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Potential analysis of e-scooters for commuting paths

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Summary

The mobility needs of society are constantly increasing, leading into congested urban areas. New mobility concepts such as e-scooters can have a traffic-reducing effect. Especially commuting paths, which generally stay within a consistent distance, are rather short and manageable through an intermodal travel chain in combination with public transport, are showing a big potential for the use of e-scooters. For intermodality, the focus is above all on mastering the first- and last-mile. E-scooters definitely offer individual benefits to some people, in case of the travel time. An ecological perspective also proposes a reduction of CO_2-equivalents for some users.

Keywords: micro-mobility, light vehicles, sustainability, mobility system, scooter

1 Introduction

Today's population shows an increasing need for mobility [1]. This results in major traffic problems, especially in cities and conurbations. The infrastructure can no longer cope with this increased traffic volume, which ultimately leads to congestion, noise and overloaded public transport. Additionally, the pollution thresholds are not adhered due to the increased individual motorized traffic. In many German cities, driving bans have therefore already been issued [2]. In addition to the optimization of conventional means of transport, new transportation and mobility concepts should also contribute to solving the problem. However, not each new mobility solutions has only advantages. A lot of them have also big disadvantages, for example at the operation model. One of the best-known examples worldwide is "O-Bike" with their bike-sharing offer, not only in Germany, but also in Australia and China [3]. Due to lacking organizational measures on the part of the suppliers, the bikes were indiscriminately parked in the city and blocked the public footpaths. The population's reaction was vandalism. Thus, the hoped-for traffic innovation has apparently not found acceptance among the population and the company has disappeared from the market today. A rather new means of transport (at least for the German market) are the so-called Personal Light Electric Vehicles (PLEV). The most common form nowadays are e-scooters. Today, not only this form of mobility but also its use is highly discussed in public and the press. However, the media attention mostly focuses on individual incidents (e.g. accidents) or suspicions. There are hardly any studies dealing with the use and impact on traffic. Because of this reason, this paper will present the potentials of e-scooters on commuting paths.

Particular relevance lies in intermodal transport chains. Because of their small size and portability, e-scooters hold great potential for the interconnection of several means of transport. For instance, taking them with you in public transport or in cars is easily feasible. This property qualifies e-scooters as an ideal means of transport for overcoming the first- and last-mile issue. It is of less relevance if the vehicles are shared or owned by the users themselves. Anyway, it is interesting if people want to share this type of mobility or if they want to own the vehicles. Especially people who commute a lot seem to have an extremely high potential because they usually have to travel predefined routes. The studied cases are commuting paths in which e-scooters are either compared to conventional means of transport or combined with them. This way, the ecological and economical potentials of e-scooters with regard to commuting distances were determined. On this basis, the potential and suitability of e-scooters in the daily lives of employed persons will be analysed. This study focuses on the German market.

2 Methodical Approach

To answer the research question, a methodical approach was developed (Figure 1). The main target is to compare commuting paths against each other by using different means of transport (alternative drive systems, public transport, bike and so on) and especially e-scooter, the "newest" form of mobility. This results in the definition of ecological and economic potentials of these e-scooters at commuting paths. Therefore, a basic research and a user-survey including a scenario development is needed. The first step is the basic research in the fields of typical commuting paths (1), properties of means of transport (2) and the relevance of first- and last-mile (3). For the analysis of typical commuting paths, it is important to know e.g. which means of transport are used by the people, how far the average distance is or how much time the people need for their daily trip to the workplace. The database is the German study "Mobility in Germany" from 2007. This study contains data from over 300.000 interviewed persons. [4] This data helps to get a good overview about the people's behaviour at their commuting paths and especially the usage of means of transport. The second step is the investigation of important properties of means of transport by commuting. In terms of mobility behaviour, the properties of means of transport are also examined, in particular motorized private transport, public transport and bicycles. The target is to define comparable properties of the means of transport. The third part of the basic research is the analysis of the relevance of the first- and last-mile. The first- and last-mile seems to get more and more important for the integration of new mobility solutions, like e-bikes and e-scooters. Often they cannot compare to a car, but as an additional transport opportunity, for example complementing the public transport, they can substitute a car. In that case, inter- and multi-modal mobility-described as the usage of more than one means of transport-increases attractiveness of public transport and makes it easier to cover greater distances. [5, 6] The first- and last-mile with e-scooters plays a predominant role in intermodal travel chains, such as combinations with public transport. This is exactly where the high potential for e-scooters evokes. A user-survey provides additional input for the comparison methodology to get a point of view from users or potential users (5). This perspective is crucial, as a mobility concept only works if implemented by the users. The user survey should contain the current state but also future mobility scenarios. To realize that, future mobility scenarios will be developed within this method (4). That gives the people the opportunity to predict their change in mobility within different future scenarios. An end-user survey also helps to get more information about knowledge, forecasts and estimations of e-scooter mobility.

