bike system	Never	48.66
	Several times a year	20.7
	Several times a month	20.7
	Several times a week	7.9
	It's my daily mode of transportation	2.05
Frequency of using car as a driver or passenger	Never	1.26
	Several times a year	9.32
	Several times a month	32.54
	Several times a week	31.12
	It's my daily mode of transportation	25.75

Table 2. *Cont.*

Question	Response Categories	Percentage of Responses
Frequency of using public transport	Never	2.84
	Several times a year	28.91
	Several times a month	27.8
	Several times a week	17.54
	It's my daily mode of transportation	22.91
Frequency of using a car or moped rented per minute	Never	70.46
	Several times a year	21.01
	Several times a month	7.11
	Several times a week	1.11
	It's my daily mode of transportation	0.32
Frequency of using a taxi	Never	43.6
	Several times a year	49.45
	Several times a month	6.32
	Several times a week	0.32
	It's my daily mode of transportation	0.32
Main factor discouraging the use of Mevo	There are too few bikes	45.97
	Mevo bike station is too far away	6.64
	It is not possible to rent a bike and a helmet	0.47
	There is no way to transport children	2.69
	Rental/subscription price is too high	0.79
	Mevo bikes break too often	3.63
	Renting a bike is complicated	0.95
	The bikes are of insufficient quality	1.11
	I have my own bike; I don't need to use Mevo	30.02
	I don't need/don't want to ride a bike, including Mevo	3.32
	No response	4.42

Source: Author's own elaboration.

5. Results and Discussion

The correspondence analysis presents the profiles of Mevo public bike users in the context of their use of other means of transport, their place of residence, and their opinions as to the main factor discouraging the use of Mevo. The questions used in the correspondence analysis and the structure of the responses are presented in Table 2.

Figure 3 presents the results of the correspondence analysis for the frequency of using various means of transport, including the Mevo public bike system. It should be noted that for the presented graphs, dimension 1 explains the dominant part of the relationship. The conducted analysis shows that people who used a car as an everyday mode of transportation had never used Mevo or did so sporadically. At the same time, people using Mevo several times a week or as a daily mode of transportation had never used cars. The obtained results suggest that the Mevo public bike was a complement to the classic public transport. The respondents who never used public transport or did so sporadically also never used Mevo. However, the respondents who used Mevo as a daily mode of transportation also used public transport several times a month. Yet people who regularly used public transport also often used a public e-bike. Mevo public bikes were a competition for cars and mopeds rented per minute (as it was predicted by Astegiano et al. [24]). People who frequently used these means of transport also used Mevo frequently. The obtained results suggest that there was also a relationship between the respondents' use of Mevo bikes and taxis. People who rarely and irregularly used both of these means of transport can be treated as a relatively similar group. In this context, the respondents who used Mevo as a daily mode of transportation stood out as a separate group. The same applied to respondents who regularly used a taxi. Similar results were obtained by Ma et al. in their study based in Delft, Netherlands, where survey respondents were found to shift from taxi and carsharing services to the BSS [75]. Conventional BSSs were already competitive with taxies for small distances. Faghih-Imani et al. compared travel times between bicycle sharing and taxis in New York City, NY, USA, and found bicycles to be as fast or faster up to the distance of 3 km (1.86 miles) [76]. E-bike sharing can also compete with taxis on longer distances [33].

