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A cross-case comparison of the use of shared mobility services in Germany

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Abstract

E-scooter and e-bike shared mobility systems are now available in many cities worldwide as a low-threshold mobility offering for a broad mass. In Germany, e-scooter shared mobility systems have been established for the first time in 2019 in large cities, primarily in inner-city areas. In the meantime, various shared mobility service providers have expanded to small towns and the outskirts of large cities with different supply strategies. Therefore, this paper aims to investigate the different aspects, such as pricing models and parking regulations that affect the usage of such services in the outskirts. For this purpose, the provided data of an e-scooter and e-bike shared mobility service provider has been analyzed. The results show that shared mobility service provider can profit from extending their supply strategies to outskirts due to similar user behaviour compared to inner-city areas. Compared to other outskirts with a lower price, a higher price does not necessarily result in lower demand. Thus, the demand on the outskirts is not necessarily price-driven but rather depends on local factors. In addition, there was a strong tendency to use e-scooters compared to e-bikes. In all case studies, an almost identical relationship between residents and users could be determined.

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Keywords: e-scooter; e-bike; shared mobility systems, shared mobility service provider; pricing models

1. Introduction

The discourse in Germany regarding a modal shift from cars to other means of transport often focuses on the different conditions and needs between urban and rural regions. Due to greater distances and a low density of supply options, car ownership is fundamentally higher in rural than in urban areas. Factors influencing the purchase of cars are the

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existing transport infrastructure and the supply infrastructure of mobility services (Yu & Zhao, 2021). As a result, there is generally a higher dependency on car in suburban and rural areas. In urban areas, the dependency to own a private car has been tackled by an increasing number of shared mobility service providers in order to foster more sustainable mobility behavior (Nijland & van Meerkerk, 2017).

In 2017, e-scooter sharing first appeared as a new form of mobility in the USA (Traynor et al., 2022). Since then, a rapid global spread of these systems has been observed. Global sales are expected to reach 1.6 billion euros by 2022 (Statista, 2022). According to forecasts, sales are expected to increase to 2.8 billion by 2026 (Statista, 2022). The market has been very dynamic in the past years and has been characterized by market entries and exits of various shared mobility service providers that are competing with each other. As a result, cities are confronted with many different vehicles that cause conflicts with other road users in public space, especially when shared mobility service providers apply the free-floating system in the associated operating area. This development of the mobility market has taken place primarily in large cities, particularly in inner city areas. In Germany, however, sharing mobility service providers are now extending their services to small towns and suburban areas, where different transport systems are established compared to large cities and inner-city areas. Compared to large cities and inner cities, the public transport system has a limited range of services in terms of means of transport, routes and frequency. Thus, sharing systems can be considered as a supplement and feeder to public transport. Its implementation with electric micro-vehicles can be considered as an opportunity towards more sustainable mobility behaviour in the urban periphery with considerable substitution potential for short distances currently made by car (Gebhardt et al., 2021a). According to Gebhardt et al. (2021b) the distance of approx. 30 million car trips in Germany is less than 2 km, which corresponds to approx. 20 % of all car trips. If this is compared with the average distance of e-scooter trips, there is a high substitution potential for replacing car trips with e-scooters. As the average distance lies between 1.9 and 3.6 kilometers for 30 investigated European cities (Li et al., 2022). In addition, another 20 % of all car trips are less than 5 km (Gebhardt et al., 2021b). This results in an additional high potential to replace car trips while keeping the examined range of trip distance. However, this potential varies depending on the calculation method as well as on the country and city under consideration. Thus, it comes to the fact that in the USA a larger number is already substituted and one can speak of a practical and real potential, as for example in San Francisco, 42% of car trips could be replaced by e-scooters (PBOT, 2020). This contrasts with the basic theoretical substitution potential in Germany, which in turn can vary and be assessed differently depending on the purpose of the trip and the type of user (Gebhardt et al. 2021a). Substitution potential has also been investigated by (Laa & Leth, 2020) that investigated the distribution of e-scooter trips within age groups and conclude that the main users are male users between 25 and 36 years and that there is comparatively little substitution potential in these age groups. This shows how diverse the consideration and assessment of the actual potential is.

In addition to the opportunities, sharing mobility services also involve risks and problems that can impair the opportunities or, in the worst case, even cause them to disappear. Therefore, the risks must be reduced or, at best, eliminated. For example, there is a risk of improperly parked vehicles supplied by shared mobility service provider. This is based on an internal and an external component: the internal component consists of the fact that it is possible to park the vehicles on the sidewalk. The technical possibilities do not yet allow full control by the providers over the parking behaviour of their customers, because there are GPS inaccuracies, which means that it is not possible to end the rental precisely at predefined local points, as the GPS signal does not always correspond to the exact position (Zou et al., 2020). Due to the incorrectly parked vehicles, two risks result from these systems, which cover the external component. On the one hand, the sidewalks are blocked, restricting pedestrians and even endangering impaired road users such as elderly people (James et al., 2019). On the other hand, this leads to a negative public perception of various sharing mobility systems and the regulator is forced to control and to restrict parking opportunities (McDonald et al., 2003). This shows the discrepancy between maximum flexibility for users and a resulting regulation of sharing mobility systems that needs to be addressed by city administrations and transport planners.

A further expansion of the business area involves an additional risk of vandalism and its economic consequences for providers since the degree of vandalism is a crucial parameter determining the duration of the life cycle of e-scooters (Moreau et al., 2020). Persistent vandalism can lead to providers limiting their offerings and, in turn, to public perception being negatively influenced by these degraded conditions of the sharing systems. Another risk ia possible cannibalization of active mobility and public transport. On the one hand, active mobility can be seen as an important pillar for public health. Thus, it would be counterproductive to cannibalize public transport, since both systems should

be linked in order to take advantage of each. In this regard, political institutions and local authorities are also called upon to promote integration. However, there are opinions that support the position that there is no risk of cannibalization, while other surveys show that e-scooters largely replace routes that would otherwise have been covered on foot (König et al., 2022; Nikiforiadis et al., 2021).

Thus, this paper aims to explore the extent to what it is beneficial for shared mobility service providers to further extend their operational area to the outskirts. Therefore, this paper is structured as follows: First, the methodology is presented in chapter 2, which is followed by presentation of the results in chapter 3. The paper ends with a conclusion and an outlook regarding further research opportunities in chapter 4.

2. Methodology

This chapter describes the methodological approaches used to investigate the benefits that are resulting from shared mobility services at the outskirts. For this purpose, chapter 2.1 explains and justifies the methodological focus of a cross-case analysis of this paper. In addition, the case studies examined are presented. Chapter 2.2 describes the data basis for the analysis that follows in chapter 3.

2.1. Methodology

To answer the research question, a cross-case comparison of three case studies is conducted. A cross-case analysis is an adequate method for the research question to be investigated, as both similarities and differences between outskirts with different properties and structures can be compared (Khan & VanWynsberghe, 2008). In addition, a comparative analysis of several case studies increases the knowledge on several framework conditions to be considered for the use of micro mobility in the urban periphery. This means that there is a sensitization for important parameters that would not necessarily have emerged from individual case studies. The research question of this paper generalizes the special type of the outskirts. Since any form of the spatial type has to be considered individually in the context of a location analysis with regard to the examination of a sharing system to be introduced there, the cross-case analysis is intended to cover as many requirements of outer districts as possible for such a location analysis. Consequently, the results of this paper can be applied to a large number of suburbs.

Fig. 1 shows the regular business area of one single shared mobility service provider and the three case studies *Zehlendorf* in the southwest of Berlin, *Lichtenrade* in the south of Berlin, *Erkner* in the east of Berlin investigated. In order to be able to include comparative values for the results of using a shared mobility service on the outskirts of the city, a case study from the city centre of Berlin is also considered, which is also marked in Fig. 1. The values for the inner city of Berlin are based on a data set from Bolt and refer to the inner city of Berlin defined within the framework of the planning instrument "*Lebensweltlich orientierte Räume*" (LOR) (english: Living environment-oriented spaces).

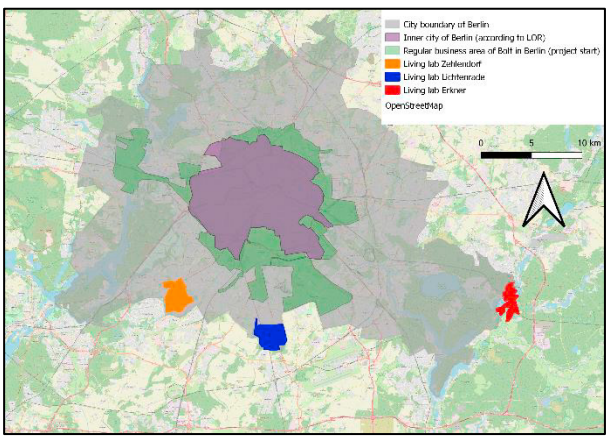

Fig. 1. Map of the living labs in and around Berlin.