The results of the basic research, scenario development and user survey are leading into the comparative methodology (6). The comparative methodology itself is based on the evaluation of relevant criteria for means of transport. The definition of five exemplary urban commuting paths helps to get values for the comparative criteria. A potential analysis is conducted by the evaluation of temporal, financial and ecological effects of the use of e-scooters based on those five urban commuting paths. The aggregated results help to identify when the use of e-scooters makes sense, with special consideration of the criteria cost, time and ecology. This finally reveals the ecological (7) and economic (8) potential of e-scooters on commuting paths, which are analysed both individually and in combination with other means of transport.

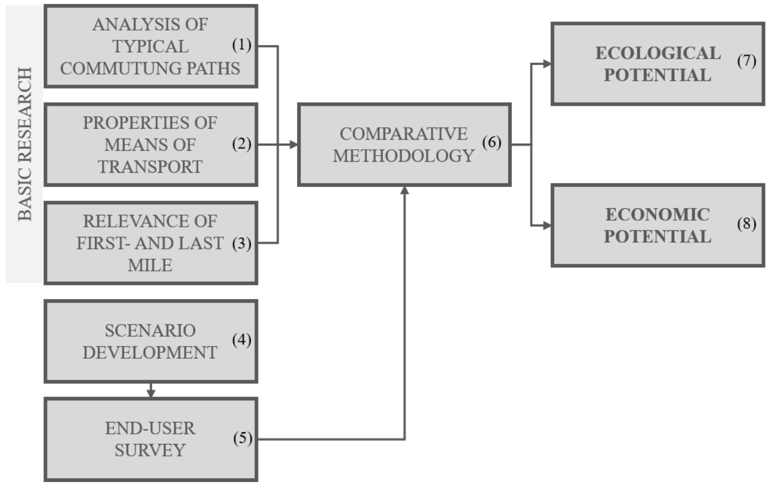


Figure 1: Methodology for the potential analysis of e-scooter for commuting paths

2.1 Basic research

The basic research is divided in the analysis of typical commuting paths, properties of means of transport and the relevance of the first- and last-mile. In order to analyse typical commuting paths**,** the data collected needs to reflect the actual mobility behaviour. However, the distance of the way to work or education institution holds significant information for the following scenarios with travel duration having an influence on the choice of means of transport too. To get an overview about the mobility behaviour, the means of transport that people choose for their commuting path is the most important data. Additionally, the combinations of different means of transport or the intermodal usage (using more than two means of transport successively) complete the big picture. If possible, it can be very helpful to split the data in urban and rural areas. The following means of transport will be examined:

Car	**Train**	**Tram**	**Bus**	**E-Bike**	**Bike**	**Foot**	**E-Scooter**

Typically, these are the transportation modes found on commuting paths. All of these have to be compared with the usage of e-scooters, whether single-use or in an intermodal mobility chain.

The next step is to identify criteria of the means of transport, which are depending to the main target, the ecological and economic potentials. Applied to the mobility sector, the *Rational-Choice-Theory* defines three factors influencing the choice of the mean of transport: time, costs and convenience. According to this, there is no need to formulate ecological criteria, as there is no rational reason to consider [7]. Alongside a lot of subjective criteria regarding the choice of means of transport (e.g. living conditions, personal attitude to transport, social environment), there are many objectively measurable criteria, especially considering the expenditure of time and costs [8]. Acquisition, fuel costs and maintenance costs should also be taken into account regarding the use of MIV (German for "Motorized Individual Transport"). Likewise, the access, departure and transfer times are factors influencing the time aspect of public transport and thus the choice of means of transport [9]. Contrary to the position of Goetz [7], an ecological investigation definitely has to be part of the analysis, because in todays (mobility) world, the ecology plays a major role. Due to the lack of objective criteria, convenience is not considered in the evaluation. To compare different means of transport, the following properties are defined:

- Time [min]
- Costs [€]
- Ecology [kg_{CO2}]

All properties depend on the distance of the commuting path, which is defined at the end of the comparison method. In this study, five representative commuting paths were designed as examples. To calculate the time needed t_{total} from starting point to aiming point, alongside the average time of travel $t_{average}$ the time durations of first- t_{in} and last-mile t_{out} and – on intermodal paths – the transfer time t_{change} have to be considered as well. The average time of travel is the ratio of covered distance x to the average velocity of the means of transport $v_{average}$.

$$t_{total} = t_{average} + t_{in} + t_{out} + t_{change} \quad with \quad t_{average} = \frac{x}{v_{average}} \tag{1}$$

The calculation is based on the researched average velocity of the means of travel. A second criterion for rating the means of transport are the costs. Therefore, they are researched in regard to the price per passenger-kilometre [€/Pkm]. The stated costs can vary greatly depending on used means of transport. Hence, data for average values (acquisition cost, maintenance, consumption, duration of use, etc.) should be used. To rate the sustainability of the different means of transport, the Global Warming Potential (GWP) will be used, which is determined through a life cycle assessment. According to Jepsen et al. [10], this is the most precise tool to estimate environmental outcomes of products in their whole life cycle, meaning from production to disposal. To compare products, a functional unit has to be chosen. A well-suited one is GWP per passenger-kilometre [g_{CO2}/Pkm]. For intermodal mobility, the first- and last-mile is especially relevant as the acceptance for public transport depends on the first and last means of transport. Therefore, the relevance of first- and last-mile mobility ranks highly, even more so in near future [11]. Methodologically, it is important to know how many people travel on intermodal commuting paths using first- and last-mile vehicles as well as how they define the first- and last-mile. Is it really one geographical mile (1.609 km)? An upcoming trend is the use of sharing systems for multi- or intermodal mobility. There are sharing systems for cars, bikes and e-bikes, scooters and e-scooters. The latter offers a promising potential based on small size, good portability (e.g. in public transport) and easy usage. The analysis of the first- and last-mile relevance includes the actual use, properties and sharing systems.

2.2 Scenario development

The comparison should also consider the influence of changes in mobility infrastructure and rules. Different scenarios have been developed to analyse a wide range of those changes in future mobility. In this paper, various existing scenarios from literature and other studies were researched and analysed instead of executing a complete scenario analysis. The most important characteristics are included in the end-user survey. Therefore, the influence of changes in mobility infrastructure and legislation for e-scooters can be estimated. The maximum timescale for the applied scenarios is 2030.

2.3 End-user survey

After the development of the scenarios, an end-user survey provides information about the acceptance and the potential of new mobility devices like e-scooters. The results, which are incorporated in the comparative methodology, help to understand the users' problems, their requirements for a pleasant commuting path and the reason to either use or not use e-scooters for commuting. The survey is based on the research question, which is defined at the beginning:

Which time- and cost-potentials do e-scooters provide for individual users and which influence do they have on the environmental balance?

From this basis, so-called programme questions were derived to answer the research question:

1) Which characteristics do typical commuting paths feature?

2) Why do people choose their means of transport?

3) How would people use e-scooters?

Next, constructs need to be defined and quantified in order to answer the research question. If the programme question is "*Which people can imagine using e-scooters?*" the construct includes also age, salary, gender and employment relationship. The constructs are highly relevant: They have to contain every necessary value to answer the programme questions without expanding the survey too much [12]. The questions of the survey will be derived from these constructs. The future scenarios from the previous chapter are also included in the survey. The participants will reflect on their mobility behaviour in the next years depending on some changing framework conditions which are introduced. This way, the current state as well as an overview of future trends are included.

2.4 Comparative methodology

The next step is to merge the results of earlier works (basic research, scenario development, end-user survey) into the comparative method. Evaluation criteria are formed out of all the collected data. This enables a comparison of different values, especially comparing conventional means of transport with e-scooters to identify the latter's potentially beneficial usage on commuting paths (figure 2). E-scooters will be considered for either single usage or in combination with public transport.

