Title: Shared Electric Scooters in Vienna: Analyzing Usage Characteristics with Limited Data

Authors:

Miklós Radics, KTI Institute for Transport Sciences Non-profit Ltd., Than Károly u. 3-5., 1119 Budapest, Hungary[1] & Vienna University of Technology, Gusshausstrasse 30/230-01, A-1040 Vienna, Austria[2]; E-Mail: radics.miklos@kti.hu

Takeru Shibayama, Vienna University of Technology, Gusshausstrasse 30/230-01, A-1040 Vienna, Austria, E-Mail: takeru.shibayama@tuwien.ac.at

Guenter Emberger, Vienna University of Technology, Gusshausstrasse 30/230-01, A-1040 Vienna, Austria, E-Mail: guenter.emberger@tuwien.ac.at

Abstract

The usage characteristics of shared electric scooters are largely unknown as private operators rarely make usage data publicly available. To overcome this barrier, we developed a methodology to monitor shared e-scooters only with publicly available data. We applied the methodology to identify trips and analyze their characteristics during a two-week period in the summer of 2019 in Vienna. We estimate that approximately 68,000 shared e-scooter trips were taken during this period. The majority of shared e-scooter trips are estimated to be between 500m and 2.5km: shared e-scooters are used in different distance and duration ranges compared to walking, cycling and bike-sharing, covering a niche of existing urban transport modes. The spatiotemporal analysis suggests use for recreation and tourism rather than everyday commuting, although its use as a public transport feeder mode is also estimated to be significant.

Keywords: electric scooter-sharing, shared mobility, usage characteristics, micromobility

1 Introduction

Various cities worldwide are in the midst of an electric scooter-sharing revolution. Similarly to the once booming but eventually declining dockless bike-sharing systems, various private companies provide free-floating shared fleets of electric scooters as an alternative means of transport for short-distance or last-mile trips within cities. These new micromobility solutions changed the transport landscape rapidly in many cities causing similar problems while offering new opportunities. The main concerns about electric scooter-sharing are related to safety (Aizpuru et al., 2019; Puzio et al., 2020), legality (e.g. Fang, Agrawal, & Hooper, 2018 for cities in the US) and occupation of public space (Fang et al., 2018).

While many public transport and bike-sharing service operators provide their data for public use, especially since standard data formats were introduced to share data about these services (such as GTFS[3] or GBFS[4]) (O'Brien, 2017; Cheetham, 2019), the operators of scooter-sharing less often provide open usage data due to their proprietary nature (civity Management Consultants, 2019). Although there are cities, especially in the US, which require private providers to share their data, the usage characteristics of such systems often remain

[1] Address at the time of the completion of the work
[2] Address at the time of the beginning of the work
[3] General Transit Feed Specification
[4] General Bikeshare Feed Specification

unavailable both for planners and for researchers. As a result, it is difficult to assess the impact of these systems due to the lack of available usage data.

To investigate the travel patterns of electric scooter-sharing users, we tracked the location of shared scooters of five providers in Vienna for two weeks between July 22 and August 4, 2019. The aim is to provide an objective, data-driven picture about scooter-sharing by analyzing the spatial and temporal distribution of scooter-sharing trips.

After collecting the positions of available e-scooters, we elaborated a methodology to identify trips with shared e-scooters from the raw dataset. As a result of the analysis, in this paper we discuss how the number of trips and available scooters changed over the examined period, as well as the temporal distribution of the trips over the days of the week. We also show how the duration and distance of the trips varied. Besides that, we generated maps to visualize the spatial characteristics of the trips and the location of the available scooters. Finally, we compare the characteristics of scooter-sharing trips with those of other means of transport available in Vienna.

Throughout the paper, the terms “scooter” and “e-scooter” refer to a two-wheeler vehicle with a steering handlebar and a standing deck equipped with an electric motor. In the context of this paper, “scooter” does not refer to a type of motorcycle also known as motor scooter.

“Scooter-sharing” refers to a vehicle-sharing service in which a fleet of e-scooters is made available throughout a service area to be rented for short term. The positions of the available scooters are shown in a smartphone app. The registered users are required to scan the QR code of an e-scooter to rent it. At the end of the trip, the users must park the vehicle in accordance with the local rules and return the e-scooter virtually in the app. The cost of the service is the sum of an unlock fee and the per minute usage fee. The pricing in most cities is similar, typically €1 for unlocking and €0.15-0.25 per minute for usage. These prices apply to Vienna as well.

The first shared e-scooters appeared in Vienna in September 2018. The providers have been regulated since the beginning: each shared scooter must be licensed by the City of Vienna and have a unique license plate (Mobilitätsagentur Wien, 2018). The users are also subject to some regulations: electric scooter riders must obey all the traffic rules applicable to cyclists and must comply with parking restrictions (BMVIT, 2019). As the market evolved, the state of Austria introduced guidelines for scooter-sharing (Presse-Service, 2019), while the City of Vienna introduced a new regulatory framework addressing both operations and usage (Leth, 2019).

At the time of our research, there were six major scooter-sharing providers in Vienna and one additional supplier had already announced the date of service commencement in Vienna. We summarized the providers and the number of issued licenses in Table 1. We should note that the number of issued licenses does not necessarily correspond to the size of each company’s fleet or to the actual number of offered scooters: some providers may have had issued more licenses than the actual number of e-scooters they offer.

Table 1: Number of issued license plates per provider.
Data from Mobility Agency Vienna GmbH (Mobilitätsagentur Wien).

Name of the provider	**Number of issued licenses**
Bird	1,500
Lime	1,500
Tier	1,500
Wind	574
Circ	1,500
Hive	790
Kiwi Ride (market entry in August 2019)	600

The service areas of scooter-share in Vienna at the time of the analysis are illustrated in Figure 1. The color scale of the map corresponds to the number of overlapping service areas. While all providers covered the inner districts, the densely populated parts of the city and the most visited tourist destinations, only two providers covered larger areas outside of the Outer Belt (Gürtel) and the northeastern parts of the city across the Danube.

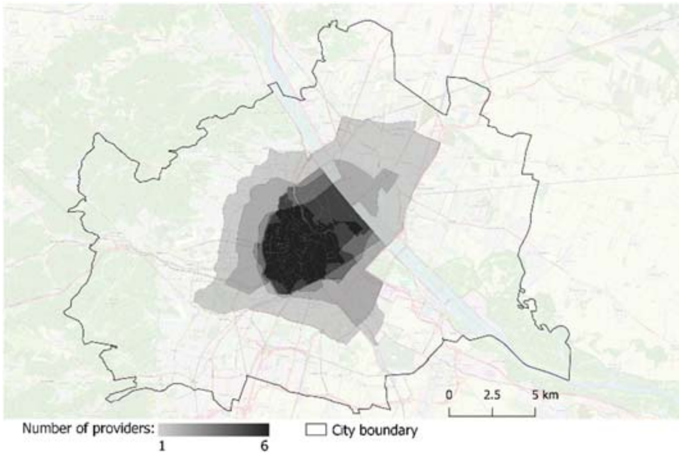

Figure 1: Service areas of scooter-share in Vienna during the analysis.
Data from Moran, Laa and Emberger (2020). Base map from OpenStreetMap.

The paper in hand is organized as follows. After a brief introduction, a summary of the most relevant scientific research related to our topic is provided in section 2. In section 3, the applied methodology of the data collection and data manipulation is described. Section 4 is about the results of the analysis. In section 5, we compare travel behavior related to scooter-sharing with that characterizing other means of transport available in Vienna and discuss the limitations of the research. In section 6, we summarize our conclusions.

2 Related works

Bike and car-sharing services in Vienna are already well studied topics. Leth, Shibayama and Brezina (2017) examined whether bike-sharing competed with or complemented the public transport system. They conclude that the bike-sharing system functions as a supplement to Vienna's public transport. Hudak (2016) analyzed the usage characteristics of car-sharing in the city. Laa and Emberger (2020) examined the regulatory aspects of free-floating bike-sharing systems describing how cities, including Vienna among many others, regulated these services. After scooter-sharing appeared in Vienna, researchers started to focus on the topic and examine its impacts. Moran, Laa and Emberger (2020) analyzed how the service area of scooter-sharing changed over time and how they were related to municipal regulations. Laa and Leth (2020) carried out a user survey to examine the socio-demographic characteristics of private and shared e-scooter users as well as their travel behavior to find out the purposes of the trips and the mode the scooters replace. Nearby major cities are also under the scope of research. For example, Radics (2018) proposed a general regulatory framework for free-floating bike-sharing systems including recommendations for Budapest.

As scooter-sharing is becoming increasingly widespread worldwide, the related scientific literature is also expanding but it is still limited. Gössling (2020) gives an overview of the market and operators of electric scooter sharing, analyzes the public opinion and acceptance based on media reports as well as summarizes policy responses of ten cities.

Only a few European papers have been published so far, as the research topic itself is a nascent field. An analysis done by a German consultancy firm summarizes the availability and usage of shared e-scooters in major European cities (civity Management Consultants, 2019). One of the major operators of e-scooter sharing, Lime (2019), also published a report about how their scooters performed in Paris. Tuncer, Laurier, Brown and Licoppe (2020) studied driver behavior of e-scooter users as well as how e-scooters fit in the existing transport landscape of Paris by analyzing video recordings.

There are more sources in the literature about scooter-sharing from outside Europe. A report introduces in detail the main drivers and characteristics of the current micromobility trends in the US and examines their long-term sustainability (Chang et al., 2019). Scientific papers analyzing and comparing the usage patterns of scooter-share and bike-share in Washington D.C. (McKenzie, 2019), and in San Francisco (Barnes, 2019), examining trip patterns and revenue in Louisville, Kentucky (Noland, 2019), and studying travel patterns (Jiao & Bai, 2020) and spatial associations (Caspi et al., 2020) in Austin, Texas are also parts of the wide range of related literature. There are other documents addressed more to practitioners about how shared electric scooters perform in Portland, Oregon (PBOT, 2018) and in the US (NACTO, 2018; Populus, 2018), discussing the financial and environmental sustainability aspects, usage characteristics and other concerns of such systems.