The three case studies have been implemented as living labs in which different prices and station concepts are tested with the aim of deriving one or more best practice approaches for the implementation of shared mobility services on the outskirts of the city. The living labs are each scheduled to run for 9 months. Employing this research design, the methodology of cross-case analysis can be strengthened. By means of the comparative analysis, concepts that do not work or work very well in one case can be compared with another case in order to conclude how deficient or appropriate the respective concept actually is for its application on the urban periphery. Consequently, more reliable findings can be obtained. As a result, the following different pricing models were introduced in the three living labs (the assignment of the price model is technically solved in such a way that the price is assigned to a vehicle and does not automatically apply in a certain area if the vehicle is located there. It is the other way around, the vehicle determines the price in an area):

- *Standard pricing model*: At the beginning the same pricing model as for the shared mobility service in the city center of Berlin was introduced (0,19 EUR). The background to this pricing model is the question of whether the same price on the outskirts as in the city center of Berlin generates demand. During the project period, the prices were increased in line with price increases in the regular inner-city business area of Berlin, starting at 0.22 EUR and subsequently at 0.24 EUR. This price is valid in the living lab in *Lichtenrade*. However, since a not insignificant part of 14 percent of trips (Table 4) came from outside these living labs, from the regular business area or one of the other living labs, and ended in *Lichtenrade* or the other way round, the price model from *Lichtenrade* was also to be found in *Zehlendorf* and vice versa. Only in *Erkner*, due to its exposed location, was the price model largely adhered to.
- *Lower pricing model*: The reason for introducing a lower pricing model is contrary to the decision for the standard pricing model. This is to test how the more attractive pricing model conditions affect demand in the outskirts of the city of Berlin. The lower price of 0,14 EUR is tested in *Erkner*.
- *Progressive pricing model*: This pricing model is based on an analysis of the distribution of the duration of journeys in shared mobility services. (Li et al., 2022) have analyzed the distribution of 30 European cities. A right-skewed distribution was observed for all cities. The basic idea of the progressive pricing model is to test the extent to which a price that becomes more expensive after a specified point in time affects user behavior. The progressive pricing model is intended to "penalize" longer journeys in monetary terms, with the aim of proving whether it is possible to control users via the price in such a way that sharing offers are used primarily as a means of transport on the first and last mile as a feeder to public transport. After the 13th minute, the price per minute doubles from 0,14 to 0,28 EUR. In addition to the distribution of trips, the time limit of 12 minutes was chosen after having performed reachability analyses, so that any destination chosen by potential user and associated location can be reached within 12 minutes by e-scooter or e-bike. Another reason for a price "penalty" is due to the fact that, according to Klassen & Jödden (2022), 40% of e-scooter trips are completed for recreational purposes. According to Nikiforiadis et al. (2021), 41% of trips with the purpose of leisure will take 15 minutes or longer. These distributions result in a considerable potential of trips where sharing systems are used for purposes other than the desired function as a feeder to the public transport system. In addition, it is still questionable to what extent the use of micro-mobility on the outskirts of the city is a factor for leisure time activities. According to Bai et al. (2021), the use of e-scooters for leisure activities is linked to the spatial environment, with e-scooters being used more for leisure purposes in the city center than in other spatial environments. This pricing model is applied in *Zehlendorf*. As already mentioned in the section above, the progressive pricing model in Zehlendorf could not be adhered to throughout due to incoming and outgoing trips, which account for 21 per cent in Zehlendorf (Table 2), and the technical link between the price and the vehicle. However, this gives the possibility of a comparison of use at different prices within the living labs and not only between the living labs (Appendix D).
- *Incentives*: To investigate how the linking of shared mobility services with public transport can be influenced, a living lab is being set up to test whether parking vehicles at stations can incentivize users to visit stations more frequently. For this purpose, free minutes are affiliated at two stations near the train station in *Lichtenrade* for parking the e-scooters and e-bikes there.

In addition to different pricing models applied in different case studies/living labs in the outskirts of the City of Berlin, a different station concept is tested per living lab. The following station concepts are examined:

- *Stationless*: In *Zehlendorf*, the shared mobility service is offered in a free-floating system. The parking of the vehicles is not bound to any station. The objective of testing a free-floating-system includes the impact of station design on usage. This approach offers the possibility to examine, which start and end points users choose in a suburb when they can decide for themselves where their rental begins and ends in the free-floating system. In this way, an image of the preferred start and end points of the users can be analysed. In free-floating, users have the opportunity to start and end their rental where their exact starting point and destination take place. In particular, the endpoints can be interpreted as a relatively safe likeness of their preferred points. At the starting point, a vehicle should be directly available, which is not always the case. The difference to the informative value of the start and end points in the station-based system is that these stations are predetermined and the journey ends or begins at the nearest stations. Based on the distribution of the start and end points, points of interest can be filtered out and potential locations for stations can be localized using the data set provided by the operating shared mobility service provider in City of Berlin as well as the outskirts of Berlin. Furthermore, by using this system, it should be checked to what extent a specific station concept on the outskirts of the city can be more useful compared to a free-floating-system.
- *Stationbased (geofencing)*: The choice of a station-system limited by geofencing can be affiliated to two essential reasons. On the one hand, this is a comparatively low-threshold concept that does not require any additional table elements. Therefore, it should be examined whether such a system on the outskirts is sufficient for regulated parking of the supplied sharing vehicles. On the other hand, it should be investigated whether this system has an influence on user behavior, since it allows a smaller radius of movement compared to the free-floating system in the inner-city areas.
- *Stationbased (geonfencing with markings)*: In this concept virtual parking is combined with a real existing parking lots which are intended for the exclusive use of shared mobility services. The concept in *Erkner* consists of a combination of geofencing in the application of the provider and yellow-colored markings on sidewalks and on roadways (Fig. 2). Due to inaccuracies in the GPS signal of the vehicles, the size of geofencing areas in the app must be larger than the actual size of the parking lots. Otherwise, there is a risk that the vehicles cannot be parked because it is not displayed in the parking area in the app, even though it is actually located within the provided area (marked in yellow). This marking is comparatively low-threshold and requires no further steps apart from a traffic law order from the city and the application. Moreover, the costs are relatively low. In this regard, the aim is to test whether such marking is sufficient for compliant parking operations. For better visibility of the purpose of the marked area, yellow pictograms (e-scooters) were applied within the marking during the project (Fig. 2).

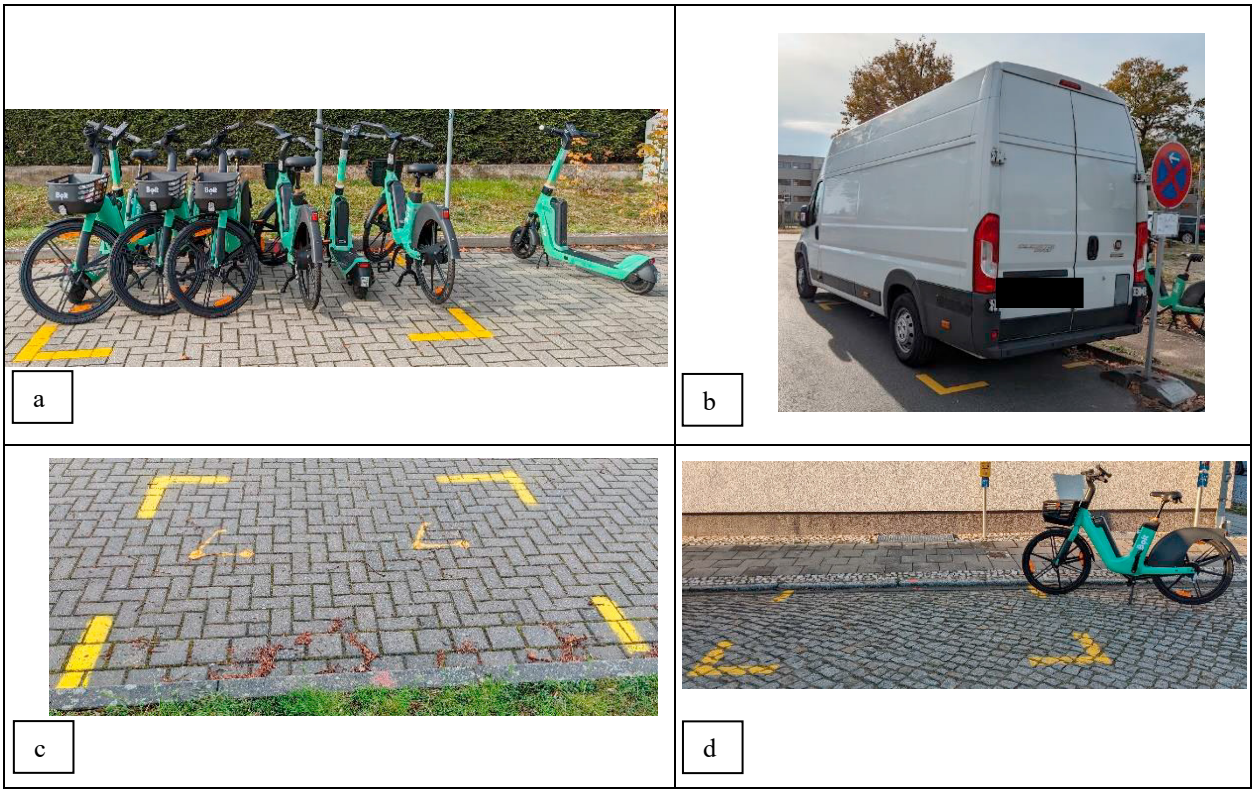

Fig. 2. (a) parking lot in Erkner; (b) parking violation in Erkner, (c) parking lot in Erkner with pictogram, (d) wrong parking.

