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Potentials and challenges of light electric vehicles (LEVs)

A use-case based analysis of the user perspective

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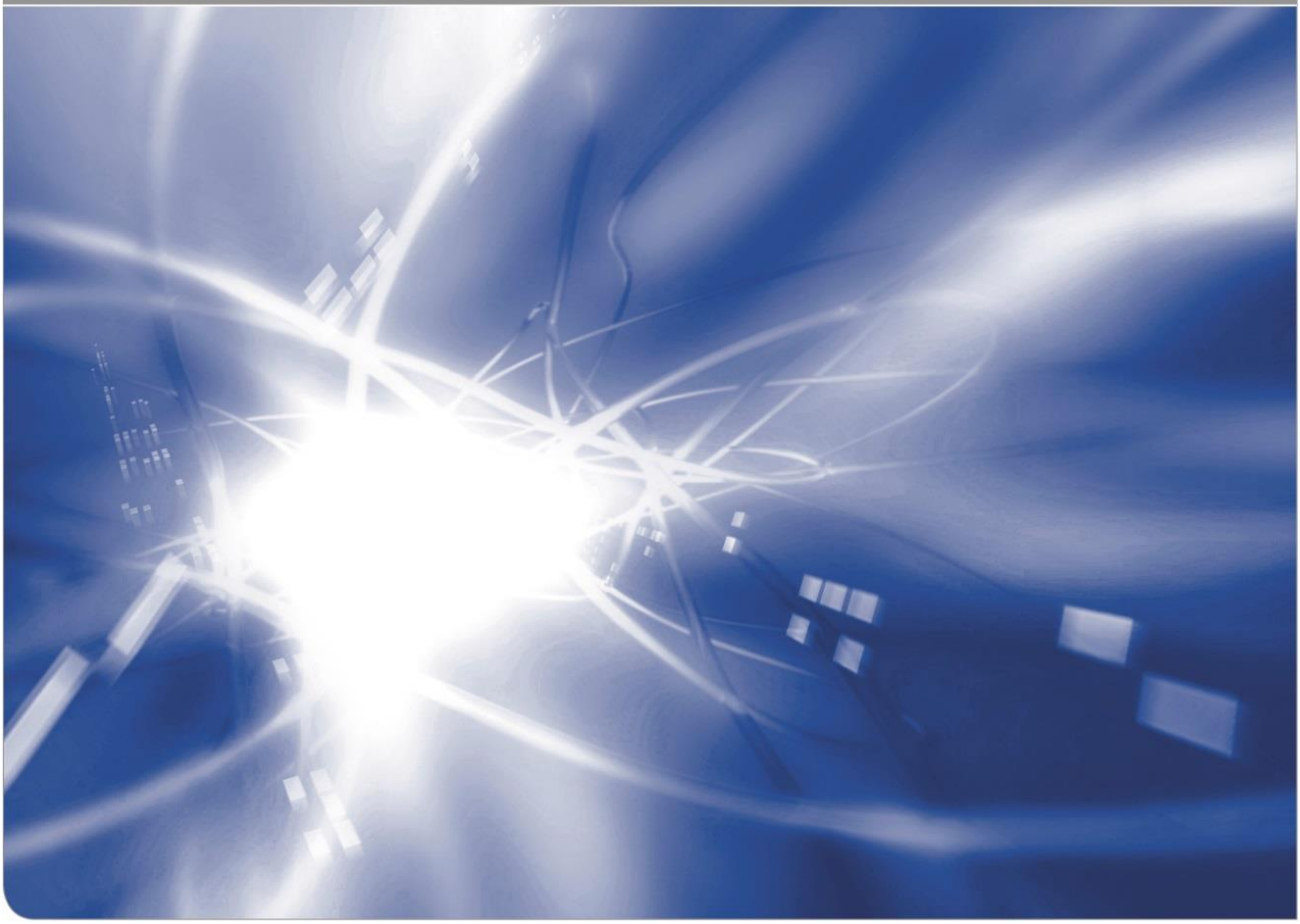

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Abstract

Light electric vehicles (LEVs) are efficient vehicles in terms of both consumption and space thanks to their light weight and small size. They can be beneficial for users and serve the latest development goals such as reducing emissions and saving space in cities. However, the sales of these vehicles in Germany (and in Europe in general) account for less than 0,03% of all car sales in a year [1, p. 2, 2]. This study explores the perspective of users by their choice of mobility solutions to illuminate why these vehicles haven't gained traction. For this purpose, first the current state of knowledge on LEVs in the literature is reviewed and presented. The focus is on the advantages and disadvantages of LEVs, their projected potential use cases, and examples of current models on the market. Based on these information, three use cases (commuting, shopping and first/last mile) and possible alternative mobility options for these use cases are selected for an in-depth analysis. Using the persona method as well as real vehicle examples and semi-randomly generated example trips, each use case and mobility option is analyzed from the user's perspective. This analysis identifies and compares the quantitative and qualitative aspects that affect users during these trips for each selected LEV and the alternative mobility options. The results of this analysis are later compared to the results of a separately conducted qualitative expert interview. The analysis shows that LEVs fulfill some important trip requirements in the investigated use case scenarios which public transport and micromobiles cannot fulfill, while LEVs and conventional passenger vehicles show little to no difference in most cases, especially in urban areas. However, these results also show that LEVs do not provide any significant benefits during use over conventional cars to justify their purchase. The study is concluded with recommendations on how to create new unique advantages for LEVs to support wider adoption of these vehicles.