Besides usage characteristics, safety (Allem & Majmundar, 2019; Maiti et al., 2019) and user behavior such as parking on the sidewalk (Fang et al., 2018) are other studied areas in the US and Australia. Hermann (2019) investigated the regulatory aspects focusing on how the users of these vehicles were regulated and how the regulations should be improved. Physical harms i.e. the number and types of accidents and injury are also among the discussed topics (Trivedi et al., 2019; Bekhit et al., 2019; Badeau et al., 2019; Sikka et al., 2019; Yang et al., 2020).

The environmental impacts of shared e-scooters are another area of research. Scooter-sharing may be an effective solution to tackle urban congestion, but the environmental impacts greatly depend on manufacturing, lifetime of the vehicles, the mode of transport the scooters replace and the characteristics of operation and usage. As Hollingsworth, Copeland and Johnson (2019) conclude, scooter-share does not necessarily reduce environmental impacts from the transportation system; however, with the implementation of the recommended measures they can do so. Severengiz, Finke, Schelte and Wendt (2020) draw a similar conclusion after carrying out a life cycle assessment of shared e-scooters in Berlin.

The performance of shared electric scooter services is influenced by the characteristics of the city, such as urban structure, density, public transport services or the level of bicycle-friendliness and walkability. Therefore, these factors as well as further societal and economic aspects should be considered when comparing different cities' reports and statistics.

Although some studies have been carried out in Vienna and elsewhere, there is still a lack of understanding of travel behavior using shared e-scooters. This paper aims to add a case study to this research landscape by developing a methodology to analyze large amount of data and applying this to Vienna's case.

3 Methodology

3.1 Introduction of the methodology

As usage data of scooter sharing in Vienna was not available, we choose the second-best option and developed a methodology to obtain the positions of available scooters for rent and reconstruct the trips from how the positions of the scooters changed.

We obtained the positions of shared e-scooters available for rent with a 20-minute temporal resolution for two full weeks between July 22 and August 4, 2019. We accessed five providers that had a publicly accessible API (application programming interface) providing information about the available e-scooters of their fleets. The response to a single request was a list of the positions of the available scooters and further information as it is shown in Table 2. The rented scooters were not listed in the response.

Table 2: Data from an API response

Column	Description
battery_percent	Battery level in percent (0-100 scale): 3 providers
battery_level	Battery level on a scale of super low-low-medium-high: 1 provider
estimated_range	Estimated range of the scooter (km) based on current battery level: 1 provider
latitude	Latitude
longitude	Longitude
vehicle_id	Scooter ID: individual IDs only in the case of 3 providers
timestamp	Timestamp of the data collection

As weather may influence the use of micromobility modes, it has to be considered to better understand e-scooter-sharing patterns. Figure 2 shows the weather conditions in terms of temperature and precipitation intensity during the period of the data collection. During the two-week period, the city experienced normal summer weather without extreme conditions except for July 25 and 26, when the highest temperature reached 35 degrees Celsius. Although not a significant amount, it rained on the first weekend.

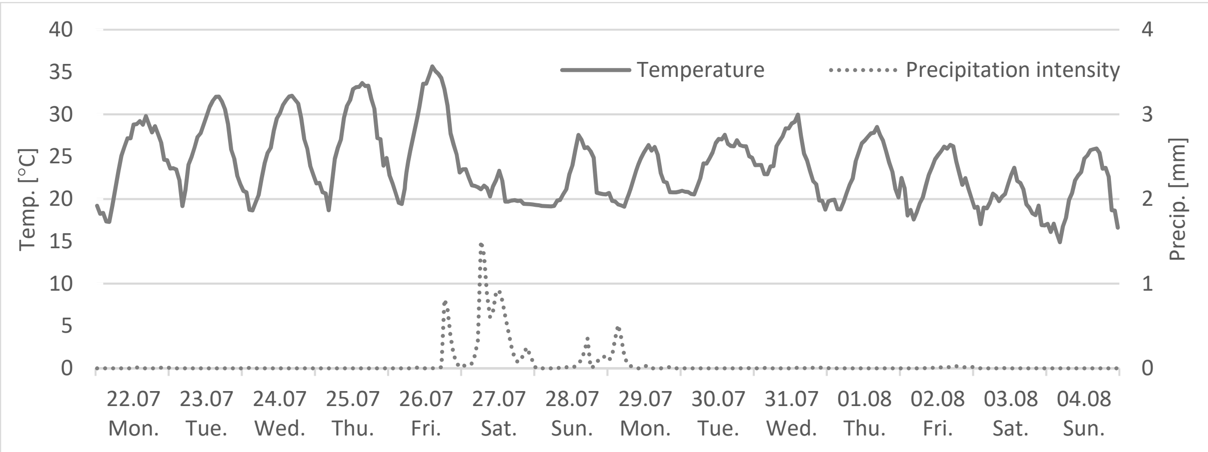

Figure 2: Weather conditions during the two weeks of the analysis.
Data from Dark Sky, darksky.net.

We introduce the methodology of the data manipulation in detail in the following parts of the chapter (see Figure 3 for the main steps).

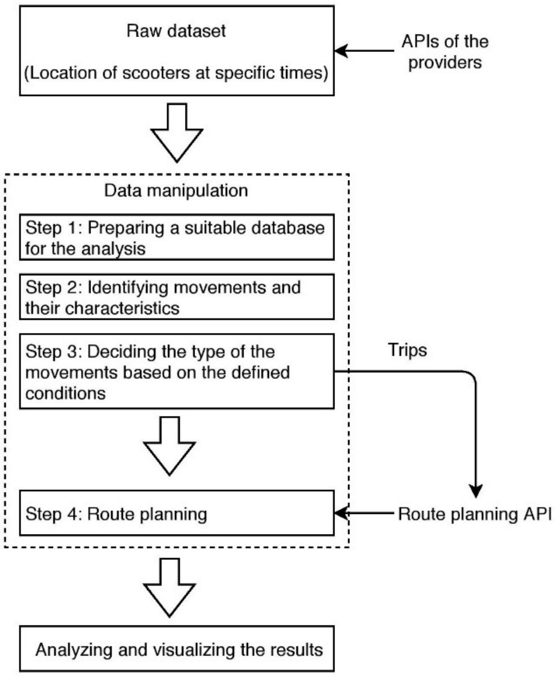

Figure 3: The main steps of the data manipulation

3.2 Identification of trips made with shared e-scooters

First, we merged the single API responses into a suitable database structured for the subsequent steps of the data manipulation (see Table 3). The raw database is a series of snapshots with a 20-minute temporal resolution including information about shared e-scooters that are ready to be rented. All in all, the dataset contains 2.28 million rows describing the 4,744 snapshots of the two-week period.

By making a “negative print” of this series of snapshots (i.e. determining how the position of a given scooter changed from one snapshot to the next one), it was possible to identify the rented scooters and reconstruct their movements inheriting information from the raw database. We applied a filter to identify rides as explained in this section.

Table 3: Legend for database structure (added new columns)

Column	**Description**
starttime	Start time of the movement (same as timestamp)
stoptime	Stop time of the movement
stoplat	Latitude of the destination
stoplon	Longitude of the destination
stopfuellevel	Battery level or battery range at the destination
typeofmovement	Type of the movement
tripdistancebeeline	Bee line distance between the start and end locations
batterydifference	Battery level difference between the start and end locations (if data available)
tripduration	Difference of the two timestamps (the exact value of the trip duration is not available as we had data from every 20 minutes)

In the next step, we determined the movements of the scooters from how the position of a given scooter changed over the series of snapshots (step 2). For each identified *vehicle_id,* we looked for the nearest snapshot where the same *vehicle_id* appeared again. We tentatively considered the second position as the end of a potential movement and therefore the following variables were determined: *stoptime, stoplat, stoplon, stopfuellevel*.

Further calculations included the bee line distance, the battery level difference (if it was applicable) and the difference between the two timestamps. Based on these variables, it became possible to decide whether a scooter moved, and if it did, we could determine the type of its movement.

Three out of the five providers used the same *vehicle_id* during the tracking period, while two providers changed the ID of the scooters over time or used different *vehicle_ids* before and after a rent, making it impossible to identify trips taken by each e-scooter. Because of this limitation, the previously described methodology in these two cases did not work.

Based on the data from the previous steps, we applied a filter to identify the types of the movements (step 3). Depending on the battery level difference, bee line distance and the time difference between the two timestamps, the trips were categorized into three types: ride, charge or rebalance, and not moved.

A movement was considered to be a ride if it fulfilled all of the following requirements:

- The change of position occurred during operating time (some operators provided 24-hour services while others were not available in specific hours of the day).
- The bee line distance was greater than 240 m.
- The difference between the two timestamps was less than 3 hours.
- The battery level decreased.

Short movements, with an estimated routed distance under 300 meters[5], were not considered to be rides because they were more likely to be rebalance movements or the location of the scooters changed due to inaccuracy of GPS. Assuming a 15-18 km/h average travel speed (Hötzinger, 2019), 250-300 meters is the range that can be covered in a minute using an e-scooter while this distance is shorter than a 5-minute walk. We assumed that it was unlikely the case for most people to use e-scooters for such a short distance.

By applying these filters, rides with origin and destination points closer than 240 meters to each other were omitted. These removed movements potentially corresponded to round trips; however, these round trips accounted for only a low percentage of the total number of trips at most[6], and therefore the removal of these did not substantially affect the further analysis.