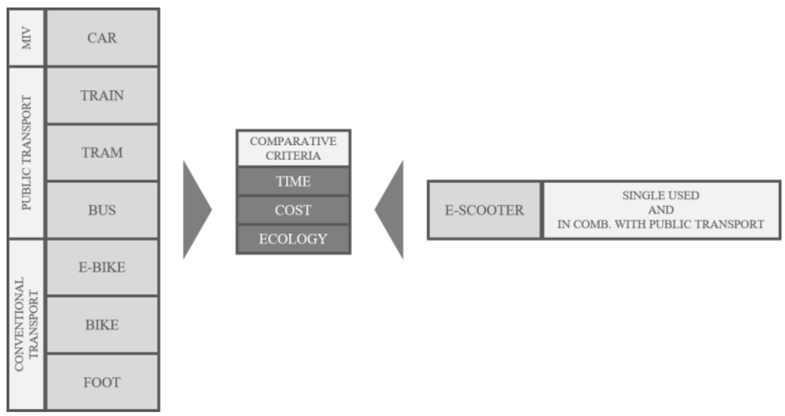


Figure 2: Considered mean of transport and comparative criteria.

From the results, the basic research, the end-user survey and in particular the comparison, economic and ecological potentials of e-scooters on commuting paths can be derived.

3 Results

The applied method helps to analyse the potential of e-scooters on commuting paths. Hereinafter, the results are displayed.

3.1 Results of the basic research

The analysis of mobility behaviour on commuting paths (including vocational training) is based on data by the Federal Ministry of Transport and Digital Infrastructure Germany, collected in scope of "Mobility in Germany" (MiD) between 2008 and 2017. On average, a respondent commuted 39 km daily in 2017, taking 80 minutes. Distances up to 5 km represent the highest share with 47%, while the segments 5-10 km and 10-20 km have a share of 18% each. Every twentieth commuter covers a distance of more than 50 km a day. Respectively, commutes and other work-related journeys (business trips, journeys to customers, etc.) each represent a third of the total mobility volume. The indicated relevance allows for a representative case for analysing the use of personal light electric vehicles. A look into the required time suggests that a third of all commutes takes less than 15 minutes. Another third takes between 15 and 30 minutes. After describing distance and duration for typical commuting paths, the chosen means of transport will be assessed. 49% of respondents use a car to commute (only MIV as driver and passenger). About 18% of them as a passenger. Public Transport, bikes and journeys on foot respectively represent 15%, 13% and 12% of commuting paths. In contrast, combinations of different modes of transport only play a minor role (Table 1).

Table 1: Usage of means of transport and combinations ([1]The numbers refer to unimodal and intermodal mobility behavior.) n=155.000 households ~ 300.000 people

Combination of means of transport	Percentage
only MIV (driver)	40%
only public transport[1]	15%
bike[1]	13%
foot	12%
only MIV (passenger)	9%
bike and public transport	1%
MIV (driver) and public transport	1%
MIV (passenger) and public transport	0%
others	0%
not specified	9%

Based on the information about the modes of transport, it can be analysed if intermodal use is prevalent. 73% claim that they are using two or more means of transport for commuting. 19% only use one. Consequently, the intermodal use of means of transport offers a great potential. The here depicted values of commuting paths are the foundation for the case study in chapter 3.4, featuring exemplary commuting paths based on data of the MiD-study. The applicability of PLEVs is tested for each of these exemplary paths. The next step in the basic research is the identification of specific properties of means of transport. The average speed, the costs per kilometre and the GWP per passenger-kilometre have to be enquired. To rate the time needed, the average velocity is used. The time durations for first- and last-mile (FLM) are calculated comparably to the time needed with the main means of transport in formula 1. Therefore, the velocities of the respective means of transport covering the FLM (e.g. by walking or e-scooter) and the distance of the FLM are used. For connections to train stations / stations of public transport, a time of 5 minutes for parking and walking to the platform is added when using individual transport (e.g. car, bike, e-scooter). When arriving on foot, only 2 minutes are added as there is no vehicle to park. Already being included in the respective routes, the transfer times between means of public transport do not have to be specified. To rate the financial aspect of the different means of transport, the costs in cent (€) per passenger-kilometre have been researched. The stated values can vary greatly depending on used means of transport. Hence, data for average values (acquisition cost, maintenance, consumption, duration of use, etc.) should be used. To rate the sustainability of the different means of transport, the Global Warming Potential (GWP) will be used (Table 2):