All three living labs have in common that they are located in an insular location so that the concepts and parameters to be investigated can be considered as isolated as possible from the use in the city centre. Another similarity of all living labs is the distribution of the vehicles. In each living lab, e-scooters and e-bikes are available in a 50/50 ratio.

Table 1 shows the car densities of the case studies examined in this paper. These areas on the outskirts of the city have a much higher density than the inner-city districts of Berlin with about 25 on average car-ownerships per 100 citizens. Table 1 summarizes general information about the case studies. *Erkner* in particular shows great differences in this respect. Both car density and population density differ greatly from *Zehlendorf* and *Lichtenrade*. *Erkner* has by far the highest car density. At the same time, *Erkner* has by far the lowest population density. Although *Zehlendorf* and *Lichtenrade* are both outer districts of Berlin, there is a difference in car density that needs to be taken into account. This is higher in *Zehlendorf* than in *Lichtenrade*. *Lichtenrade* is the most densely populated living lab. With regard to the age structure, there are no significant differences between the living labs. The largest age groups are found in all living labs in the 50 and 55+ range (Table 2 and Table 3).

Table 1. Overview of case studies (AfS 2021; AfS 2022; AfS 2023, Landkreis Oder-Spree 2021; NEXONWARE, 2022).

Case study	Pricing model	Station concept	Population	Size of living lab [sq km]	Population density	Private car density (per 100 inhabitants)	Data collection period
Erkner	Lower pricing model	Stationless	11,935	3.9	719	51	19/09/2022-31/03/2023
Lichtenrade	Higher pricing model	Stationbased (geofencing)	52,469	6.1	5,195	30	18/07/2022-31/03/2023
Zehlendorf	Progressive pricing model	Stationbased (geonfencing with markings)	54,862	5.9	2,918	38	18/07/2022-31/03/2023
Berlin (inner city)	Regular pricing model	Stationless	1,397,505	113	12,367	25	18/05/2021-30/06/2022

Table 2. Age structure in Lichtenrade and Zehlendorf (AfS, 2022).

Case study	Under 6	6-15	15-18	18-27	27-45	45-55	55-65	Over 65
Lichtenrade	3,157	4,697	1,486	4,491	10,325	6,562	7,982	13,769
Zehlendorf	2,421	4,518	1,586	4,764	9,923	7,007	8,555	16,088

Table 3. Age structure in Erkner (Landkreis Oder-Spree, 2021).

Case study	Under 3	3-6	6-15	15-18	18-25	25-30	30-40	40-50	50-65	Over 65
Erkner	289	270	907	264	586	343	1,559	1,304	2,757	3,656

2.2. Analysis of data sets from a shared mobility service provider

The basis for the comparison of the three different study areas is the data set of conducted rentals from a shared mobility service provider. The data set can be used to derive information on distance, duration and the influence of pricing models on the use of shared mobility services provided. In addition, the temporal and spatial distribution of trips can be analyzed. The data collection took place in the regular operation of shared mobility service providers, which is the condition for the classification of the collected data in the context of the common business practices. Due to the already described circumstance of incoming and outgoing trips, which mainly occurred in *Lichtenrade* and *Zehlendorf*, only trips that started and ended within the living labs are taken into account for better comparability. However, the not insignificant proportion of trips leaving and entering the living labs show that there is a demand for micromobility services to travel longer distances to and from the inner city. The results of the data analysis are presented in chapter 2.

3. Results

This chapter focuses on the results obtained from the analysis of the data sets for each living lab and contains a comparative analysis of statistical parameters of the three living labs. Since all living labs differ regarding basic factors like population density or size the comparison should be conducted on the basis of relative utilization rates.

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Table 4 and Table 6 show that the absolute figures differ considerably in terms of the number of trips and users. In each case, *Lichtenrade* shows the highest values. Since the period of data collection in *Erkner* is shorter, a parameter

has to be introduced that adjusts for this shorter period. This reveals that the average daily use is also highest in *Lichtenrade* (Table 6).

The higher absolute number of trips can also be attributed to the higher number of users in *Lichtenrade*. Looking at the ratio of users to residents, it becomes clear that this ratio is almost identical in all living labs (Table 6). Thus, the number of potential users on the outskirts of the city is independent of the specific location and the existing pricing models and station concepts. Compared to the reference data set in the for the inner city of Berlin, this ratio is even higher in all living labs. In contrast, usage behaviour varies in terms of average usage per user. *Erkner* has the most trips per user, followed by *Lichtenrade* with 1.5 trips less, while *Zehlendorf* had two trips less per user than *Lichtenrade*. This value is between the values in *Zehlendorf* and *Lichtenrade* in Berlin's inner city. *Lichtenrade* has the highest rate in terms of density of use. Per square kilometer, the most trips per day are completed in *Lichtenrade*. This factor is lowest in *Erkner*. The value for *Zehlendorf* lies between the two other living labs (Table 6). A comparison with the inner city of Berlin shows that these values are higher for all living labs than in the inner city.

In general, there is a strong tendency among users to ride e-scooters. The ratio of the shares of vehicles in the trips made is almost the same in *Zehlendorf* and *Lichtenrade* each with over 80 percent. Only in *Erkner* there is a higher proportion of e-bikes in use. With a share of over a quarter, the importance of e-bikes in *Erkner* should not be underestimated. The preference for using e-scooters over bicycles has already been demonstrated in another case study in Washington, D.C. (McKenzie, 2019). It is interesting to note that bicycles without electric assistance were available in the study. In this case study, the possibility to use e-bikes does not reverse this preference.

There are also differences between the living labs in terms of the distance traveled and the duration of the trip (Table 7 and Table 8). In *Erkner*, both the average distance and duration are the highest. In *Zehlendorf*, the trips take the shortest time on average, but they cover a longer distance than in *Lichtenrade*. This may be related to progressive pricing model, whereby customers try to overcome the distance to be covered more quickly in view of the threat of rising price starting from the 13th minute. In general, the distributions of trip duration and trip distance are almost identical on average in all case studies, which is visualised in the boxplots in Appendix A. While the average distance travelled in the inner city of Berlin is slightly higher than in the three living labs, the average time needed for this is significantly higher than in the case studies on the outskirts of the city. One possible reason is the low average speed in the city center, which means that the services on the outskirts can be used more quickly and thus more cost-effectively. The assumption of a higher average speed can be confirmed by other studies of journeys in Berlin (Heumann et al., 2021).

About every fifth trip starts or ends at the station in *Erkner* and *Lichtenrade*. It is striking that the proportion of terminated rents is almost the same in *Lichtenrade*, where parking is incentivized, than in *Erkner*. Against the background of similar proportions in all living labs, this suggests that a certain fixed proportion of users go to the station anyway and that the incentive has no effect on increased use of the stations. The values in *Zehlendorf* are lower. However, this should not be over-interpreted as it is an estimate. Due to the operation in the free-float system, a large number of trips have accumulated in the vicinity of the stations in *Zehlendorf*. Here, it was not possible to assign the location of the trips to the station as clearly as in the station-based system (see Appendix B).

Table 4. Proportion of started and ended in the living labs.

Case study	Number of total trips	Number of trips started and ended within the study area	Proportion of trips that started outside or ended outside the study area
Erkner	12,579	12,064	0.04
Lichtenrade	34,829	30,113	0.14
Zehlendorf	28,344	22,262	0.21

Table 5. Proportions of trips per vehicle and of started and ended trips at train stations.

Case study	Proportion e-scooter	Proportion e-bike	Proportion of started trips train station	Proportion of ended trips train station
Erkner	0.72	0.28	0.20	0.19
Lichtenrade	0.86	0.14	0.20	0.20
Zehlendorf	0.83	0.17	0.12	0.11

Table 6. Relative rates of usage.