We could not calculate the actual temporal duration of the movements; the trip duration was substituted by the time difference between the timestamps describing the start and end of the potential movements. The maximum temporal duration of 3 hours was set by analyzing the distribution of temporal durations and considering a 30-40 km battery range.

We could not determine a straightforward relationship between the battery level difference and the bee line distance, and therefore we set a less strict criterion for the battery level difference. We considered every movement as a potential ride where the battery level decreased.

If a movement did not fulfil all the requirements of a ride, it was assumed that it was a charge or rebalance movement and was excluded from the further analysis.

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[5] We used a 1.25 detour factor to estimate the routed distance of the movements from the bee line distance (Leth et al., 2017).

[6] The number of potential round trips a week were less than 1% of the total number of trips considering a short bee line distance but a significant battery level difference.

3.3 Routing

The final step of the data manipulation (step 4) was the calculation of potential routes for each ride, the related trip distance and the temporal duration of the trips as well as the input for the heatmaps of the scooter-share trips.

In the dataset, only the start and end points of the movements could be derived, and no information about the route of the trips or any intermediate points was available. Ideally, the intermediate positions could ideally have been collected by tracking the smartphones of the users; however, such data was not available. Alternatively, a route planner provided information about optimal routing between the start and end points, as well as some additional characteristics such as trip distance and duration. If there had been a particular routing engine for e-scooters, it would have been a better solution; however, at the time of the research, no such routing engine was available for Vienna. As an alternative, we used the cycling route planner Bike Citizens[7], choosing a balanced (other options are easy and fast), city bike (other options are mountain bike and road bike) profile. We assumed that e-scooter trips followed similar patterns to bicycle trips as e-scooters have a similar travel speed of 15-18 km/h and have to follow the traffic rules applicable to bicycles in Vienna (Hötzinger, 2019).

This was the most reasonable alternative to reconstruct the routes of the trips with the available data and tools.

4 Results

4.1 Number of trips and scooters

By applying the aforementioned method, approximately 25,000 shared e-scooter trips in the 14 days of the observation period are identified. The number of daily trips and available scooters over the examined period of those three operators whose trips are identifiable are illustrated by Figure 4. The number of trips varies between 1,700 and 2,150 on weekdays and around 1,500-1,700 on weekends, while the number of available scooters are between 950 and 1,200.

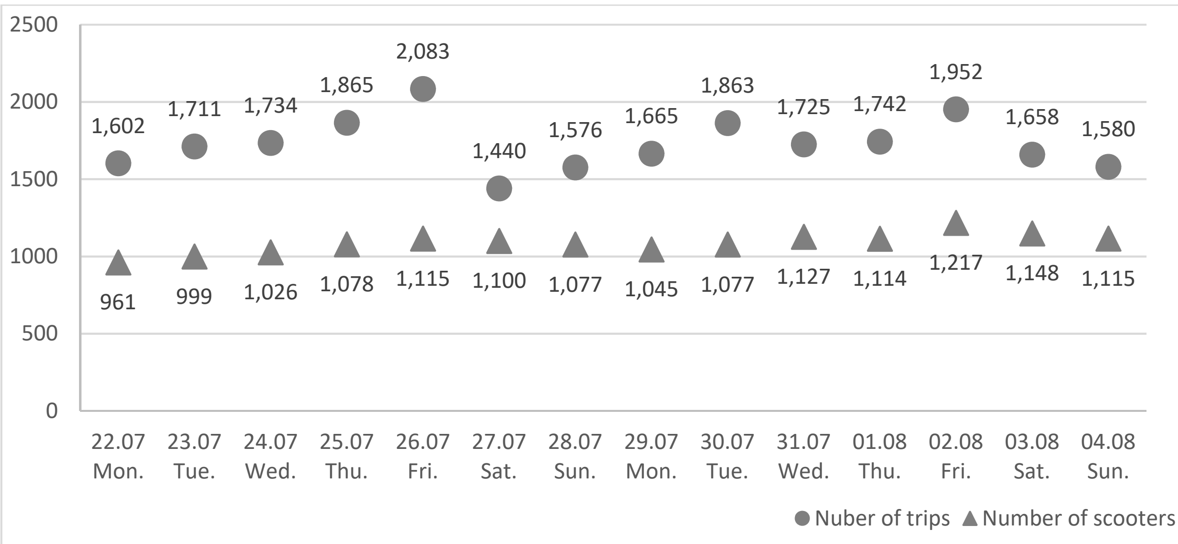

Figure 4: Number of observed daily rides and scooters during the examined period (3 providers)

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[7] www.bikecitizens.net, BikeCityGuide Apps GmbH

4.2 Number of daily rides per scooter

Based on the number of trips and available scooters, we calculated the average number of daily trips per scooter for two of the three operators. It has a mean value of 1.72 with a standard deviation of 0.15. One of the three operators is excluded from this calculation because it was about to leave the market, and therefore, had a lower number of daily rides per scooter during the two-week period (mean: 0.73, standard deviation: 0.19, while the number of scooters decreased from 120 to 5).

Operating the right fleet size is crucial for two main purposes. Vehicles should be available around key destinations within a short walking distance, while it should be avoided that an excessive number of abandoned and underused scooters dominate the cityscape.

4.3 Temporal distribution of the trips

The aggregated numbers of all trips by the start time and all available scooters per hour on weekdays and weekends are summarized in Figure 5.

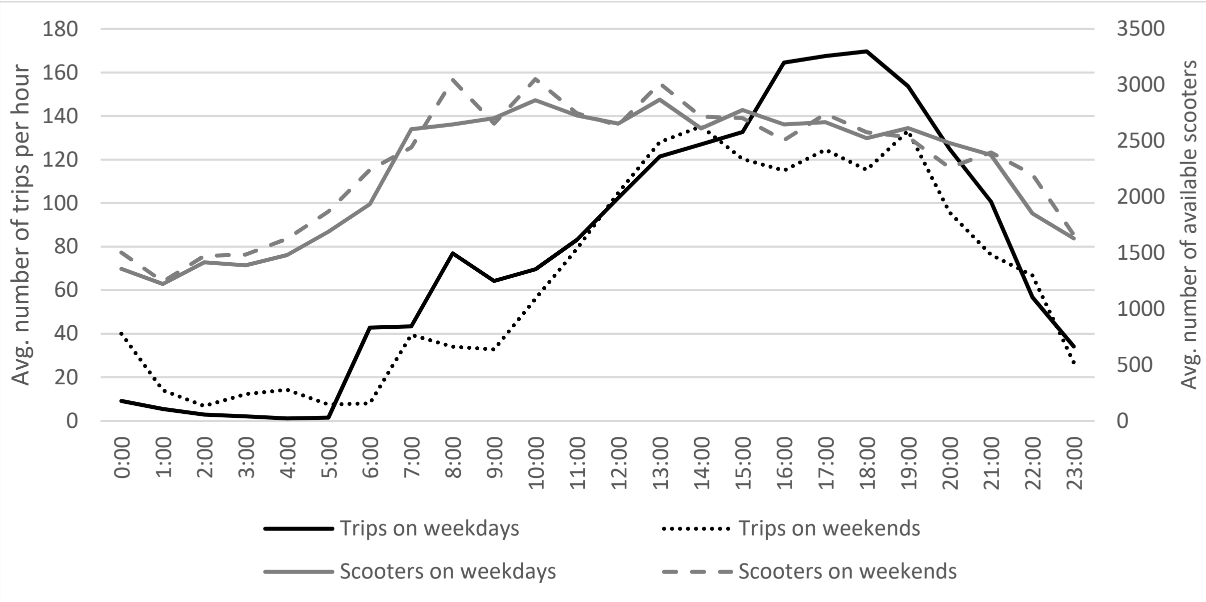

Figure 5: Temporal distribution of trips and number of available scooters on weekdays and weekends (3 providers)

The availability of scooters, in terms of their numbers on weekdays and weekends, is fairly constant over daytime and no significant differences can be observed. However, there is a considerable peak of usage during the late afternoon hours (15:00 – 19:00) both on weekdays and weekends. On weekdays, there is a small peak between 7:00 and 9:00: this peak is presumably rather due to commuting trips; however, the number of trips in the morning peak is much lower than during the afternoon peak. The differences in the number of scooter-sharing trips on weekdays and on weekends (see Figure 4) are well explained by the average number of trips during morning and afternoon hours: about 120 and 635 trips are observed during the weekday morning and evening peak hours respectively, while there are 75 and 475 rides on average for the same time periods during the weekends.

The results presented above imply that shared e-scooters are primarily used rather for leisure trips (e.g. recreation after work) and tourism, and to a much lesser extent for commuting. The difference between the curves of weekday and weekend trips suggests that there is a base amount of leisure trips and a smaller number of weekday commuting trips is added on top of that. Studies found similar patterns in other cities (Chang et al., 2019; civity Management Consultants, 2019; NACTO, 2018). It has to be noted however, that the data collection of the current research was carried out during the summer period, which might affect this result.

4.4 Bee line trip distance

As mentioned before, our data collection methodology only allows for obtaining the start and end locations of the trips, and it does not allow for obtaining the information about intermediate points en route. Therefore, only the bee line distance between these two known locations can be used to estimate the travel distance. The results of this analysis are shown in Figure 6. The bee line distance of the trips has a mean value of 1.28 km (standard deviation: 0.91 km, median: 1.03 km).