Table 2: Properties of means of transport

Means of transport	Car	Train	Tram	Bus	E-Bike	Bike	Foot	E-Scooter
Average Speed	24,1 km/h $_{1}$	~27,1 km/h $_{2}$	~24,4 km/h $_{2}$	~23,6 km/h $_{2}$	18,5 km/h $_{1}$	15,3 km/h $_{1}$	4,0 km/h $_{1}$	15,0 km/h $_{3}$
Costs	50,5 €ct/km $_{4}$	regional timetable $_{2}$			17,7 €ct/km $_{5}$	6,6 €ct/km $_{5}$	0,0 €ct/km	15,0 €ct/km $_{7}$
GWP	240,0 g/Pkm $_{7}$	60,0 g/Pkm $_{7}$	60,0 g/Pkm $_{7}$	110,0 g/Pkm $_{7}$	25,0 g/Pkm $_{7}$	5,0 g/Pkm $_{7}$	0,0 g/Pkm $_{8}$	12,5 g/Pkm $_{8}$

$_{1}$[15] $_{2}$[16] $_{3}$[17] $_{4}$[18] $_{5}$own calculation besed on actual bike prices $_{6}$[19] $_{7}$[20] $_{8}$self-assessment due to lack of data

This property data is integrated in the comparison methodology. Especially young adults (20 – 29 years) use public transport, the bike or walk. This is also true for car owners who use their car less often than in the past and showcase a higher multimodality in traffic [5]. Data from a German mobility panel proves the same constant increase of people with multimodal behaviour, from 3-6% in 1997 (depending on age) to 4-9 % in 2011. A survey of 170 people in the Rhine-Neckar region suggests that 18% of covered distances are covered intermodal [11]. 82% of that are found on paths with three stages, mostly with public transport as main means of transport. Thus, intermodal sections are paths to cover the first and last mile. According to these studies, one can expect the relevance of the FLM to increase furthermore, meaning that research considering the first- and last-mile is necessary. A study on the behaviour of underground railway users in New Delhi especially analysed the characteristics of the FLM. A majority of the FLM-paths has been covered by walking (mostly more than 50%). The covered distance for the FLM reaches – depending on the location of the station – between 0.7 and 4.2 km [13]. A study in the USA found that there are big differences when choosing the means of transport depending on the setting the public transport station is in. In the inner city, two thirds of people reached their station by walking, while in the suburbs only 5% arrived on foot (compared to 85% by car). The cause for this seems to be the maximum reasonable walking distance of 400 to 600 metres, which at times can be doubled through good infrastructure (e.g. safe walkways). For distances over 1.6 km, the share of pedestrians decreased to under 10% and the motorized individual transport reached its maximum. The share of cyclists did not depend on the distance, being in the lower single-digit percentile range all over [14]. The results underline both the current relevance and the importance as a field in future urban mobility.

3.2 General results of the end user survey

In the context of this study, 152 people have been surveyed in total, 120 of them online and 32 personally. The share of male participants ranks in at 73,0% (111 people) and the one of female participants at 26,3% (40 people). One respondent chose the sex "diverse" (0,7%). A sample size of one is not considered further. The survey aimed at interviewing people with and without experiences with e-scooters and comparable vehicles, to get an overview of opinions and estimate the potential as a commuting vehicle. The survey has been conducted at "*micromobility-expo*" in Hannover, Germany, as well as online. In total, 50,7% (77 people) did not have experience with e-scooters, 27,6% (42 people) have already tested one and 21,7% (33 people) either own a PLEV or use one regularly (e.g. in sharing systems). Figure 3 present the means of transport the respondents have access to. The means of transport with the most access is the car with 81.6%. Shortly after follow bike (77,6%), bus (76,3%) and train (72,4%). As underground and rapid railways are only available in cities, their share (57,2%) is smaller than the one of other public means of transport. Further modes as MaaS, e-bikes or motorbikes are used by less than 20% by the respondents. 15,8% (24 people) own or have access to a personal light electric vehicle.