Case study	Number of trips	Number of users	Average trips per day	Percentage of users to residents	Daily trips per sq km (size of living lab)	Trips per user
Erkner	12,064	1,075	62.5	0.09	16.6	11.2
Lichtenrade	30,113	3,589	136.1	0.07	22.3	9.7
Zehlendorf	22,262	3,659	110.7	0.07	18.8	7.7
Berlin (inner city)	732,570	85,537	1,795	0.06	15,9	8.6

Table 7. Descriptive Statistics of trip distance in km.

Case study	Min	1st quantil	Median	Mean	3rd quantil	Max	Sd
Erkner	0	0.9	1.4	1,5	1.9	13.6	1
Lichtenrade	0	0.7	1	1.3	1.6	17.9	1.1
Zehlendorf	0	0.7	1.1	1.4	1.9	16.4	1.1
Berlin	0	0.7	1.2	1.7	2.2	31.2	1.6

Table 8. Descriptive Statistics of trip duration in minutes.

Case study	Min	1st quantil	Median	Mean	3rd quantil	Max	Sd
Erkner	0	4	6	6.9	8	60	6,4
Lichtenrade	0	3	4	6.3	7	120	6.7
Zehlendorf	0	3	5	6.4	8	120	6.3
Berlin	0	4	6	9	11	121	9.4

3.1. Comparison of specific statistics

Table 9 summarizes the results of correlation analyses regarding the influence of pricing and station concept on various dependent variables. For the correlation analysis, the data sets of the three living labs were merged to capture the different prices and station models. Rank coefficients were introduced for the station models. It was assumed that the free-floating system in *Zehlendorf* was the least constraining for users and the station system with local markers in *Erkner* was the most constraining.

It is striking that although pricing has a significant influence, it the negative correlation is very small. In Appendix C, it can be seen that the average trip duration decreases with increasing price, but a strong statistical correlation could not be proven. It should also be taken into account that the different prices have different numbers. In addition, there are latent variables that could also affect the duration and distance of trips, such as the weather or the time of year.

For the stations, a significant influence on the duration and distance of the journeys could also be demonstrated, which, however, is still somewhat lower than the price.

Taking both variables into account, similar findings can be observed. There is a significant correlation, with a low positive correlation.

Only for the influence of the stations on the choice of the shared mobility service in the form of journeys per hour could a medium correlation be demonstrated. However, this should be classified with caution, as there are many other latent factors that influence the number of trips. For example, *Erkner*, where the station model with the fewest journeys is located, also has the fewest residents.

Table 9. Correlations between Pricing model/ Station concept and trip duration, trip distance and average trips per hour.

	Pricing model		Station concept		Pricing model + Station concept	
Dependent variable	Cor.Coeff. (Pearson)	p-value	Cor. Coeff. (Spearmann)	p-value	Cor. Coeff. (R-squared)	p-value
Trip duration	-0.07108759	<2.2e-16	-0.0390683	2.2e-16	0.005071	<2e-16
Trip distance	-0.07536561	<2.2e-16	-0.0446175	2.2e-16	0.005906	<2e-16
Average trips per day	-	-	0.3314883	0.004449	-	-

It is noteable that in all living labs the most frequent uses per weekday take place at on Fridays (Fig. 3). In *Erkner*, a more pronounced gradient can be observed. After a low point of the number of trips per weekday on Sunday, the higher use at the weekend builds up successively. In *Zehlendorf* and *Lichtenrade*, the trend is relatively constant during the week. In *Erkner* and *Zehlendorf* there is a stronger drop from Saturday to Sunday. This increasing distribution per weekday towards the peak at the weekend corresponds to a distribution proven by (Bai & Jiao, 2020) for a city centre. It should be noted that city centres can also have relatively constant patterns over the course of the week, which is also the case for the city centre in Berlin (Fig. 3). These patterns can also be seen in all three living labs, especially in *Lichtenrade* and *Zehlendorf*. The distribution of trips over the week in the living labs is an indication that a similar usage pattern as in city centres could be present here. Consequently, the expansion of providers to the outer districts could be classified as worthwhile. The boxplots in Appendix A show the distance and duration per day of the week for each living lab. It is striking that, despite the decrease in the number of trips compared to Saturday and Friday, the distance and duration of trips on Sunday remains similarly high or even increases. One possible reason for this finding is the use of shared mobility services for leisure and excursion purposes. The demand in this regard could be a decision criterion for shared mobility service providers to expand their services to the outskirts of cities. Furthermore, in these distributions over the week, very similar and comparable usage patterns are recognizable on the outskirts of the city in comparison to the inner city of Berlin.

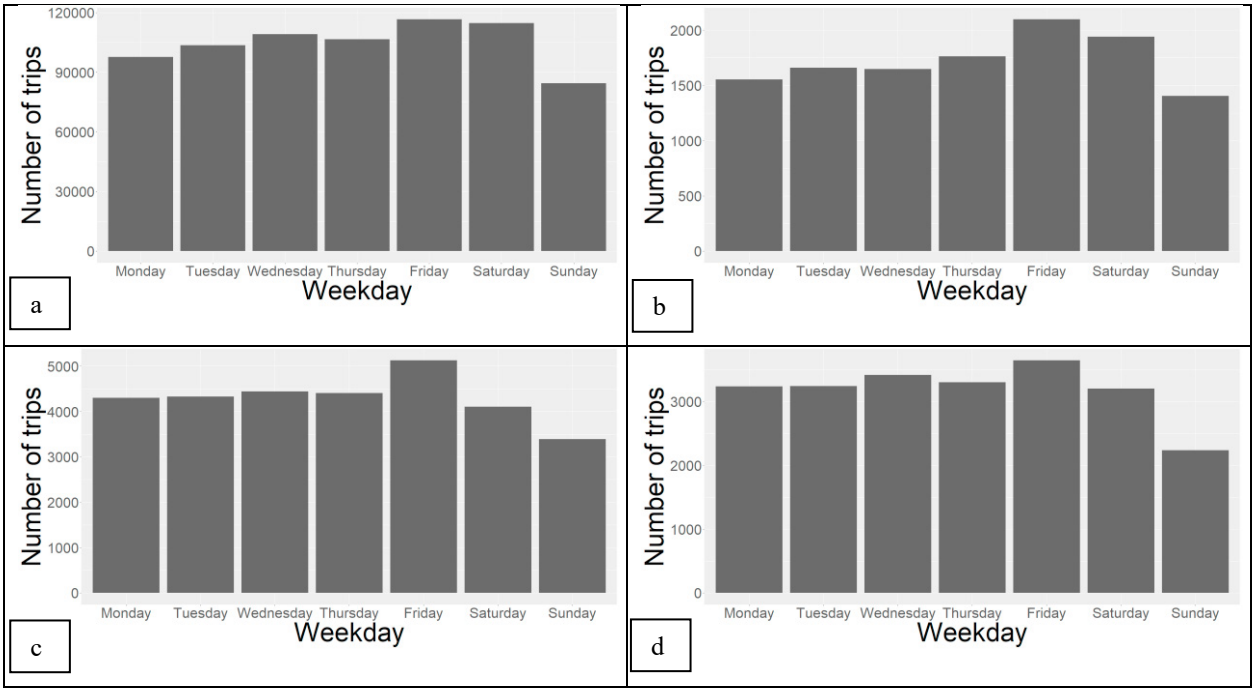

Fig. 3. Usage per weekday in: (a) Berlin (inner city); (b) Erkner; (c) Lichtenrade; (d) Zehlendorf.

Figure 4 displays the usage in the run of the day. It is evident that all living labs show a similar distribution of demand throughout the day, with demand increasing from the early morning hours until the peak in the afternoon, which is either between 2 pm and 3 pm or between 3 pm and 4 pm. After that, demand drops again, only to rise again from midnight or 3 a.m. onwards. This daily pattern is usual for the use of micromobility services. Compared to other evaluations, this daily pattern also reflects the usage behaviour in inner-city areas (Li et al., 2022). The pattern of use over the run of the day in Berlin is similar to that of the three living labs. What is particularly striking is that in *Zehlendorf*, the same pattern as in the inner city of Berlin can be seen, in which an increase in the number of journeys per hour can be recorded from 3 am. Contrary to the daily pattern of other modes of transportation, which usually includes peaks at rush hour in the morning and the afternoon/ evening. Nevertheless, a low peak can be seen in all living labs in the early morning. This suggests that the public transport lines are not yet running or are still running at irregular intervals. Consequently, the shared mobility service could be used as an alternative means of transport at this time of day.