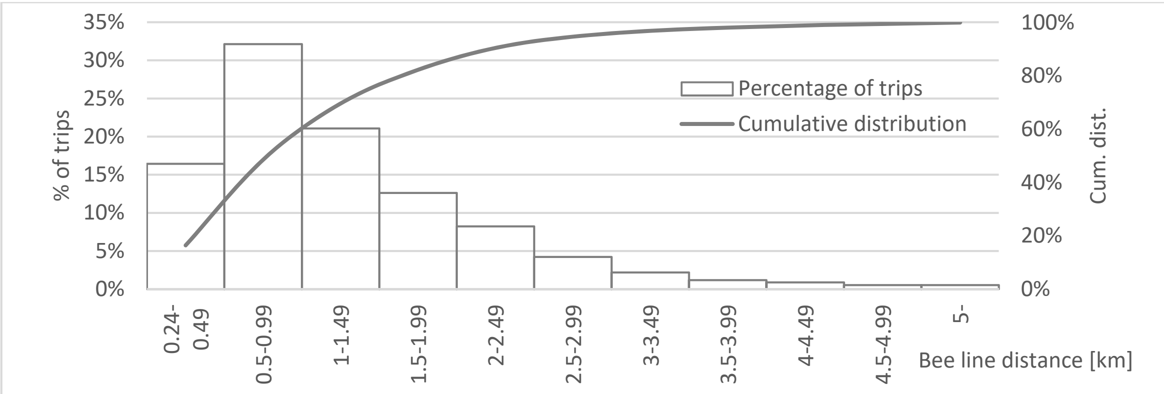

Figure 6: Histogram and cumulative distribution of bee line distance

4.5 Estimation of total number of trips

Assuming that all providers performed with a similar average number of daily rides per scooter, the number of daily rides was estimated for the remaining two providers whose trips could not be identified by applying our method. Based on the average number of scooters available during the day, it is estimated that there are approximately 1,500-2,100 more scooters and 2,400-3,500 more trips a day in the two-week period. Summing up the estimated figures and the ones in the sample, there are approximately 68,000 trips during the two weeks (see Figure 7 for daily details).

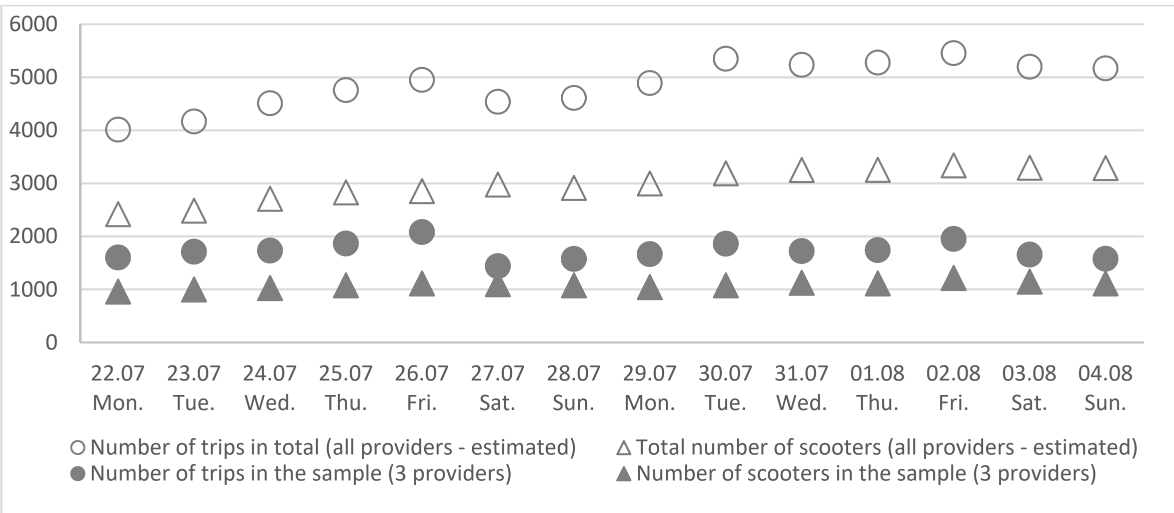

Figure 7: Number of observed and estimated daily rides and scooters during the examined period

4.6 Estimation of routed trip distance and duration

Because the dataset used for the analysis has a 20-minute temporal resolution, it is not possible to derive the actual trip duration based on empirical data more accurately than 20-minute units. A 20-minute e-scooter ride corresponds to the distance range of 5 to 7 km, which goes way beyond the average bee-line distance of 1.28 km and also beyond the service area of e-scooters in Vienna. Furthermore, a 20-minute ride would cost between EUR 4 and 6, which is much higher than the cost of a single public transport ticket in Vienna (EUR 2.40, flat rate). Therefore, the majority of actual shared e-scooter trips is presumably shorter than 20 minutes. Alternatively, assuming that e-scooters' routing and travel time follow bicycle-like patterns, we estimated the route for each trip with the online journey planner Bike Citizens[8], choosing a balanced, city bike profile. This may not fully represent the real distribution of trip duration, but enables us to estimate the trip duration and the routed trip distance.

As a result, we obtained a mean routed trip distance of 1.73 km (standard deviation: 1.16 km, median: 1.44 km). The trip duration is estimated to have a mean value of 7.2 minutes (standard deviation: 4.68 minutes, median: 5.92 minutes). The results can be seen in Figure 8 and Figure 9.

About 23% of the routed trips fall in the range between 500 m and 1 km. This distance corresponds to a walking duration of about 5 to 15 minutes (assuming a 4 km/h walking speed). Approximately another 23% of trips fall between 1 km and 1.5 km, corresponding to a 15 to 22 minute walking duration. Only about 7.5% of the trips fall in the range between 300 m and 500 m.

A 500 m walking distance accessing or egressing from public transport stops is acceptable for only about 5% of passengers if the walking environment is not pedestrian-friendly, and for about 30% of passengers in a pedestrian-friendly environment, such as in a pedestrian zone. The aforementioned acceptance rates decrease with walking distance increasing (Peperna, 1982). The results show that shared e-scooters are mainly used in the distance range beyond acceptable walking distance.

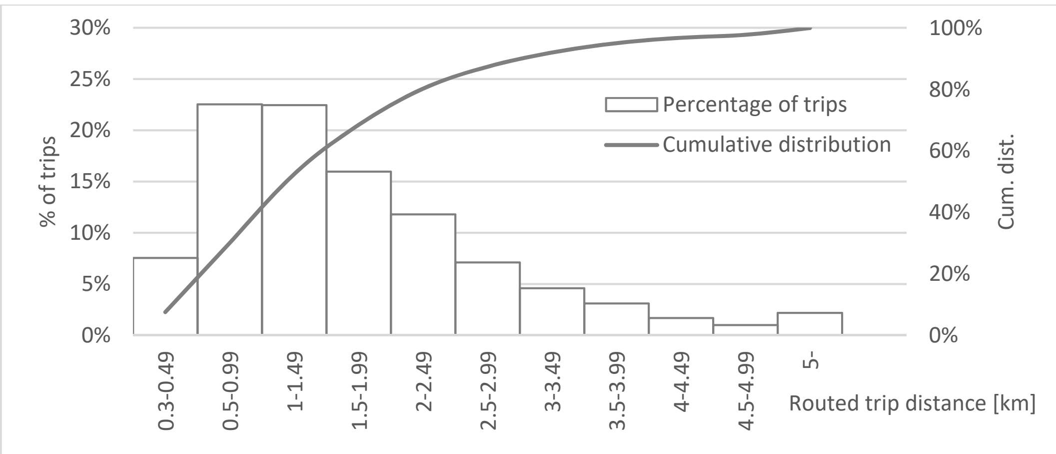

Figure 8: Histogram and cumulative distribution of routed trip distance

[8] www.bikecitizens.net, BikeCityGuide Apps GmbH

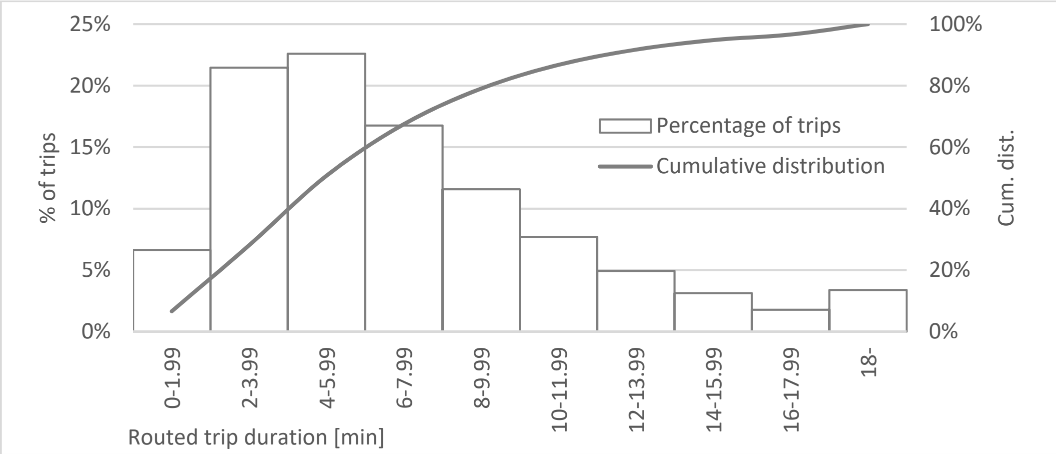

Figure 9: Histogram and cumulative distribution of routed trip duration

4.7 Spatial characteristics – availability of e-scooters

To better understand the spatial distributions of e-scooters, we used a 50x50 m grid covering the service areas in Vienna. We calculated the average number of scooters per hour available in a grid segment distinguishing the morning and evening peak hours (Figure 10 and Figure 11) as well as weekdays and weekends in total (average hourly number, Figure 12 and Figure 13). Figure 10 and Figure 11show that the e-scooters become more scattered out throughout the city over time during weekdays. This is probably due to the fact that the e-scooters are relocated to certain places during the night and early in the morning, and after being used, the locations of the scooters become more scattered. Figure 12 and Figure 13 show that the locations of scooters are a bit less dispersed on weekends than on weekdays and scooters are slightly more concentrated around primary tourist attractions and leisure destinations.