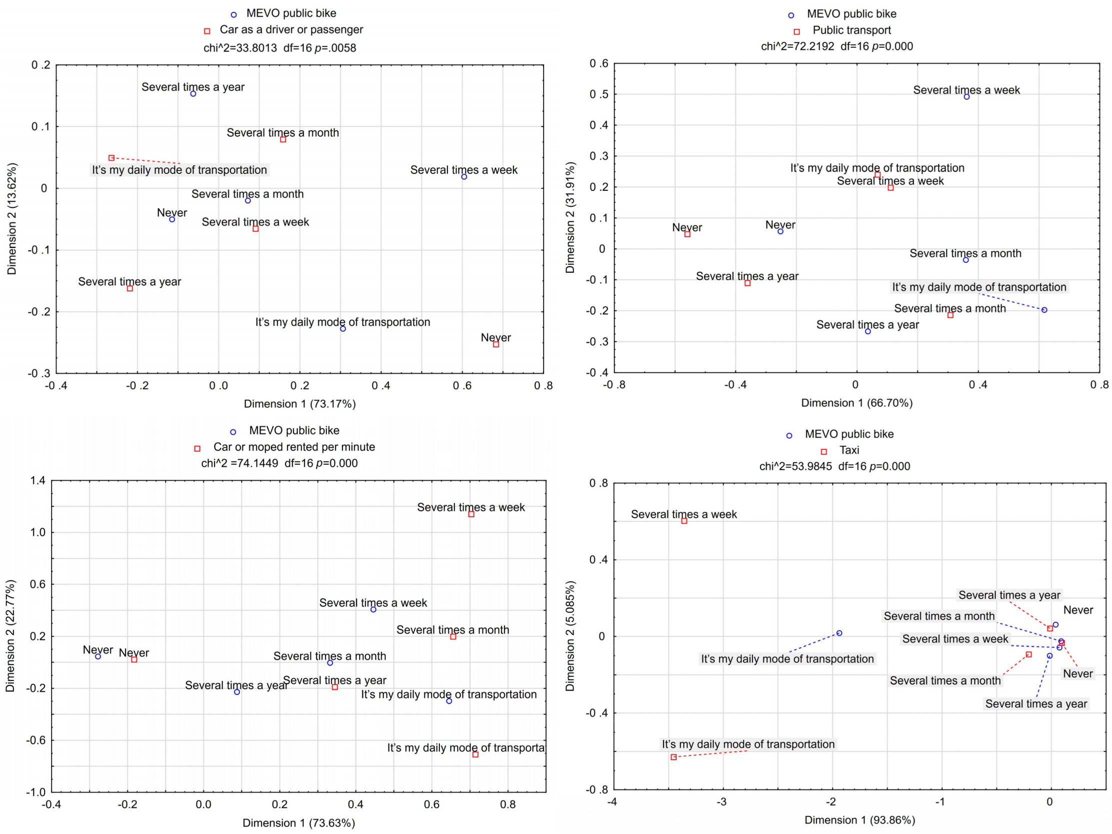

Figure 3. Correspondence analysis: The frequency of using the Mevo public bike system and other means of transport. Source: Author's own elaboration.

We found that the barriers for bike sharing were different among people who had never used a BSS and who were active users. The analysis of the main factors discouraging the use of Mevo (Figure 4) shows that in the case of respondents who had never used Mevo, the most important factors were having their own bikes, no possibility of transporting children, complicated bike rental, long distance to Mevo station, or general lack of interest in cycling. Some of the people simply did not feel any need for the BSS, as they had their own bicycle. This finding matches results from previous research on barriers to the usage of BSSs in reference to bike ownership [67,77], complicated bike rental [77], and distance to the docking stations [40,78–80]. Yet for people who used the Mevo several times a week or several times a month, the biggest problems were too few available bikes and too frequent breakdowns. In the literature, the quality and availability of bikes are seen as important for the public to use a BSS [81–83]. Considering the place of residence, the main factors discouraging the use of Mevo for residents of MAGGS periphery were the lack of possibility of transporting children, the high price of bicycle rental/subscription, and long distances to a Mevo station. Moreover, the main factors discouraging the inhabitants of the MAGGS core from using Mevo were too few available bikes and having their own bikes. The effect of having children on the choice of shared transportation was previously analyzed by Wielinski et al., who found that BSS users were less likely to have children than carsharing users [84]. Although e-bikes are perceived as vehicles that can enable parents to shift from cars to cycling [85], e-bike sharing, which does not offer cargo bikes, is not going to allow residents of suburbs to transport their children.