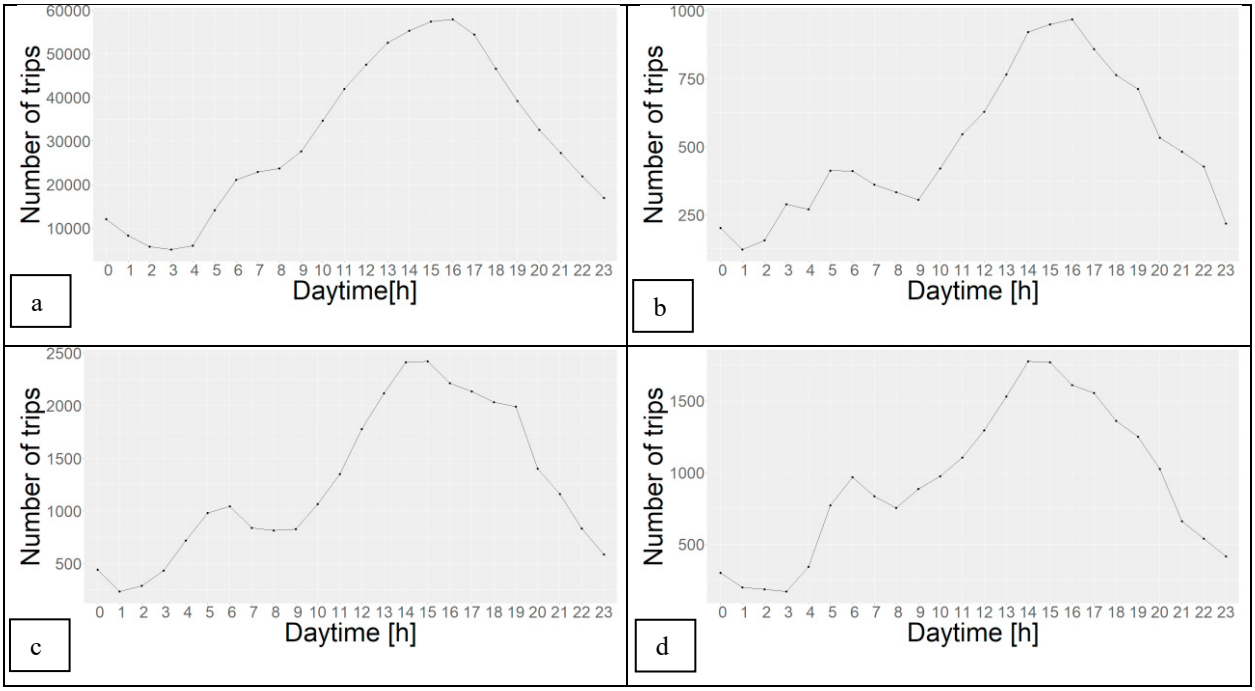

Fig. 4. (a) Usage per daytime in: Berlin (inner city); (b) Erkner; (c) Lichtenrade; (d) Zehlendorf.

4. Conclusive discussion and future research

The main objective of this paper was to investigate the extent to what a further expansion of their operational business into outlying areas is beneficial for shared mobility service providers. For this purpose, a cross-case analysis was carried out comparing three different living labs in the outskirts of the City of Berlin. For each living lab, different service designs were considered in terms of pricing models and station concept. Based on the analysis of the data set for the respective living labs, it was possible to compare different parameters, such as distance and duration per trip and the distribution of trips per daytime and weekday.

In summary, the results show that shared mobility service providers can profit from an expansion of their operational area to the outskirts of the City of Berlin. In the living lab (*Lichtenrade*) with the highest price and a station-based system without markings (only geofencing), the highest absolute use was achieved. The statistical analysis of the influence of the price per minute on the usage pattern could not prove a strong correlation. It is therefore questionable at this point to what extent the higher price in *Lichtenrade* in the present price range is a decisive obstacle to more intensive use in *Lichtenrade*. In addition, a medium statistical correlation between the available station concept and the use of the shared mobility service was found. According to this, the number of trips increases when the station concept is less restrictive for the user. In *Lichtenrade*, the highest number of trips has been measured in absolute terms despite the restriction by a virtual station concept. Thus, this station concept can be implemented as a low-threshold compromise solution for low-conflict parking in the area of the pavements. It can be concluded that a similar willingness to pay exists in the outskirts of the City of Berlin and that corresponding revenues can be generated. The aspect that the station-based system in *Lichtenrade* does not result in lower user numbers can be interpreted as a sign for shared mobility service providers that regulated parking is not seen by users as a restriction for the attractiveness of the mobility offer. Nevertheless, it has been shown that a station system based only on geofencing is not regulative for adequate parking, as the exact position of the vehicle within the virtual stations is at the user's discretion. Figure 5 shows an example of the constellations that can arise without marking the parking area.

Fig. 5. Example of insufficient parking in *Lichtenrade*.

The ratio of users to residents was similar in all living labs. Therefore, shared mobility service providers can use these insights as a basis for estimating the number of users they can expect after implementing a service on the outskirts of the city. This can provide a strategic advantage in terms of expected revenues and required human and financial resources. Differences have emerged in usage behaviour with regard to the distance and duration of the trips made. Although these differences are rather small, they should be taken into account and observed by providers. Only a very small negative correlation was found for the duration and distance of the trips as a function of the underlying price. A slight disadvantage can only be seen from a price of 0.22 EUR (Appendix C and D). However, it should be noted here that the higher prices were introduced as the project progressed and that these price increases occurred during the winter time. It can therefore still be ruled out that the influencing factor weather had an impact on the duration and distance of the trips. The extent to which this factor matters should be considered in more complex models. It has already been shown that the duration and distance of e-scooter journeys reduces slightly during winter (Mathew et al., 2019). In addition, the informative value of the influence of the price on the use in this paper must be critically questioned, since the underlying price range is very small.

Analyses of usage per weekday and at various times of the day showed similar trends to those of established shared mobility services in inner-city areas. The extent to which the peaks in use on Fridays are related to leisure activities should be the subject of future research. The design of the shared mobility service depends largely on the purpose for which the vehicles are used. This aspect is particularly important with regard to use as a supplement or feeder to public transport. In particular, shared mobility service providers should take into account the trend towards the most frequent trips on Fridays and partly on Saturdays, longer durations and distances per rental on Sundays, and the low peak in the morning hours, and draw appropriate conclusions for their services on the outskirts of the city. With regard to this, it would be advisable to identify specific use cases and to bind or address existing or potential users with appropriate offers. It should be pointed out that this analysis lacks specific data on users, which is essential for identifying and evaluating use cases. It is therefore necessary to include the perception and travel purposes of the users in future surveys. The profitability of a shared mobility service on the outskirts of the city is also linked to the targeted analysis of the demand and the associated services there and to the development of a corresponding offer.

At the current time, there are no findings for the reason why most users prefer the use of e-scooters. This tendency on the outskirts of the city has already been identified in the mentioned case study (Chapter 3). Relevant factors here could be, among others, the perception of safety, personal effort when driving, aesthetics and speed. Knowing which user groups prefer which types of vehicles and for what reasons is a critical factor in determining the ratio of vehicles in the most efficient and profitable way.

In addition to the users of shared mobility services, the newly introduced shared mobility services are also new for the involved stakeholders in city administrations of the investigated living labs. There are no regulative mechanisms applied in dealing with and designing such sharing mobility services. Therefore, beside the opportunities that such

sharing mobility services offer, there are also risks and problems that need to be solved by the city administrations. This results in a field of tension in which the needs of the users are confronted with public discourse, and transport politicians and planners are faced with the challenge of maintaining a balance between restrictions and concessions that includes and protects other road users and at the same time can guarantee a qualitative service for users. Furthermore, shared mobility service providers must weigh up their decisions, competing alongside other providers with other transportation modes and services as well. Against this background, shared mobility service providers are faced with the task of fulfilling the expectations and requirements of society and politicians, while not limiting or deteriorating the service from the point of view of their users by making these concessions. In this area of conflict between different stakeholders and different interests, it is necessary to develop and establish a suitable pricing model. Since there is no socio-demographic data regarding the specific user characteristics, such as gender, age and income of the investigated sharing system for which the data set has been provided by the shared mobility service provider operating in the inner city and outskirts of Berlin. This can be compensated for example by app-based surveys of users. However, it is expected that certain user groups may not be willing to take part in the survey. Certain incentives in form of free minutes for riding could be offered to motivate for participation in the survey.

The initial findings and tendencies will be specified by further in-depth investigations. This includes separate analyses per vehicle type in order to be able to attribute the existing large differences in the preference for the use of the respective to the associated reasons. In addition to user surveys, the use per vehicle needs be clustered into times of day and days of the week in order to be able to derive possible trip purposes in advance of the surveys.