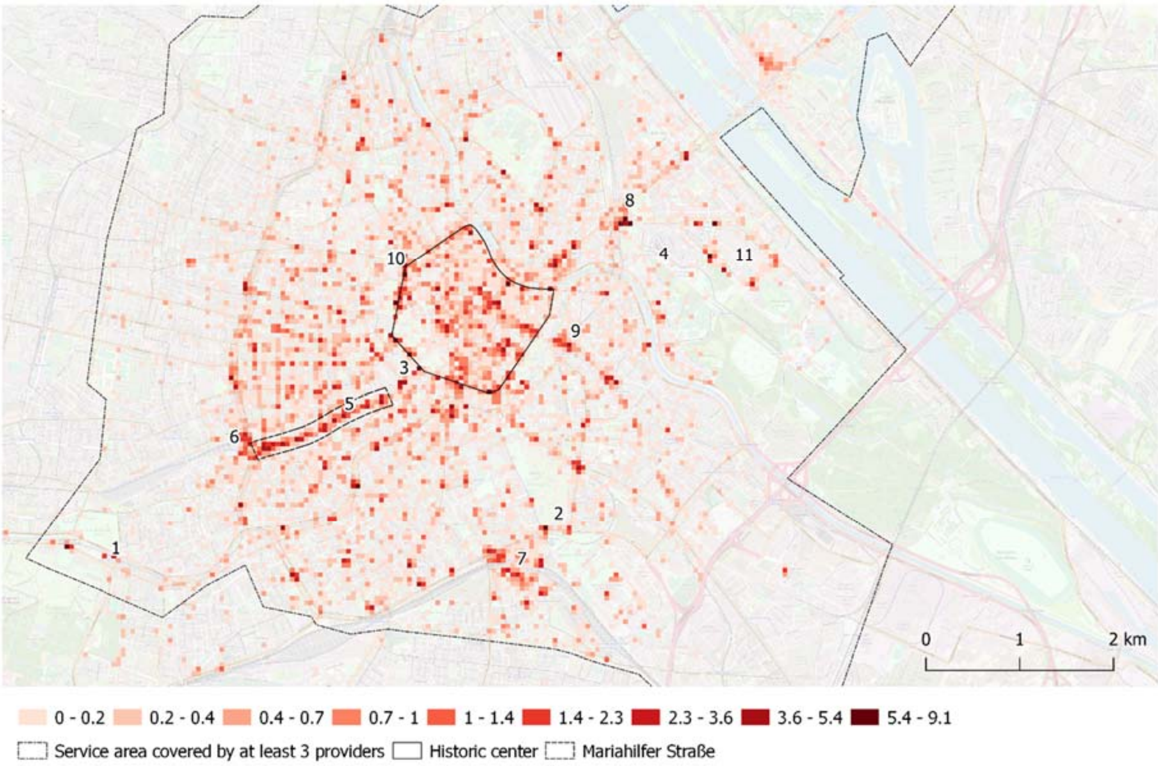

Figure 10: Location of available scooters on weekday mornings (7:00-9:00). The color scale corresponds to the average number of hourly available scooters in a 50m x 50m grid cell during the visualized time period (5 providers). Base map from OpenStreetMap.

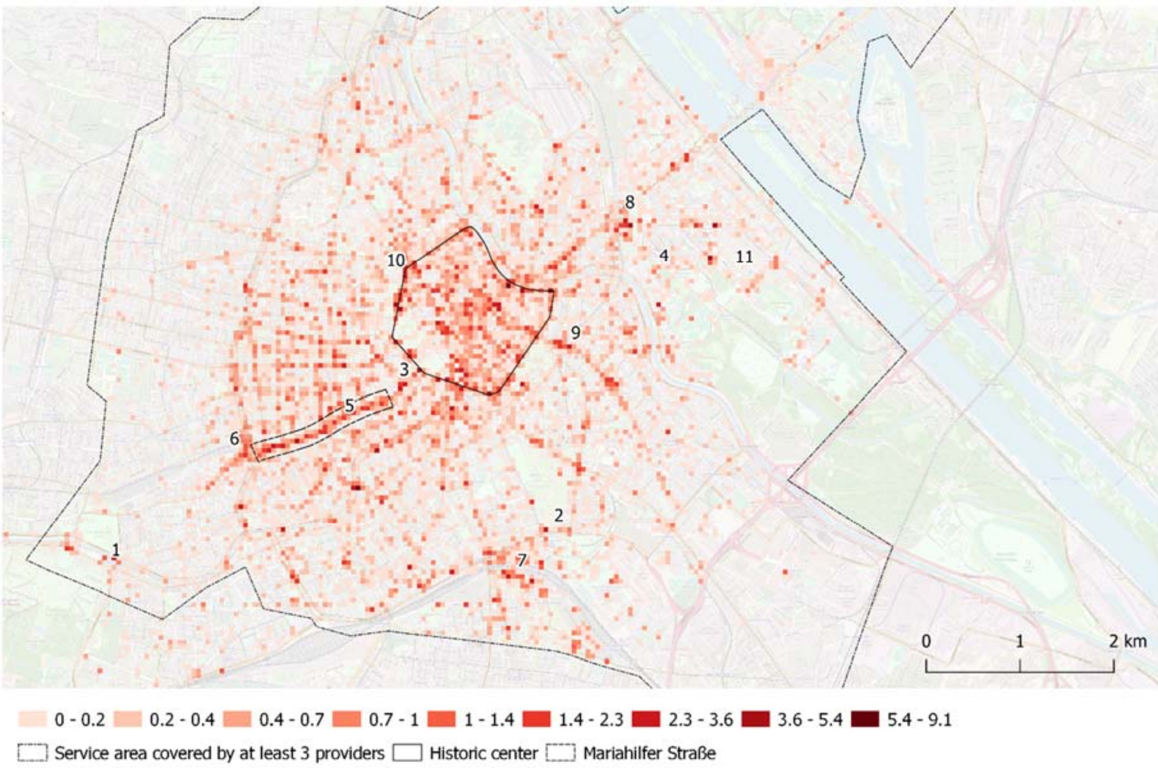

Figure 11: Location of available scooters on weekday evenings (15:00-19:00). The color scale corresponds to the average number of hourly available scooters in a 50m x 50m grid cell during the visualized time period (5 providers). Base map from OpenStreetMap.

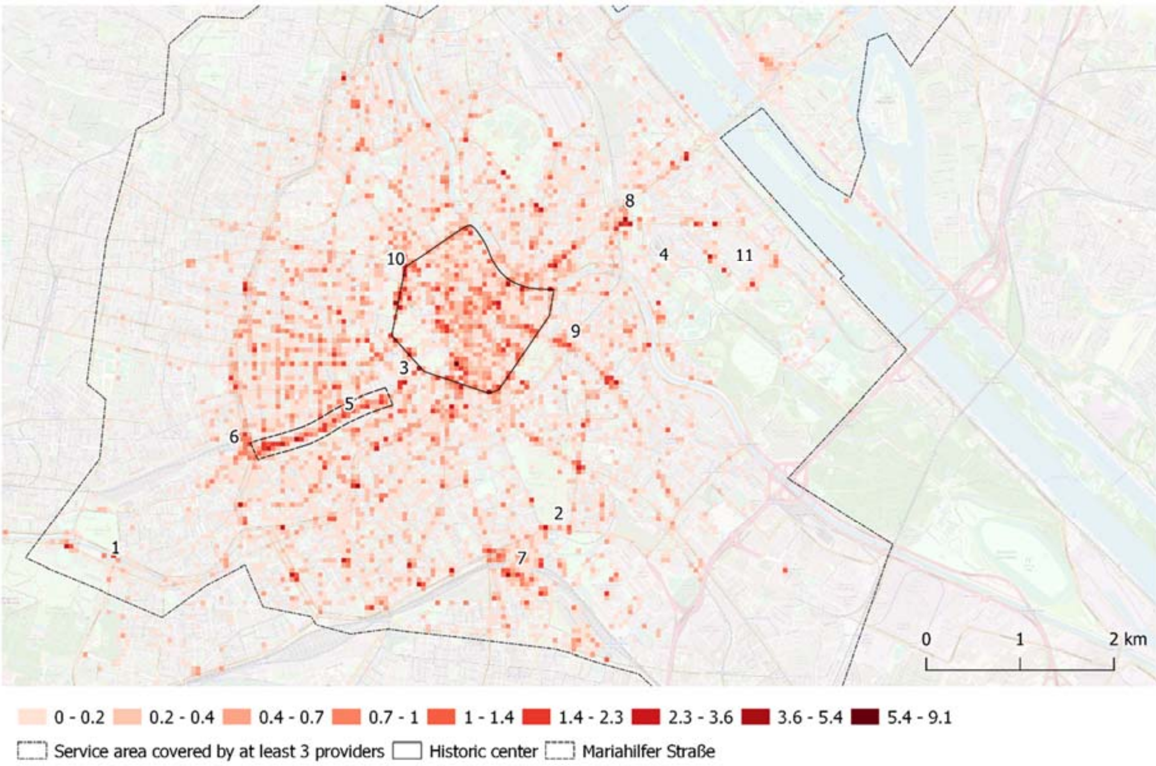

Figure 12: Location of available scooters on weekdays. The color scale corresponds to the average number of hourly available scooters in a 50m x 50m grid cell during the visualized time period (5 providers). Base map from OpenStreetMap.