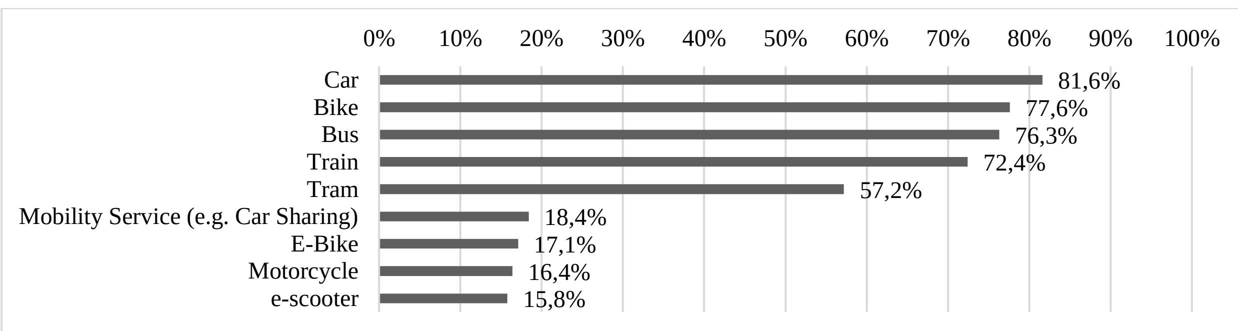
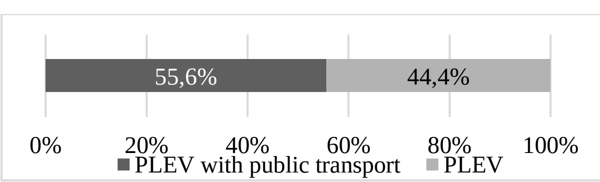


Figure 3: Access to means of transport (n=152, multiple choice)

In spite of the low number of only nine respondents already using a PLEV for commuting, a brief summary indicates considerable differences in usage patterns (figure 4). Thus, five people (55,6%) use their PLEV intermodal in combination with public transport. The remaining 4 respondents (44,4%) exclusively use the PLEV for the direct commute to work. Also, the distances of commuting paths covered (partly) with PLEV vary greatly: 44,4% are distances of over 20 km, all of them combined with the use of public transport systems. Each category with shorter distances is also present, although the PLEV is used exclusively in most of these cases. To conclude: The field of application of PLEVs is widespread, ranging from unimodal to intermodal uses.



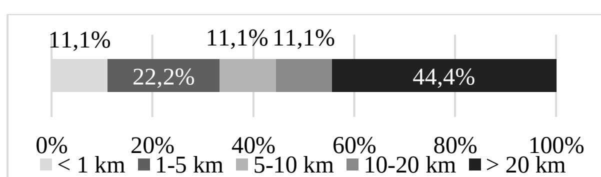


Figure 4: Usage of e-scooter at commuting (left, n=9) and Distances of commuting paths with e-scooter (right, n=9)

Subsequently, every participant was asked if they can imagine replacing a means of transport of their commute with a personal light electric vehicle. Slightly more than half of the respondents (53,9%) cannot. Another 5,9% already use an e-scooter on their commute. The residual 40,2% of interviewees can principally imagine using an e-scooter. Figure 5 demonstrates the share of potential users of PLEVs within the different means of transport. 42,1% of people walking more than 500 m on their commute would cover this distance with a PLEV. In the case of motorized individual transport, 28,4% would substitute their car with a PLEV and 20,0% would do so with their motorbike/motor scooter. In public transport, the share is almost as high: 27,8% of bus users and 18,2% of underground/rapid railway users are interested in PLEVs. As PLEVs are generally put into action on short distances, only 5,6% of train users would replace their current means of transport with e-scooters. The respondents also view the PLEVs as a competitor for bikes: every forth cyclists is interested in switching modes. Therefore, an ecological assessment is difficult as both motorized traffic and trips by bike and on foot are replaced – in contradiction to the hopes and expectations of the new means of transport.

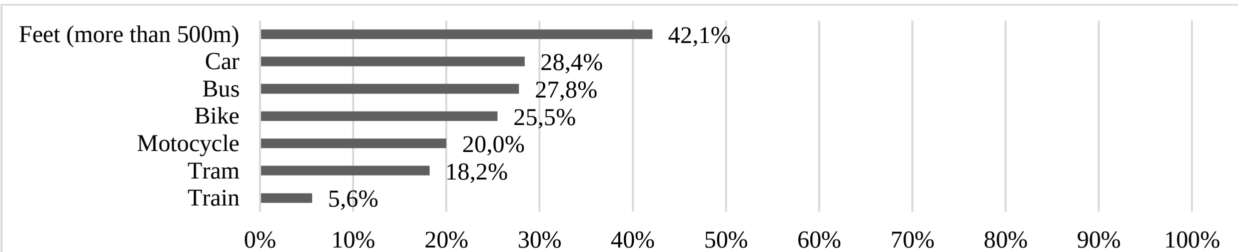


Figure 5: Means of transport replaced by e-scooters (n=152, multiple choice)

The maximum time of use of PLEVs on one way differs notably as well. Only 5,2% of people without experience with PLEVs can imagine using them for more than 45 minutes non-stop. However, 33,3% of e-scooter users do not share that opinion. Accordingly, the groups of people with little to no experience dominate the categories "*up to 5 minutes*" and "*up to 15 minutes*" over groups of e-scooter owners. Of the latter, none would use e-scooters for less than 5 minutes. This reveals a high acceptance of e-scooters for durations up to 15 minutes.