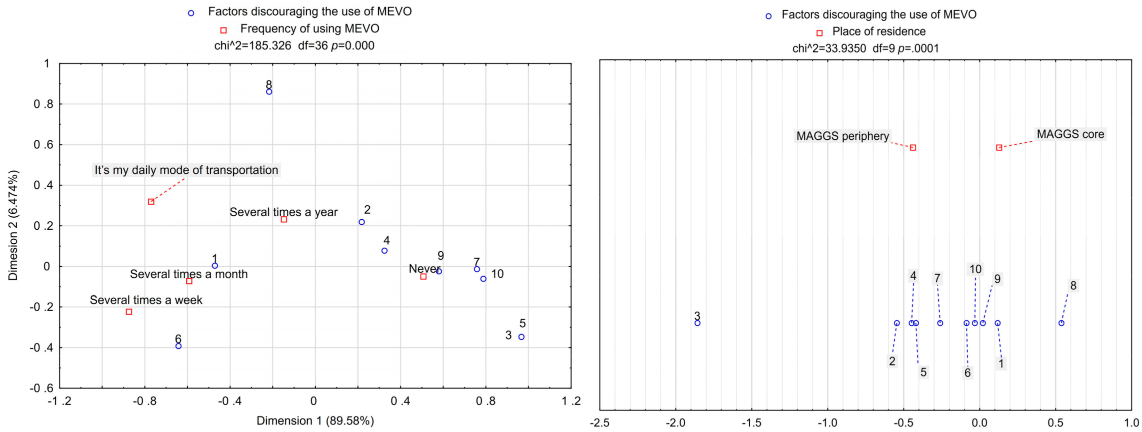

Figure 4. Correspondence analysis: Main factors discouraging the use of Mevo versus the frequency of using Mevo and place of residence. Source: Author's own elaboration. Notes: The factors are marked with the following labels: 1 (there are too few bikes); 2 (the Mevo bike station is too far away); 3 (it is not possible to rent a bike and a helmet); 4 (there is no way to transport children); 5 (the rental/subscription price is too high); 6 (Mevo bikes break too often); 7 (renting a bike is complicated; 8 (the bikes are of insufficient quality); 9 (I have my own bike; I don't need to use Mevo); and 10 (I don't need/don't want to ride a bike, including Mevo).

In Table 3, we present the relationship between the frequency of using the Mevo public bike system and the obstacles influencing the decision to ride a conventional bike. The groups distinguished in terms of the frequency of using the Mevo differed most in terms of the loss of time while cycling compared to other modes of transport. This obstacle was the least significant for the respondents who used Mevo as a daily mode of transportation and the most significant for the respondents who used Mevo several times a week. This obstacle was also important for people who have never used a Mevo. We observed similar dependencies for the factor related to the lack of a properly developed network of bike paths. Yet the group using Mevo public bikes indicated that the lack of space to store their own bicycle was significantly more important. Less pronounced differences between the groups concerned the lack of respect for cyclists (which was previously identified as an important barrier to cycling in the literature [86,87]), too high slopes, and the cost of purchasing and maintaining a bicycle. However, each of these obstacles was the least important for respondents using Mevo as their daily mode of transportation and the most significant for respondents using Mevo several times a week or never.

Table 3. Obstacles influencing the decision to ride a conventional bike and frequency of using the Mevo public bike system—Kruskal–Wallis test.

I have no place to store my bike		
Kruskal–Wallis test: H = 10.340 **		
Frequency of using Mevo	No. of observations	Mean rank
Never	308	304.79
Several times a year	131	318.28
Several times a month	131	334.62
Several times a week	50	363.33
It's my daily mode of transportation	13	237.46
There is no properly developed network of bike paths		
Kruskal–Wallis test: H = 9.651 **		
Frequency of using Mevo	No. of observations	Mean rank
Never	308	332.22
Several times a year	131	287.51
Several times a month	131	315.05
Several times a week	50	330.82
It's my daily mode of transportation	13	219.73