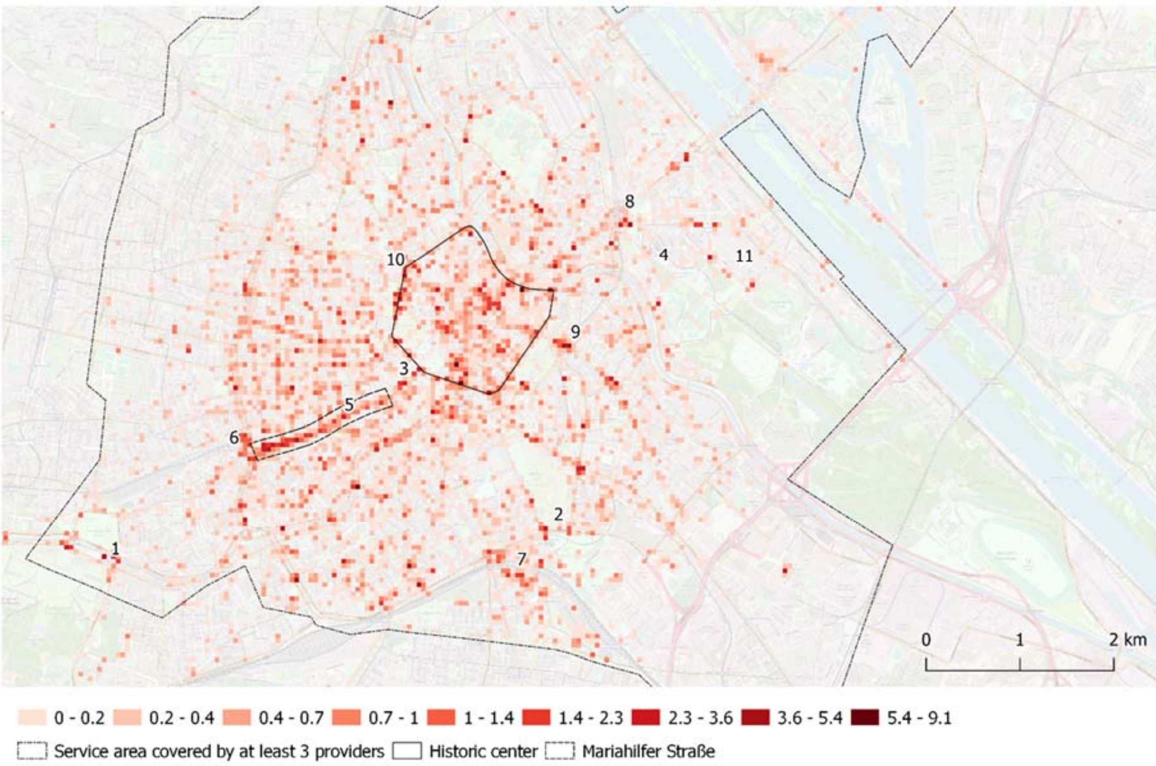

Figure 13: Location of available scooters on weekends. The color scale corresponds to the average number of hourly available scooters in a 50m x 50m grid cell during the visualized time period (5 providers). Base map from OpenStreetMap.

4.8 Spatial characteristics – start and end points

Using the same 50 m x 50 m grids, we plotted the origins and destinations of all identified trips on Figure 14 - Figure 17.

The destinations of the trips are more dispersed than the origins: this is due to the everyday operations as shared e-scooters are relocated and concentrated at certain locations. The hotspots of origins and destinations are largely the same both on weekdays and weekends.

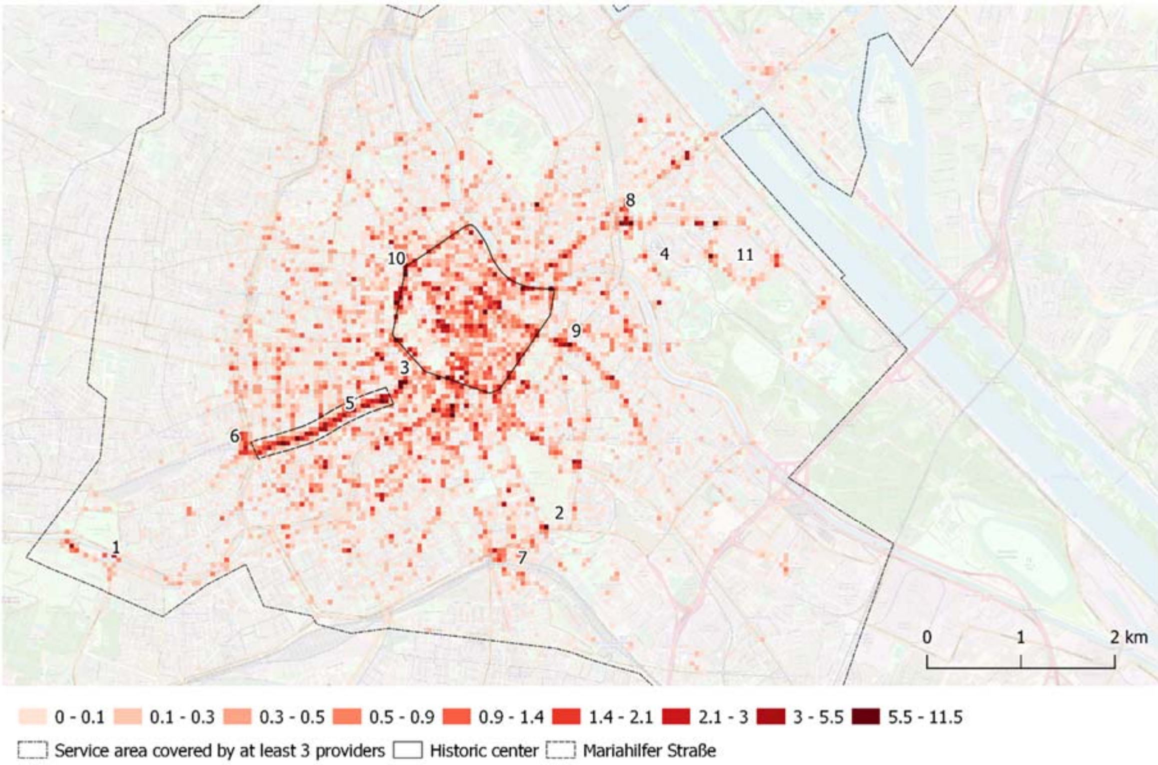

Figure 14: Origins of trips on weekdays. The color scale corresponds to the daily hourly average number of origins in a 50m x 50m grid cell (3 providers). Base map from OpenStreetMap.

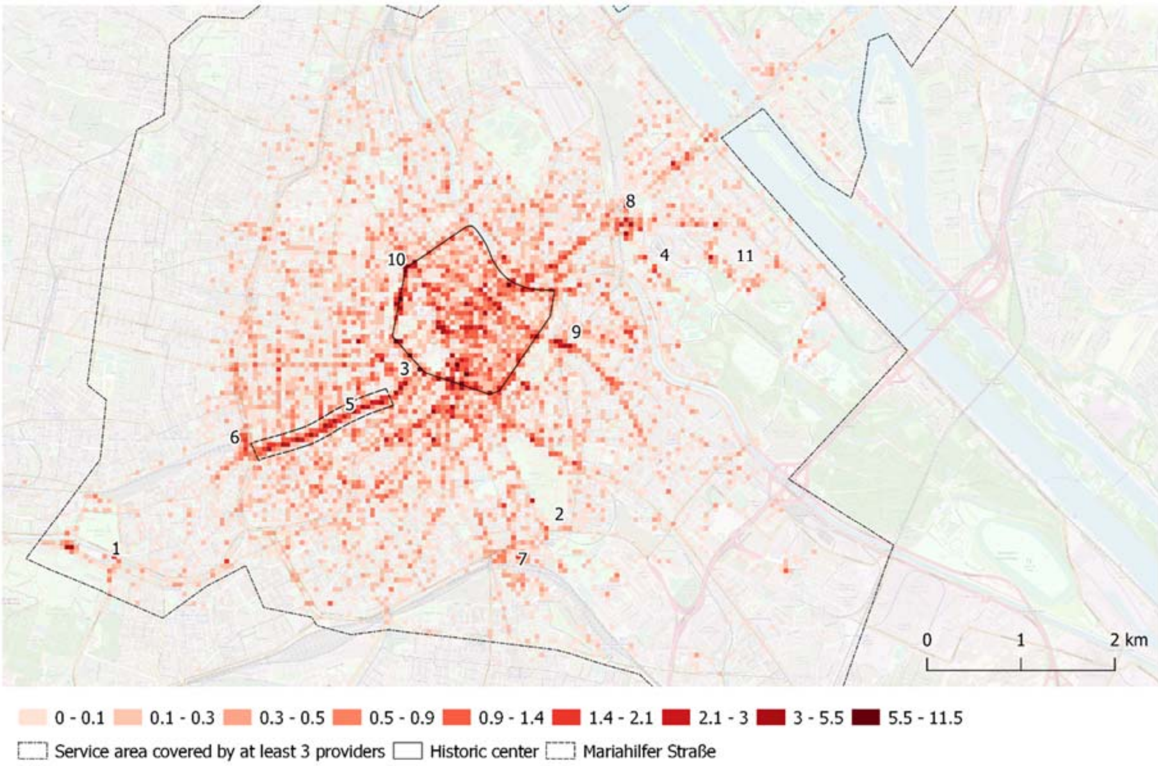

Figure 15: Destinations of trips on weekdays. The color scale corresponds to the daily hourly average number of destinations in a 50m x 50m grid cell (3 providers). Base map from OpenStreetMap.