Even if the underlying trip purpose of the trips to and from the train station has not yet been clearly classified, the distribution of trips shows a possible benefit of getting to the train station on the outskirts of the city more flexibly compared to the bus in terms of the time required and compared to the car in terms of the space required to park. This results in the possibility for the city administration or district administration to create a comparatively space-saving offer for the multimodal connection of the outskirts with the city center compared to Park&Ride by car. On the other hand, however, this results in the need to implement the appropriate infrastructure for parking the sharing vehicles at the train stations. Here, both an attractive offer for users and the safety of other road users must be taken into account. The current concept of charging for micromobility services and public transport is a potential obstacle to their use in connection with a transfer to the train. Both services have independent pricing systems in the living labs that must be paid per trip. From a cost perspective, this would therefore argue in favor of using the bus, as this is integrated into the price of using the train, at least in a subscription model. For the best possible multimodal connection of the city periphery with the city center, a deep integration of the tariff systems of public transport and micromobility services should be discussed.

In all three living labs it is apparent that commuter train stations are both the strongest sources and the strongest destinations of trips (Table 5**,** Appendix B). The differences in the heat maps between the living labs can also be attributed to the underlying station systems. Since a free-floating system is operated in *Zehlendorf*, no individual points can be identified there; the trips are distributed over the entire business area. This suggests that on the outskirts of the city, without a regulation of the parking location of vehicles by predetermined stations, there is at least a small demand for a large proportion of all residential streets. Another common finding in all three living labs is the intensity of use in the residential areas. The dark blue coloured stations or in *Zehlendorf* the dark blue areas show low use at these locations per se. However, if all these areas are taken together, it can be deduced that a large proportion of all trips (approx. 50 %) start or end in the residential areas and are distributed to other points of interest. The main destination in all three living labs is the local train station, which connects the living labs with the city centre of Berlin. In addition, it can be seen that in all three living labs the distribution of trips at the start and end is almost identical. This distribution can probably be attributed to the distribution of the vehicles, but may also be an indication of similar demand at the start and end of the trips. This also indicates that most of the trips flow towards the station or from there to the wider areas of the living labs.

This paper is intended to serve as a basis for further research into the attractiveness of such an offer on the outskirts of the city. Various factors were listed and critically classified, which are not completely covered in the presented results. In addition, it must be critically questioned to what extent the results of the case studies are transferable or generalizable. One aspect that limits the generalisability of the results is the price strategy of the provider implemented during the data collection. For the most part, the pricing strategy was experimental and not necessarily recognisable as consistent for the users. This results in a limitation for the transferability to the regular operation on the outskirts of

the city. In all the living laboratories, slight differences were found with regard to the parameters examined, but many tendencies on key figures are very similar. Since all the living labs have a different geographical structure, but the use is nevertheless similar and there are also comparable use patterns to the inner city of Berlin, it can be stated at this point that the results achieved here can at least be transferred to other areas on the outskirts of Berlin. However, a critical and comparative classification of other potential business areas on the outskirts is essential. In all three living labs studied, it is obvious that the shared mobility service is mostly used to reach the local centre or train station. To what extent the offer is attractive depends on the particular interests of all actors involved. Therefore, the implementation of such an offer takes place in a field of tension between the municipality, the shared mobility service provider and the user. The future success or such a service on the outskirts of the city also depends on a common tariff system that combines the travel of public transport and micromobility, which can facilitate the handling and possibly create price advantages for the customers. For other pilot projects in Berlin and Hamburg, it has already been established that there are indications that e-scooter shared mobility services can be used as a supplement to public transport (Gebhardt et al., 2021a).

Acknowledgements

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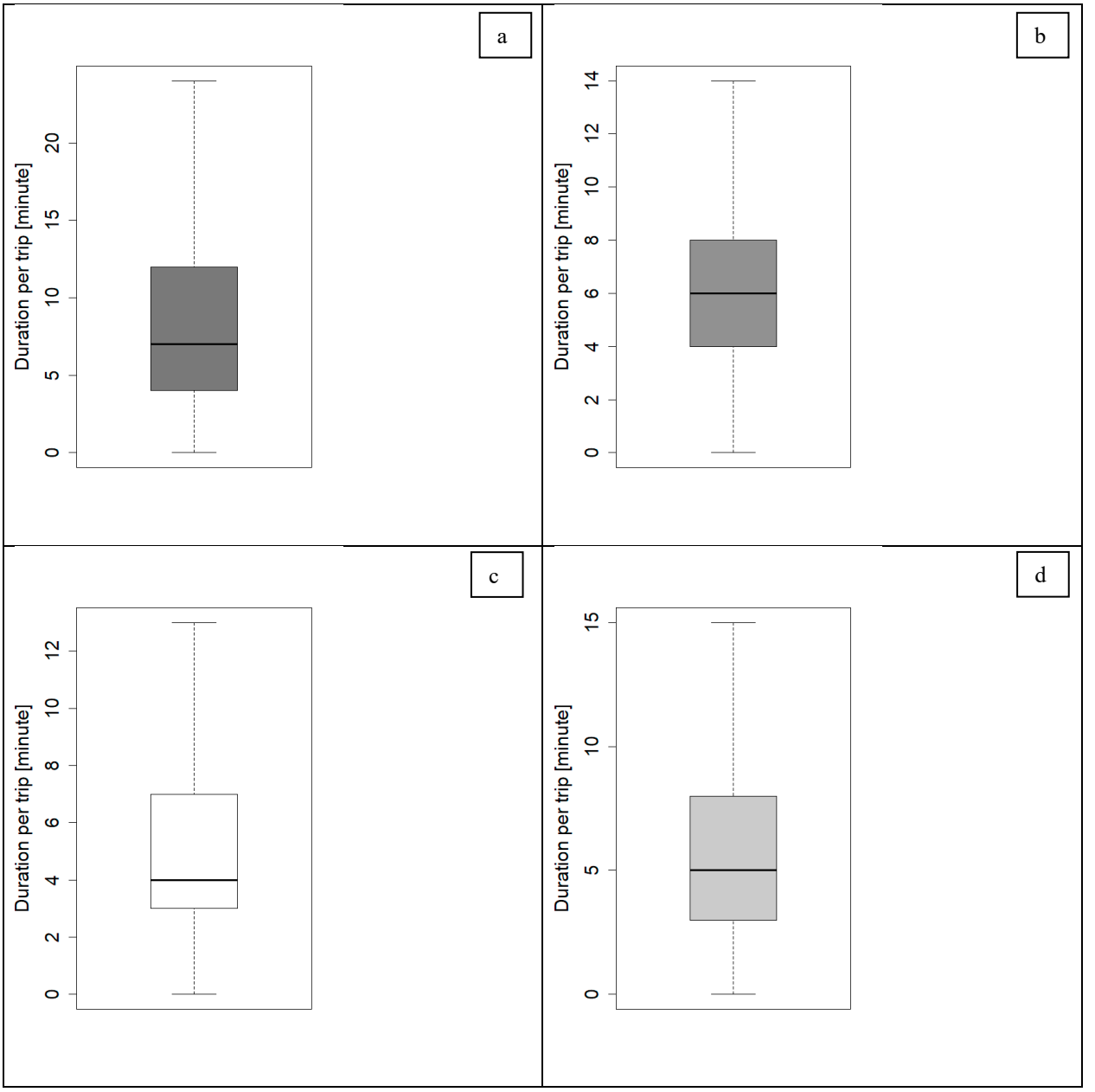
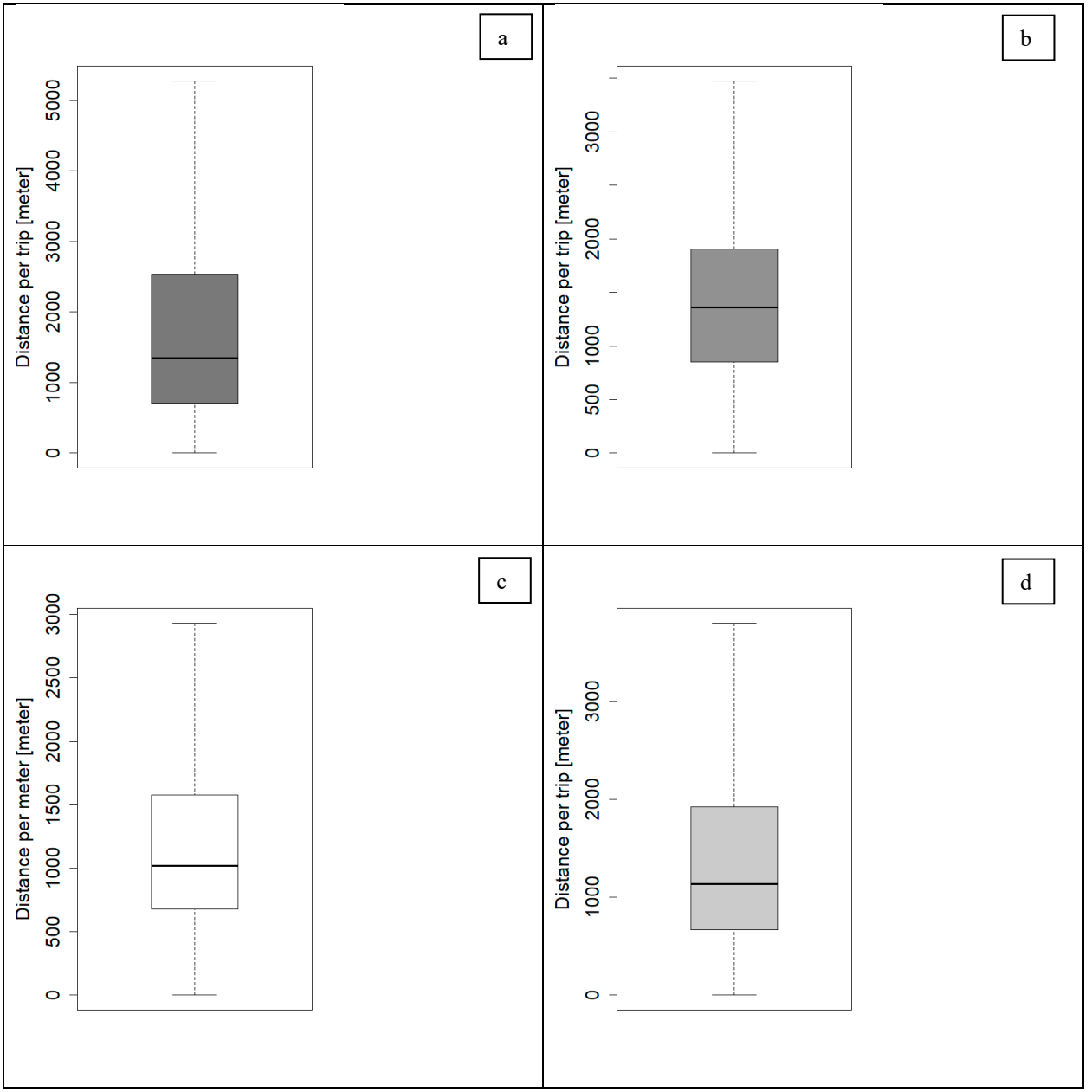
Appendix A. Boxplots