Table 3. *Cont.*

Some drivers disrespect cyclists		
Kruskal–Wallis test: H = 8.031 *		
Frequency of using Mevo	No. of observations	Mean rank
Never	308	329.72
Several times a year	131	297.67
Several times a month	131	319.96
Several times a week	50	310.59
It's my daily mode of transportation	13	205.12
The slopes are too high, making it difficult to ride the bike uphill		
Kruskal–Wallis test: H = 7.808 *		
Frequency of using Mevo	No. of observations	Mean rank
Never	308	313.28
Several times a year	131	295.42
Several times a month	131	338.08
Several times a week	50	356.96
It's my daily mode of transportation	13	256.34
Too much time lost while riding a bike compared to other means of transport		
Kruskal–Wallis test: H = 18.046 ***		
Frequency of using Mevo	No. of observations	Mean rank
Never	308	337.90
Several times a year	131	294.83
Several times a month	131	289.69
Several times a week	50	350.65
It's my daily mode of transportation	13	190.88
Too high cost of the bicycle and/or its maintenance		
Kruskal–Wallis test: H = 9.007 *		
Frequency of using Mevo	No. of observations	Mean rank
Never	308	312.92
Several times a year	131	305.95
Several times a month	131	333.53
Several times a week	50	344.61
It's my daily mode of transportation	13	252.00

Notes: The obstacles were measured on an ordinal scale ranging from 1 to 10. The second row in every section represents the value of the H-statistics from the Kruskal–Wallis test. The hypothesis about the equal median in all groups is rejected at the level of significance: *** (1%), ** (5%), and * (10%). The results for other obstacles influencing the decision to ride a bike are not reported in this table because of their insignificance. Source: Author's own elaboration.

Figure 5 indicates that there were statistically significant differences in the use of the Mevo public bike system by the inhabitants living in the core of MAGGS and those living in its periphery. Only 25% of respondents living in the periphery of the metropolitan area used Mevo several times a year or more. For people living in the core of the metropolitan area, 50% used Mevo several times a year or more, of which 25% used Mevo several times a month or more.

Our second data source (the automatically acquired data on the number of bikes available and rentals) seems to confirm the above findings. Users in the core area used the system more in absolute terms and more intensively (Figure 6). Demand for bikes was lower in the periphery of the metropolitan area than in the core. Even though the bicycles available for the citizens of the periphery were less numerous than in the core, the number of rentals per one bicycle was disproportionally smaller. Moreover, in the core area, use increased in the morning rush hour and especially for the one in the afternoon. In contrast, in the periphery area, use only increased significantly in the afternoon. It, therefore, seems that in these areas, the system played a much smaller role in commuting.