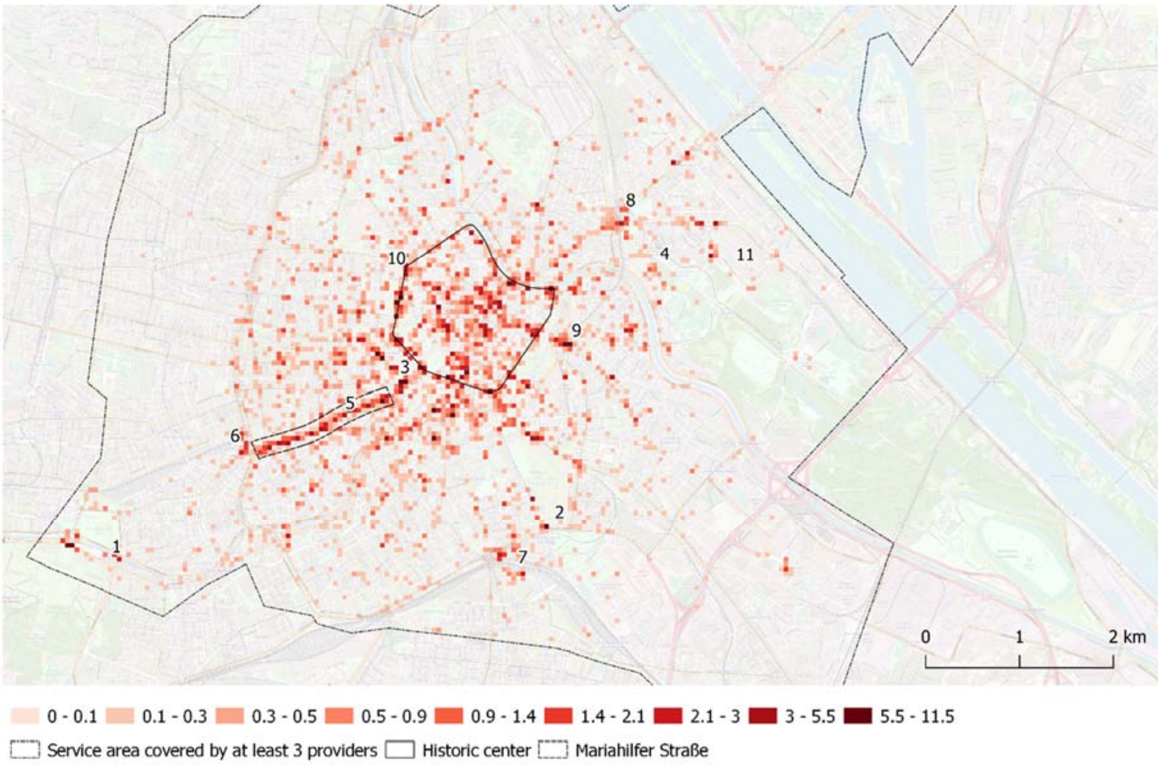

Figure 16: Origins of trips on weekends. The color scale corresponds to the daily hourly average number of origins in a 50m x 50m grid cell (3 providers). Base map from OpenStreetMap.

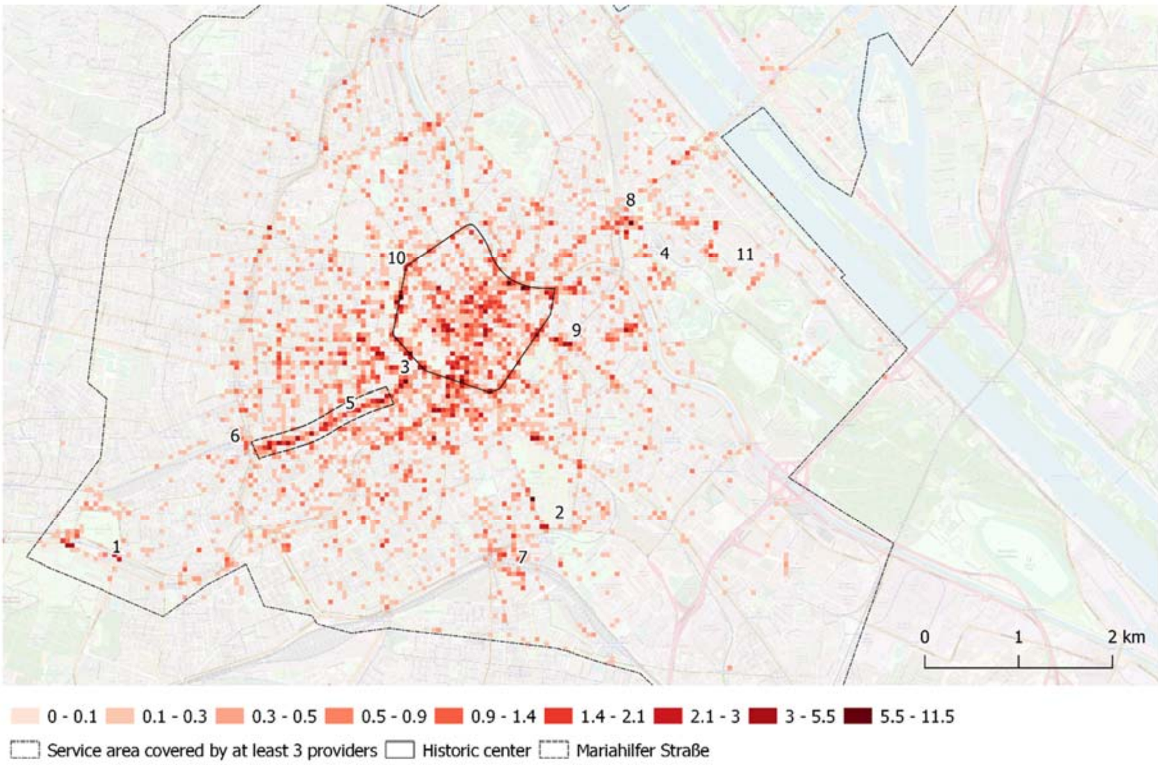

Figure 17: Destinations of trips on weekends. The color scale corresponds to the daily hourly average number of destinations in a 50m x 50m grid cell (3 providers). Base map from OpenStreetMap.

In the maps showing the locations of available e-scooters, concentrations around tourist attractions and main public transport nodes, such as main railway stations and intersections with frequented tram stops, can be observed. Especially, during weekday mornings, the available scooters are much more concentrated around major public transport nodes: this implies that the operators of e-scooter sharing services relocate their fleet closer to the public transport nodes during the night or in the morning hours.

Looking at the origins and destinations, the locations of hotspots imply use for leisure or tourism. Such places are Schönbrunn Palace (no.1 location on the map), Belvedere (art museum, no.2), the Museum Quarter (no.3), Prater (a large park, no.4), Mariahilfer Straße (shopping street, no.5, dashed line),the historic center inside the Ring Road (the area is marked with a solid line) and the Ring Road itself (especially the section between Universitätsring and Kärntner Ring), where many tourist sites are concentrated. Some concentrations are observed around major public transport nodes, such as Wien Westbahnhof (West Train Station, no.6), Wien Hauptbahnhof (Main Train Station, no.7), Praterstern (no.8) and Landstraße-Wien Mitte (no.9). This may imply that e-scooters are used to access and egress from public transport stops. However, further research is needed as these stations and their surroundings not only attract public transport passengers, but they are also important destinations for shopping, accommodate the offices of companies and public administration or serve other urban functions. Concentrations around two particular universities, University of Vienna (no.10) and Vienna University of Economics and Business (no.11) can also be observed on the origin and destination maps.

5 Discussion

5.1 Synthesis of the analysis results

According to our analysis, approximately 25,000 trips were undertaken during the two-week period in summer 2019 with the scooters of three providers whose data could be obtained. Assuming similar performance for the remaining two providers whose data was not available, approximately 68,000 e-scooter trips took place in total in Vienna over the two-week period. Two peaks of usage can be identified on weekdays from 7:00 to 9:00 and from 15:00 to 19:00, and a less significant but longer peak on weekends covering the whole afternoon. The number of trips on weekends dropped to around 80% of that on the weekdays.

The average number of daily trips per vehicle is a general performance indicator used for bike-sharing. Ideally it should be at least 4 to achieve satisfactory performance (ITDP, 2018). If we look at the calculated 1.72 rate for scooter-share in Vienna, it indicates a rather low performance. For comparison, scooter-share systems in the US operate with average number of daily rides per scooter varying from less than 1 to little over 4 (NACTO, 2018).

By plotting the locations of available scooters and start and end points of e-scooters on the map, we found that e-scooters were more scattered out throughout the service area in the evening than in the morning. This is probably because of the redistribution activities of the sharing service providers which is typically carried out in the night or early in the morning. The start and end points imply that the e-scooters are often used to reach tourist attractions or leisure destinations, and also as an access mode to or egress mode from public transport stops. Based on the temporal and spatial distributions of the trips, it is estimated that shared e-scooters are primarily used for leisure trips and tourism, and the share of commuting trips is lower.

Assuming that e-scooter trips followed similar patterns to bicycle trips, a bicycle route planner was used to estimate routes for each of the e-scooter trips. The average routed trip distance is estimated to be 1.73 km, and trip duration to be 7.2 minutes. This is further discussed in comparison with other similar modes in the next section.

5.2 Comparison with other urban travel modes

To compare the characteristics of scooter-share trips with those of other modes of transport, one indicator can be the length of trips. Figure 18 shows the cumulative distribution of trip distances and Table 4 introduces the average trip distances, durations and speeds comparing similar modes of transport. The data on walking and cycling are from the national household travel survey in 2013 and 2014 (Tomschy et al., 2016), while the data on station-based bike-sharing is from the same two weeks of 2019, obtained from the operator (Citybike Wien, personal communication, February 14, 2020). The bike-share and scooter-share trip distances are estimated routed trip distances generated by a route planning application. It should be mentioned that the pricing of scooter sharing follows a pay per use approach (€1 for unlocking the scooter and €0.15-0.25 per minute for usage), while Citybike Wien users are required to pay a registration fee of €1 to have access to the bikes, the 1st hour of usage is free and the hourly usage fee gradually increases after this free period (the 2nd hour is €1, the 3rd hour is €2 and every further hour is €4).