Appendix A contains boxplots for selected parameters for the three living labs analysed. For each selected parameter, the boxplots are embedded in a respective subchapter.

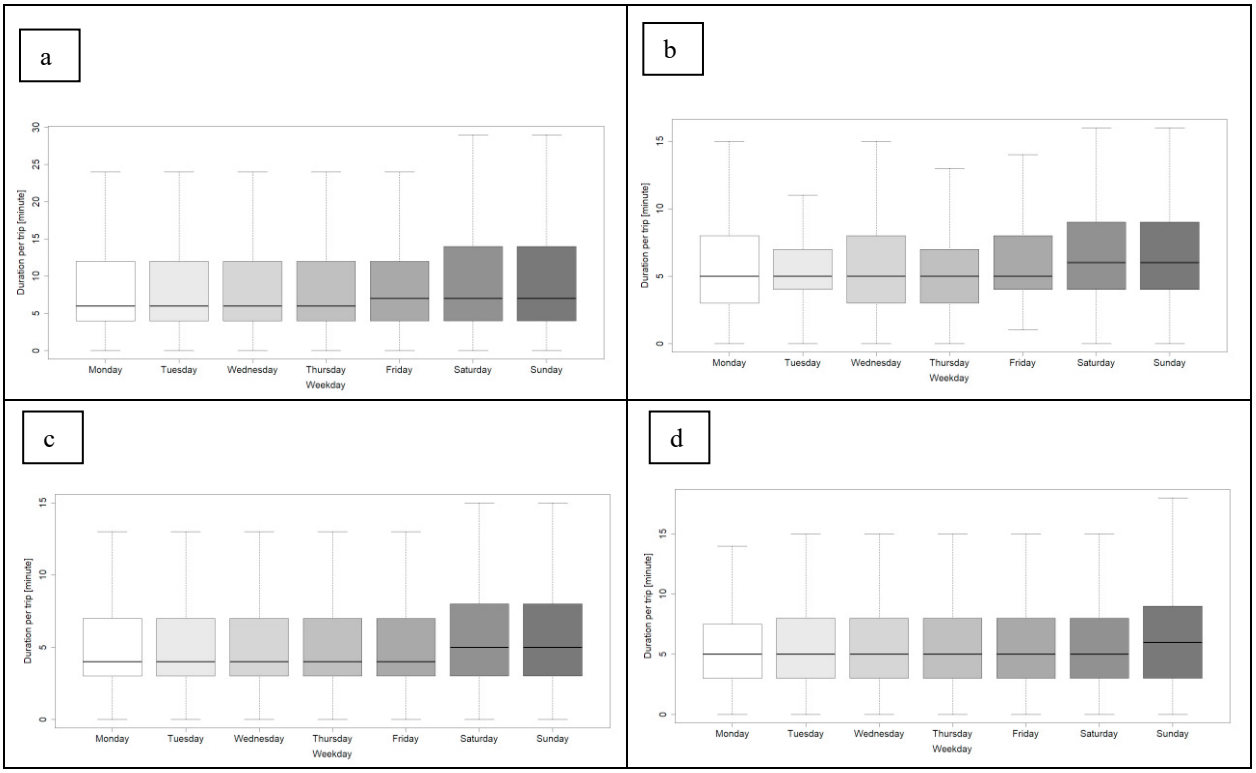
A.1. Boxplots of the distribution of duration per trip for Berlin (inner city, a), Erkner (b), Lichtenrade (c), Zehlendorf (d)



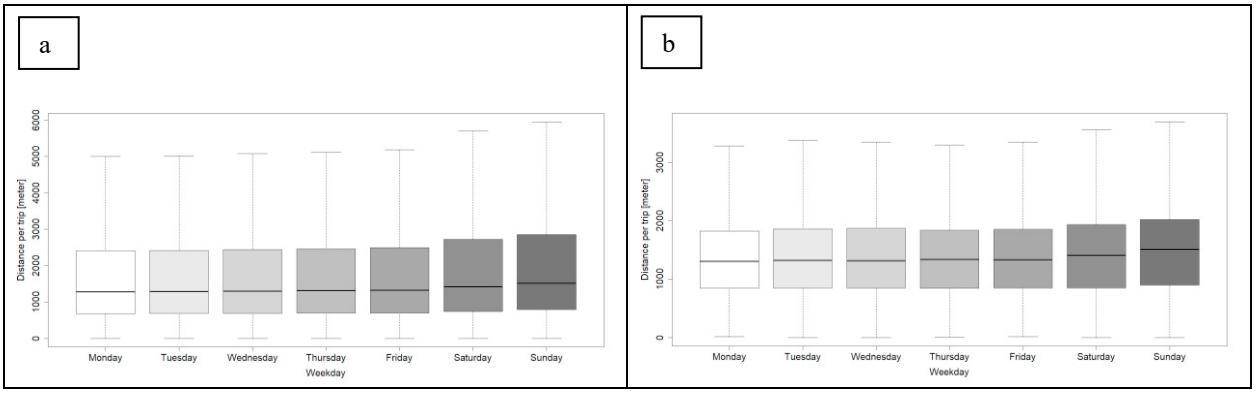
A.2. Boxplots of the distribution of distance per trip for Berlin (inner city, a), Erkner (b), Lichtenrade (c), Zehlendorf (d)

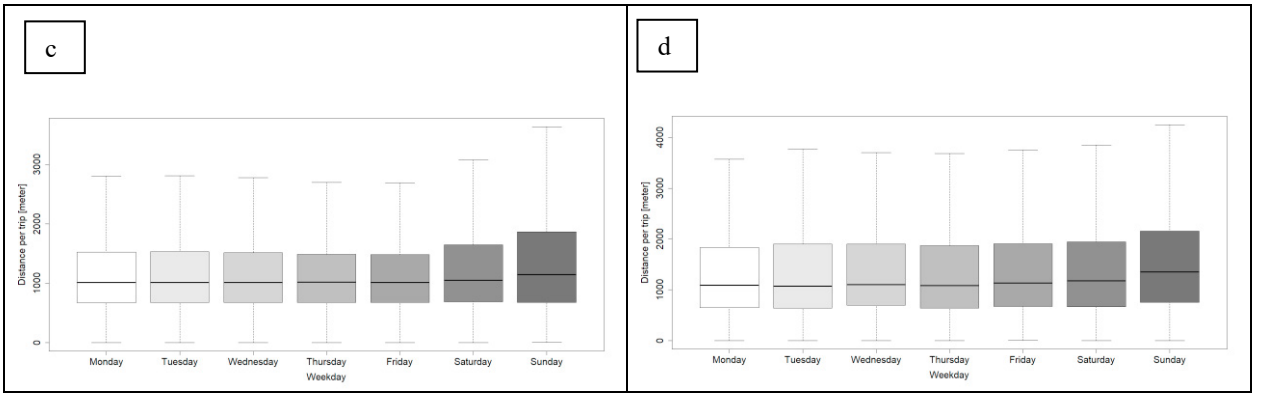


A.3. Boxplots of the distribution of trip duration per weekday: (a) Berlin (inner city), (b) Erkner, (c) Lichtenrade, (d) Zehlendorf