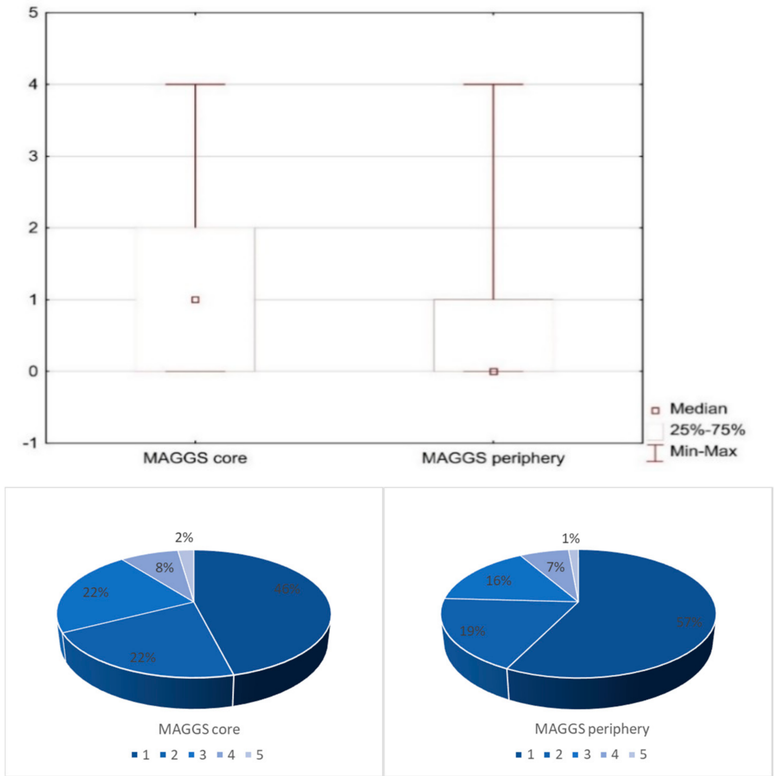

Figure 5. Difference in frequency of using the public bike system in the core and in the periphery of MAGGS. Source: Author's own elaboration. Notes: The answers of the respondents were transformed on a ordinal numerical scale (0–4), where "never" = 0; "several times a year" = 1; "several times a month" = 2; "several times a week" = 3; and "it's my daily mode of transportation" = 4. The Mann–Whitney test rejected the hypothesis about the equal median in both groups at the 5% significance level.

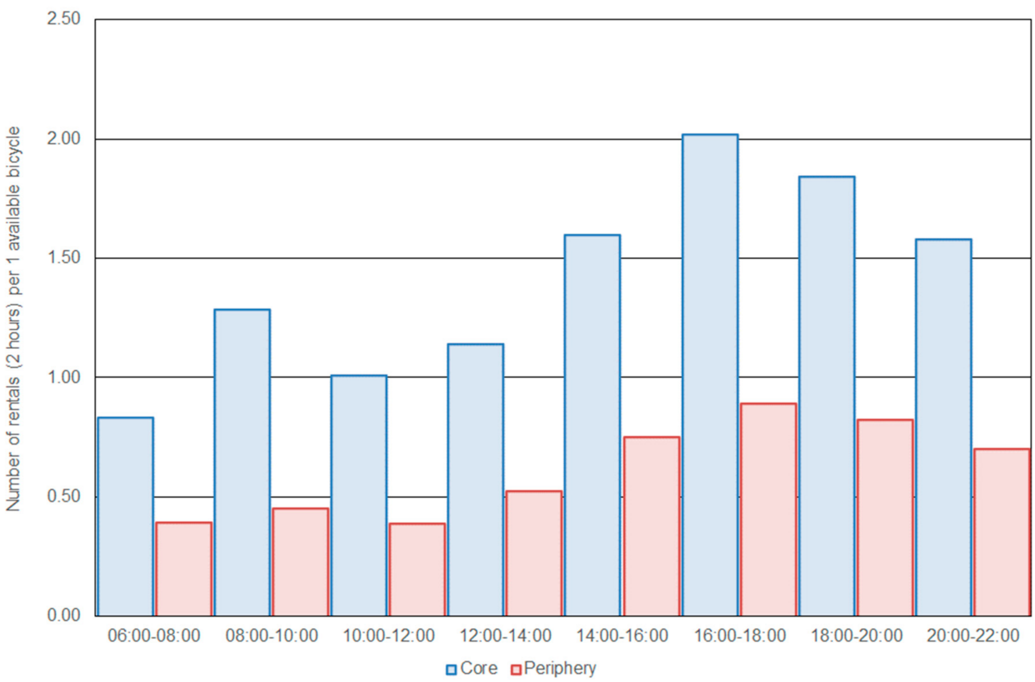

Figure 6. Difference in relative intensity of using the public bike system in the core and in the periphery of MAGGS. Source: Author's own elaboration.

We also found that in many peripheral municipalities, the Mevo system was used as the first/last mile transportation complimentary to rail transport. In all peripheral municipalities, those that have access to rail transport docking stations situated near railway stations were among the most popular ride destinations. Examples of the most popular routes in peripheral municipalities are presented in Figure 7.