Comparing the two shared modes, it can be concluded that scooter-share trips tend to be shorter than bike-share trips. The average routed trip distance of scooter-share and bike-share trips are 1.73 km and 2.71 km respectively. Comparing scooter-share to walking and cycling, using shared or private bicycles, scooter-share trip distances fall between those of walking and cycling. These cumulative curves show that shared e-scooters are used to cover longer distances compared to walking, but shorter distances compared to using shared or private bicycles. This result implies that under Vienna's circumstances, e-scooters cover the niche of urban travel distances which are beyond acceptable walking distances but are slightly shorter than the most common distances for cycling with shared or private bicycles. Additionally, for longer distances, cycling could be more appropriate than riding shared e-scooters because of riding comfort and the per minute usage fee of the scooters.

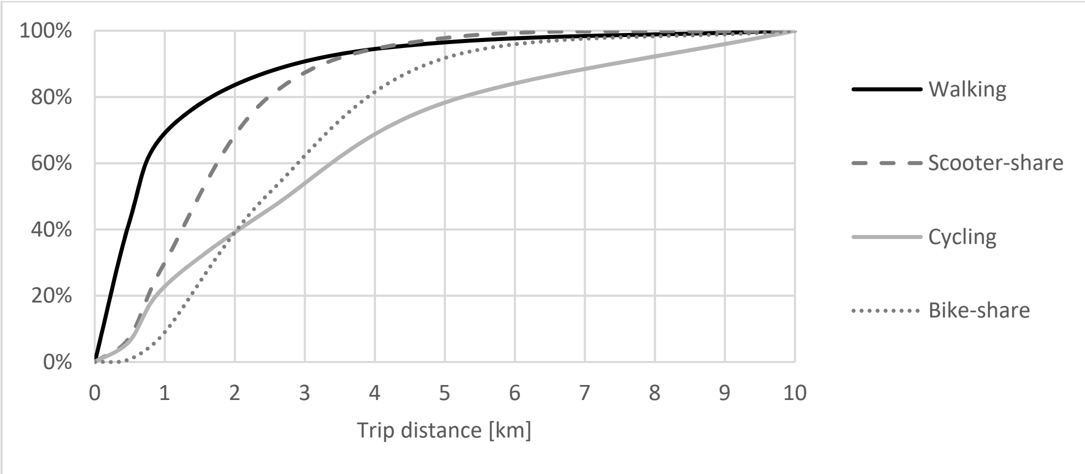

Figure 18: Cumulative distribution of trip distances using different modes of transport. Data on walking and cycling from Tomschy et al. (2016)*, on bike-share from Citybike Wien (Citybike Wien, personal communication, February 14, 2020).*

Table 4: Average trip distance, duration and speed of different modes of transport. Data on walking and cycling from Tomschy et al. (2016), on bike-share from Citybike Wien (Citybike Wien, personal communication, February 14, 2020).[9]

	Average trip duration [min]	**Average trip distance [km]**	**Average speed [km/h]**
Walking	19.46	1.35	4.16
Cycling	21.5	4.07	11.36
Bike-share	14.18	2.71	11.47
Scooter-share	7.24	1.73	14.34

By comparing the temporal distribution of scooter-sharing and bike-sharing trips (see Figure 19), similar distribution and peak hours can be observed both on weekdays and weekends.

[9] *The average speed is based on the average trip distance and trip duration as other information was not available in the case of the travel survey (Tomschy et al., 2016).*

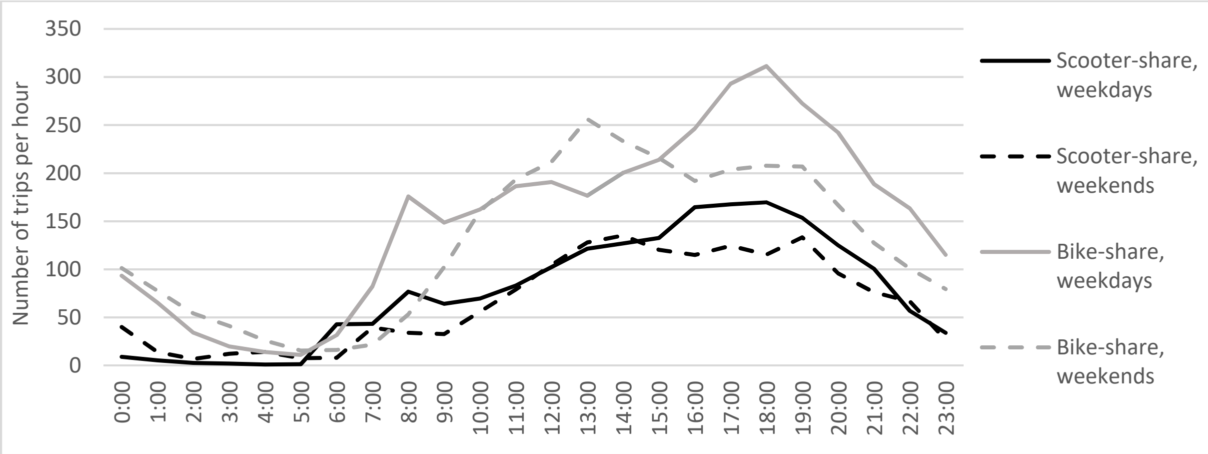

Figure 19: Temporal distribution of bike-share and scooter-share trips on weekdays and weekends. Data on bike-share is from Citybike Wien (Citybike Wien, personal communication, February 14, 2020).

5.3 Limitations and caveats

As the temporal resolution of the data that we used is 20 minutes, and the mean estimated temporal duration of the trips is merely 7.2 minutes, it is likely that some shorter trips are not identified in our dataset. Due to the applied methodology, each trip with a bee-line distance shorter than 240 m is dropped. Eliminating round trips having the start and end points closer than 240 m and trips that are longer than three hours result in a focus on utilitarian uses of the e-scooters. The timing of the analysis also limited the research opportunities, especially as the data collection was carried out during the summer period when the number of commuters might have been lower than the average. Because of these, we might have underestimated the number of trips.

The trip distances and travel times were estimated using a cycling route planner as the exact values are not identifiable with the method that we deployed, and no route planners existed for e-scooters in Vienna at the time of the research. This assumption of similarity of cycling and scooter-share trips will have to be further researched, and the research results that rely on the routed data may have to be updated depending on the findings.

6 Conclusions and future outlook

In the research presented in this paper, aiming at understanding the usage characteristics of scooter-sharing in Vienna, the positions of the available shared e-scooters of five operators for a two-week period are collected, and trips with shared e-scooters are estimated. We reached to an understanding that more than 90% of the shared e-scooter trips are to cover distances longer than the acceptable walking distance of 500 m, while 80% of the trips are shorter than 2.5 km, which corresponds to a ride on the Viennese tram for 6 to 7 stops or on the underground railway for 3 to 4 stops (Wiener Linien, 2018). Comparing the characteristics of scooter-share trips with those of other transport modes, we found that scooter-sharing trips tend to be longer than walking but shorter than cycling and bike-sharing trips.

By analyzing the temporal and spatial distributions of shared e-scooters, we conclude that the shared e-scooters are presumably used primarily for leisure trips to reach leisure facilities, but also by commuters to some extent especially as a feeder mode to and from public transport. At large, Viennese people tend to use e-scooters rationally, covering the distance ranges in which other sharing services and modes of transport have less strengths.

Our findings indicate that shared e-scooters are used in different distance and time ranges compared to walking, cycling and bike-sharing covering a niche of existing transport modes. It is too early to conclude that shared e-scooter is the optimal micromobility option as the service is relatively new and its long-term viability is yet unknown. Nevertheless, policy-makers and urban planners will have to bear well in mind that shared e-scooters or potentially other micromobility options may well be integrated into the urban transport system to cover short but beyond-walking distances as well as feeder modes to public transport nodes, even in a city with a dense and extensive public transport system.

Our methodology highlights the applicability of a data mining approach based merely on the publicly available information of e-scooters to estimate trips inversely. We successfully estimated a full picture of scooter-sharing based on information only about the positions of the available scooters for rent, and without further data about the trips or about the users.

Nevertheless, our study poses an issue about data availability, which is one of the biggest takeaways from our research. At the time of the research, scooter-sharing operators are not obliged to provide any open data platforms about their systems' performance in Vienna. Some providers changed the IDs of their scooters over time: we do not know if such change occurs because of their technical requirements to protect users' privacy or they change it intentionally so that their e-scooters are not individually tracked, but in any case, such scrambling makes our methodology inapplicable. This limitation of data availability hinders an in-depth analysis related to e-scooters, leading to a large extent of estimations to gain a full picture with many assumptions, making our research results less robust. Considering that vehicle sharing operators, including e-scooter-sharing operators, primarily make use of public street space to generate their income, it is recommended to adapt the legal framework so that the data of sharing operators useful for transport policy-making is made publicly available in return. In such transport policy-making contexts, the open data of vehicle sharing operators enables more robust and reliable analysis results than relying on estimations to gain a full picture as we had to do. This will eventually help the city to integrate sharing services into transport policy in a more evidence-based manner, mitigating the risk of random prioritization of particular shared modes in its policy.

Future research on examining and understanding the implications of scooter-share will be needed to understand its potential roles in the entire urban transport system better, and also to optimize the operations. To supplement the main characteristics of usage presented in this paper, further steps will have to be taken to understand user preferences and gain more insights about user behavior. Considering that our research methodology is largely restricted by the availability of data, to make such in-depth analysis possible, the aforementioned data availability is crucial to continue our research.

Furthermore, trip purposes could potentially be estimated based on the type of land use of the origin and destination areas (McKenzie, 2019). The research results can be complemented by a questionnaire-based survey to the users. By applying such methodologies, our conclusions will be made more robust. Expanding data collection periods will provide the possibility to verify the findings of our research and also to examine the long-term developments of scooter-share trips, to analyze how the usage characteristics change over time, and to understand the impact of weather conditions or other seasonal effects such as school period compared to holiday season.

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