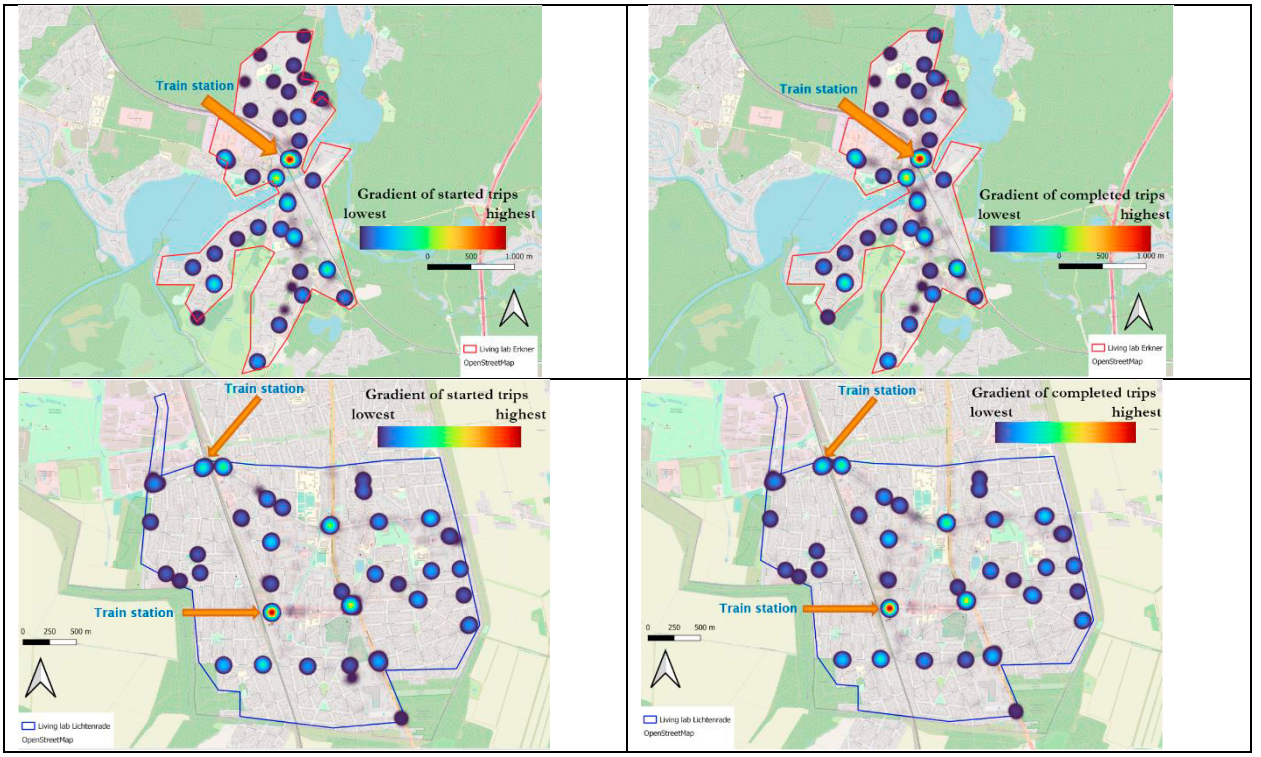
A.4. Boxplots of the distribution of trip distance per weekday: (a) Berlin (inner city), (b) Erkner, (c) Lichtenrade, (d) Zehlendorf

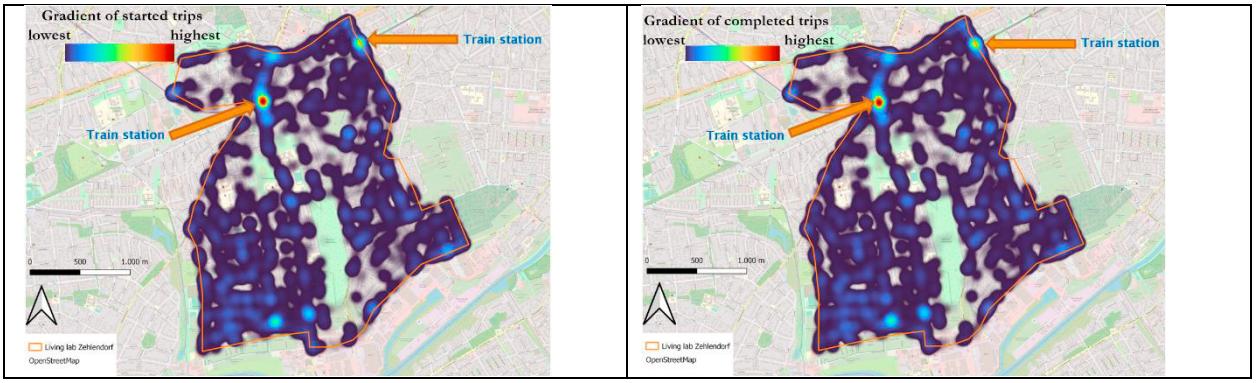




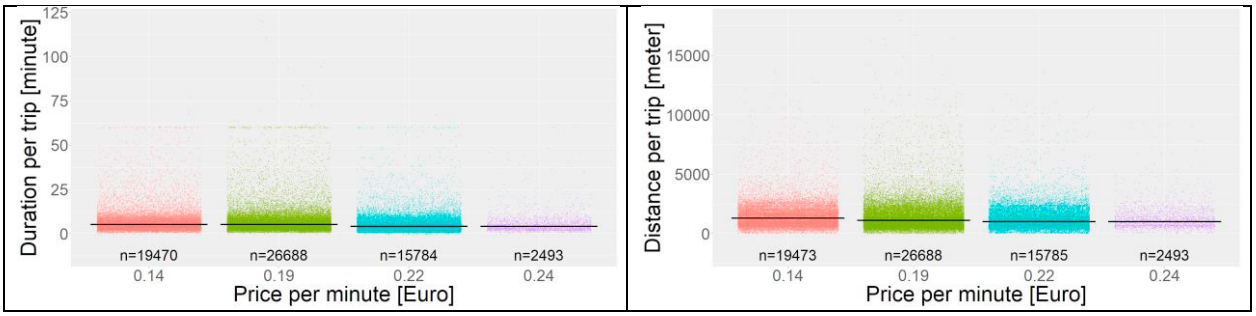
Appendix B. Heatmaps

Appendix B contains heatmaps for the density of the use of stations on departing and terminating trips for the three living labs. Left side: locations where trips begin; right side: locations where trips terminate.





Appendix C. Distribution of trip duration (left) and trip distance (right) depending on the price per minute for all three living labs (with median)



Appendix D. Descriptive Statistics of trip duration in minutes depending on price per minute

Table 10. Descriptive Statistics of trip duration in minutes at a price of 0,14 EUR

Case study	Min	1st quantil	Median	Mean	3rd quantil	Max	Sd
Erkner	0	4	6	6.9	8	60	6.4
Lichtenrade (progressive pricing)	1	3	5	7.8	9	77	8.3
Zehlendorf (progressive pricing)	0	3	5	6	8	60	5.4

Table 11. Descriptive Statistics of trip duration in minutes at a price of 0,19 EUR

Case study	Min	1st quantil	Median	Mean	3rd quantil	Max	Sd
Erkner	1	4	7	9.3	9	60	10.3
Lichtenrade	0	3	5	6.8	8	120	7.1
Zehlendorf	0	3	5	7	8	120	7.3

Table 12. Descriptive Statistics of trip duration in minutes at a price of 0,22 EUR

Case study	Min	1st quantil	Median	Mean	3rd quantil	Max	Sd
Erkner	0	3	5	6.3	7	41	6.4

Lichtenrade	0	3	4	5.3	6	60	5.6
Zehlendorf	0	3	4	5.6	7	67	5.3

Table 13. Descriptive Statistics of trip duration in minutes at a price of 0,24 EUR

Case study	Min	1st quantil	Median	Mean	3rd quantil	Max	Sd
Erkner	-	-	-	-	-	-	-
Lichtenrade	0	2	4	5.2	6	60	5.5
Zehlendorf	0	3	5	5.7	7	46	5

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