Figure 7. The most popular routes taken by Mevo users in the chosen peripheral municipalities. Source: Author elaboration based on MAGGS presentation "Konslutacje Mevo 2.0.: Spotkanie z mieszkańcami", January 2020.

Table 4 presents the results of the Mann–Whitney test, showing differences in the responses of inhabitants living in the core and in the periphery of MAGGS in relation to obstacles influencing the decision to ride a bike.

Table 4. Obstacles influencing the decision to ride a conventional bike. Differences in the responses of inhabitants living in the core and in the periphery of the MAGGS.

Obstacles	Sum of Ranks—MAGGS Core	Sum of Ranks—MAGGS Periphery	No. of Observations—MAGGS Core	No. of Observations—MAGGS Periphery	Mann–Whitney Z Statistic
I don't feel safe in traffic as a cyclist	151,045	49,616	488	145	−1.888 *
I often have to travel too long of a distance	151,997	48,664	488	145	−1.395
I have to transport children or other family members	148,326	52,334	488	145	−3.294 ***
My health condition does not allow me to use a bicycle	153,731	46,929	488	145	−0.498
I have no place to store my bike	154639	46,021	488	145	−0.028
I have to transport shopping or other loads that are too big or heavy	152,286	48,375	488	145	−1.246
I do not have adequate physical condition to ride a bike	151,619	49,042	488	145	−1.591
I cannot wash myself and change clothes in the place I work or study	155,730	44,931	488	145	0.534
There is no properly developed network of bike paths	148,421	52,239	488	145	−3.244 ***
I do not have space to securely fasten my bike in the places I travel to	151,913	48,747	488	145	−1.438
Some drivers disrespect cyclists	150,910	49,751	488	145	−1.957 *

Table 4. *Cont.*

Obstacles	Sum of Ranks—MAGGS Core	Sum of Ranks—MAGGS Periphery	No. of Observations—MAGGS Core	No. of Observations—MAGGS Periphery	Mann–Whitney Z Statistic
The slopes are too high, making it difficult to ride the bike uphill	157,961	42,699	488	145	1.688 *
A too frequent inability to conveniently transport bikes by public transport	153,267	47,393	488	145	−0.738
The bike is not convenient for me	151,933	48,728	488	145	−1.428
The weather is bad too often	152,857	47,804	488	145	−0.95
I need to use more convenient or more prestigious means of transport	152,283	48,378	488	145	−1.247
I often wear clothes that make cycling difficult	152,799	47,862	488	145	−0.98
Too much time is lost while riding a bike compared to other means of transport	148,925	51,735	488	145	−2.984 ***
I can't ride a bike well	153,912	46,749	488	145	−0.405
The cost of the bicycle and/or its maintenance is too high	150,399	50,262	488	145	−2.222 **

Notes: The obstacles were measured on an ordinal scale ranging from 1 to 10. The last column represents the value of the Z-statistics from the Mann–Whitney test. The hypothesis about the equal median in both groups is rejected at the level of significance: *** (1%), ** (5%), and * (10%). Source: Author's own elaboration

The necessity to transport children or other family members was a more significant barrier for the inhabitants living in the periphery of MAGGS than for the inhabitants living in the core of MAGGS. Moreover, the lack of a well-developed network of bicycle paths was more significant in the periphery. The inhabitants of the peripheral municipalities also indicated a large loss of time while cycling as a significant problem in comparison to other means of transport. The study also found that the two populations differed in terms of the impact of the bicycle's price and its maintenance costs. It was more important for the inhabitants of the periphery.

Less significant differences were noted in the terms of safety and respect of drivers towards cyclists. Both factors were more relevant for the residents of the periphery; however, in this case, the hypothesis about the equal median in both groups is rejected at the 10% significance level.

It is worth mentioning that for the inhabitants of the MAGGS core, too high slopes were a greater barrier to using the bike.