More results have been achieved and considered in the applied method. For reasons of space, they cannot be included in this paper. For more information, please contact the authors.

3.3 Results of the commuting scenarios

To estimate the impact of ambient conditions on the use of PLEVs, a literature research regarding mobility scenarios has been conducted. The chosen scenarios in this paper are based on studies [21 – 28]. Participants have been surveyed on their potential future use of PLEVs within a period from now to year 2030.

Scenario 1 "*Business as usual*" describes a future with only little changes compared to today. The increase of motorized individual transport continues, including further congestions and traffic jams. This is part of the reason that pollution thresholds are exceeded more often and severely. PLEVs haven't been established, thus entrainment in public transport is banned. The respondents agree that e-scooters could relieve the traffic (68%). The same value is reached when asking if the participants feel confident using a PLEV on public streets. The questions regarding an increase in accidents and about e-scooters as an alternative to bikes show a slightly less distinct accordance (56 and 58%). The affirmation of the statement "more PLEVs lead to more accidents" depends on infrastructure as well, with the interviewees being unsure whether bike paths are adequate for PLEVs - 48% indicate a neutral evaluation, though the result underlines the importance of infrastructure, conforming with the conclusion of the previous chapter. At the same time, entrainment of PLEVs in public transport seems to be a relevant criterion for potential users. 59% of respondents anticipate a ban of PLEVs in public transport to lead to a decrease in usage. However, 37% do not share this opinion. Essentially, the participants are open for the use of PLEVs, though the available infrastructure and potential accidents are seen as critical aspects.

The future setting of scenario 2, "*individual, but regulated*", is one in which problems have been recognized but only met with a few single and individual measures. In this scenario, motorized individual transport is more expensive than today, while PLEVs are financially subsidized. Bike infrastructure has been improved for use of new means of transport (e.g. PLEVs) where possible. Scenario 2 demonstrates that all key factors lead to an increased use of e-scooters. Especially state subsidies result in more people using these modes (64%), whereas an improvement of bike infrastructure only convinces 24% of respondents to change their behaviour. Some interviewees noted that improved bike paths rather benefit the attractiveness of cycling, eliminating the necessity of PLEVs. Furthermore, a rise in costs for car usage is a reason for 38% of respondents to recognize the potential of PLEVs. However, in this case more than half of the participants (58%) state to keep using the car or to favour different means of transport. In conclusion, scenario 2 still leads to a considerable increase in the use of PLEVs.

Scenario 3 follows a "*holistic approach*" of mobility. Therefore, private car traffic has been banned from inner cities completely and replaced by carsharing systems. Public transport is free and expanded greatly. The freed space in cities is amongst others used for an improved bike infrastructure, which can also be used by PLEVs. Thanks to more vehicles available, the sharing of PLEVs has been established as a real alternative for short paths and the first- and last-mile. For 63% of respondents, a ban of car traffic in inner cities is the main for an increased use of PLEVs. This high value originates from frequent car users being forced to switch to another means of transport. The controversially debated idea of free public transport offers a potential for decline for 13% of respondents. By removing transportation costs, the attractiveness of public transport increases, thus eliminating a reason for using PLEVs. However, for a fifth of interviewees (21%), an appealing public transport results in more interest for the intermodal use of PLEVs and thus an increased use of these means of transport. The expansion of public transport does not have an influence on the use of PLEVs (-1%). Similar to the effect explained above, people replacing PLEVs with public transport and people using public transport intermodal with PLEVs neutralize, neither increasing nor decreasing the usage intensity. The impact of an optimized sharing system of PLEVs is met by opposite opinions as well. For about one half (46%), there is no impact, as they are generally not interested in sharing services, while for the other half (50%), the attractiveness of these means of transport is increased. The current establishment of sharing service providers, which expands daily in Germany [29], therefore can lead to an increased use if offers are presented in an engaging way (e.g. availability, costs, vehicles). In scenario 3, the use of PLEVs is more widespread than today, but is falling short compared to scenario 2, as changes in public transport (expansion and free use) negatively impact the use of PLEVs. In this context it has to be kept in mind that the design of the scenarios only features key factors which are directly related to PLEVs. An indirect impact of other key factors found in the consulted studies (e.g. more home office, less social value of owning a car, etc.) has not been published. Therefore, the conducted survey offers a first view on the future use of personal light electric vehicles. In the survey, participants have been asked about their potential future use of PLEVs in respect to the key factors of the scenarios.