6. Conclusions

This analysis of the actual implementation and collapse of the e-bike sharing system in the MAGGS metropolitan area provides several important implications, which are lessons for future attempts to implement such a system in different agglomerations. First of all, maintaining a system in which bikes are charged by replacing the battery rather than using stationary chargers is a severe operational and financial problem. Such an important issue as the extensive use of e-bikes should be preceded by an in-depth feasibility study, especially in terms of operating costs. In the case at hand, this element failed. The Mevo is an example of the implementation gap problem [60], as the original assumptions partially differed from the effects of implementation. Second, a significant risk factor results from the specific nature of the area. Implementation in several cities and rural communes at once made it difficult to adjust the system to the diversity of local conditions. It increased the logistical difficulties in maintaining the system.

Despite its advances over a conventional BSS, this study has found no evidence suggesting that e-bike sharing can replace the large number of private car trips, which was one of the aims of the municipal transport policy that led to the introduction of this system. This conclusion is in line with the recent findings of Bigazzi and Wong [88], who argued that private e-bikes are more likely to become a substitute for public transportation than for the other modes of transportation. It also supports previous research on conventional BSSs, which showed their low efficiency in replacing private cars [89–93]. Mevo bicycles were likely to be competitive to carsharing, moped, and taxi services. This conclusion is consistent with the survey results published by Ma et al. [75]. However, e-bike sharing can be integrated with public transport systems and serve as first/last mile transportation. Additionally, electric bike-sharing may be able to enhance public transportation services in the suburbs by providing flexible on-demand transport, where a fixed-route (or frequent service) is not efficient or practical due to lower density, which is consistent with the findings of Shaheen et al. [94]. Municipal authorities and city planners interested in introducing e-bike sharing systems should consider building cycling infrastructure that can enable residents of peripheral areas to make comfortable and safe rides to rail and other public transportation stations.

We have also found that the perception of the major barriers to e-bike sharing are different for people that never used them and for people that are actively using this kind of service. Our research shows that the studied population was divided into three main groups in this respect. For the people that never rode a shared e-bike, the barriers are mainly connected with having their own bikes, no ability to transport children, difficulties in renting an e-bike, distance from the docking station, or general lack of interest in cycling. The active users of e-bike sharing were mostly concerned about the availability of bicycles and their frequent breakdowns. However, only a small group of people used Mevo bikes as a daily mode of transportation, despite the above-mentioned inconveniences. Moreover, they were the same people for whom the barriers related to the general use of the bicycle were the least important. Our research indicates that there was also a group of users for whom the e-bike system addressed some of the general problems that discouraged conventional cycling, such as the lack of a place to store their own bike. However, for this group, the lack of an adequate number of bicycles and their frequent breakdowns were a significant deterrent to using the Mevo electric bicycle system. The group of people using Mevo as a daily mode of transportation would probably be larger if the system itself operated more efficiently.

The major barriers for e-bike sharing also differed among residents in the metropolitan core area and its suburbs. What stopped people living in central cities from using the e-bike sharing system was the lack of available bikes and having their own bicycles, whereas for residents of the suburbs, it was the need to transport children, the high price of a bicycle rental/subscription, and the long distance to a Mevo station.

This study's limitations include the relatively small number of e-bikes and the short time during which the electric BSS was available. With wider availability and more time, some other users might have been attracted by e-bikes and have become active users. Another limitation to our study relates to the characteristics of the MAGGS area, which is not homogeneous. Among the 14 municipalities taking part in the Mevo project, there are towns of different sizes with diverse environment characteristics. Our research was performed on one BSS, and further research is needed in other cities to confirm our findings. This issue may, however, be hard to overcome, as MAGGS is the only metropolitan area in Europe where an electric BSS was the only one implemented. Other systems usually include e-bikes and standard bicycles; other conventional BSSs operate in cities. These facts make the Mevo system unique and our research hard to replicate. Further research is also needed in the subject of other electrically assisted forms of micromobility, such as scooters and other personal transporters.

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and A.W.; funding acquisition, T.B. and A.W.; All authors have read and agreed to the published version of the manuscript.

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