3.4 Economic and Ecological potential

To estimate the potential of e-scooters on the basis of practical commuting paths, five starting points (places of residence) have been defined. The Fraunhofer IAO in Stuttgart-Vaihingen serves as the aiming point (place of work) for each commute. The whole range of possible commuting paths should be represented, which is why short as well as long distances within and in between cities are considered, according to the results of the survey. As an exemplary commuting path, table 3 displays the analysis for the trip from Stuttgart Downtown-West to the Fraunhofer Institute IAO. Based on the calculated and aggregated paths above, it is evaluated in which case the use of an e-scooter is reasonable, considering the criteria costs, time and ecology. E-scooters are considered both individually and in combination with public transport. Furthermore, a short discussion suggests which users benefit of the switch from conventional means of transport to e-scooters.

Table 3: Results for an exemplary commuting paths

	Car	Public Transport (PT)	PT + e-scooter	Savings compared to…	
				…Car	…PT
Time [min]	32,0 min	85,0 min	34,4 min	-8%	60%
Costs [€]	8,50 €	2,00 €	2,60 €	69%	-35%
GWP [kg_{CO2}]	4,0 kg	0,6 kg	0,7 kg	84%	-10%

Costs of transport: Regarding the costs of transport, the single use of e-scooters is reasonable in comparison with each means of transport except bike and walking. The most savings (70% per km) are found on distances currently covered by car. E-scooters combined with public transport can offer considerable savings as well. Compared to only using public transport, the combination of e-scooters with train, subway or bus is more expensive, as the first- and last-mile are covered by e-scooters instead of being walked.

Time: To evaluate the time needed, a differential view is necessary. Individually, an e-scooter covers a distance faster than walking, equally fast as a bike or e-bike and slower than a car. In combination with public transport, the time needed to cover distances in inner cities is comparable to the travel time with a car. However, on paths from the suburbs into the city, the car is faster even than the intermodal use of e-scooters and public transport. E-scooters offer the most important potential in connection to rapid public transport (e.g. rapid railways). Replacing bus rides from and to the rapid railway promises the most time savings, especially when minimizing transfer and waiting times.

CO_2-equivalent: E-scooters cover distances with higher emissions of CO_2-equivalents than when walked or cycled. In contrast, the emissions of public transport and cars are even higher, making the e-scooter the better alternative. Regarded in combination, the intermodal use of public transport and e-scooters scores well compared to the use of cars. However, it cannot definitely be said if an intermodal use offers reducing potentials when compared to the unimodal use of public transport. Here, the particular paths and chosen means of transport vary a lot in ecological impacts.

4 Conclusion

People using public transport have the opportunity to use PLEVs to cover the first- and last-mile as well as feeding paths, resulting in great time savings. Persons who commute by cycling do not benefit from e-scooters that much. Only the entrainment in public transport is easier and the physical work is removed. If the latter aspect really is a benefit, depends on the individual. For unimodal car users, PLEVs can potentially reduce costs and CO_2-equivalents on commuting paths. However, this relates to an increase in travel time, depending in extent on the characteristics of the commuting path. Compared to the unimodal use of public transport, the combination with e-scooters is faster. How the examples above suggest, e-scooters definitely offer individual benefits to some people. An ecological perspective also proposes a reduction of CO_2-equivalents for some users. General statements can be made for costs, time and CO_2-equivalents per kilometre and means of transport, but not for complete commuting paths. Among personal preferences, the place of residence, connection to public transport, the location of the place of work and the kind of streets on the commuting path (city traffic, country road, motorway) play a role as well. If and for which criteria (costs, time, CO_2-equivalents) e-scooters enable an improvement hence has to be examined depending on the specific case.

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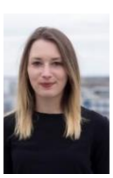

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