Keywords: energy efficiency; land use in cities; urban mobility; Sustainable Development Goals (SDGs); user centric; expert interviews; commuting; first/last mile vehicle; three- and four-wheeled light electric vehicles; small electric vehicles; L2e; L5e; L6e; L7e

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List of Abbreviations

Abbreviation	Explanation
cm	centimeter
cm^3	cubic centimeter
CO_2	carbon dioxide
etc.	Et cetera (used at the end of a list to indicate that further, similar items are included)
EU	European Union
EUR/€	Euro
kg	kilogram
km	kilometer
km/h	kilometer per hour
kW	kilowatt
kWh	kilowatt hour
L2e	LEV category for three-wheel mopeds
L2e-P	LEV subcategory for three-wheel mopeds for passenger transport
L5e	LEV category for powered tricycles
L5e-A	LEV subcategory for tricycles
L6e	LEV category for light quadricycles
L6e-BP	LEV subcategory for light quadri-mobiles for passenger transport
L7e	LEV category for heavy quadricycles
L7e-CP	LEV subcategory for heavy quadri-mobiles for passenger transport
LEV	light electric vehicle (LEVs stand for light electric vehicles)
m	meter
m^2	square meter
M1	vehicle category for the conventional passenger cars
mm	millimeter
W	watt

1 Motivation and structure of the study

Topics such as urbanization and environmental protection pose numerous challenges for the future of mobility in both urban and rural areas. According to the United Nations, there is a continuous trend of migration to cities and it is expected that by 2050, 83,7% of the European population will live in so-called functional urban areas [3]. The continuous growth of the urban population leads to an overburdening of existing urban structures. This in turn leads to economic and social problems, due to reasons such as lost time and stress. For example, in 2019, the average time lost in traffic for a person in Rome was 166 hours per year [4, p. 13]. On the other hand, there is also an increased demand for public spaces in cities - for example, to increase green areas - to improve the quality of life in cities and for further social purposes. One of the most pressing environmental issues is global warming. The transport sector is responsible for 29% of total economy-wide greenhouse gas emissions in the EU, and about 70% of these emissions are caused by road transport [5]. The European Union aims to achieve a carbon-neutral EU by 2050 and a 55% reduction in greenhouse gas emissions by 2030 [6]. Moreover, the goal of mass transition to battery electric vehicles may lead to increased consumption of rare materials and increased waste in the long run. Cars currently account for a significant share of the modal split in Germany and Europe. Due to their relatively high weight, size, and low occupancy rate (in Germany, the average occupancy rate of a vehicle is 1.46 people [7]), a mobility system dominated by these conventional cars represents a suboptimal state in light of these upcoming challenges. Small and light electric vehicles offer a potential solution to this problem.

The main idea behind promoting light electric vehicles (LEVs) is to take advantage of the higher efficiency of these vehicles compared to conventional cars. Because of their smaller size, they weigh less and therefore require less energy to operate. This also translates into a smaller battery size needed for a given range. So not only do these vehicles require less material to build, they're also more efficient in using the materials needed for batteries, which have a more critical environmental impact than the materials used to build the rest of the vehicle, such as steel. For the same reasons, they also produce less waste at the end of their lifecycle. The efficiency of these vehicles isn't limited to energy and materials, either.

Thanks to their smaller footprint, they take up less space on the road and contribute positively to traffic flow. They are less threatening to vulnerable road users such as pedestrians and cyclists than larger vehicles. They also take up less parking space and can therefore contribute to saving space in cities if implemented on a large scale. In addition, LEVs can have lower operating costs than conventional vehicles and some can be driven at a younger age, depending on regulations in the country where they are used. The smaller size also makes it easier for users to find parking spaces. Together, these benefits align with several aspects of UNDP's Sustainable Development Goals [8] and make LEVs a topic of interest for sustainability research.

While the advantages of LEVs are mostly related to their smaller size compared to conventional vehicles, their advantages over the smaller mobility solutions such as bikes and e-scooters come from offering more comfort and functionality. They have a partially or fully enclosed space for the user, which brings more safety and partial or full weather protection, depending on the body type of the vehicle. They are capable of higher speeds compared to (e-)bikes and e-scooters and can use the lanes for vehicles, which makes them suitable for more mobility needs. Most of these vehicles also offer small storage compartments for carrying small items, which can be problematic when riding a bike or e-scooter. Taken together, LEVs aim to fill the gap between conventional passenger vehicles and micro-mobility solutions, and contribute to efforts to improve intermodal and multimodal travel.

Despite the aforementioned advantages, sales of light electric vehicles in Europe remain very low. While the total number of newly registered passenger cars in Europe exceeded 11,5 million in 2020 [2], the number of sold quadricycles (L6e and L7e vehicles) was limited to 2816 vehicles in 2019 [1, p. 2].

The idea of using the benefits of LEVs as a solution to current challenges of mobility has been around for some time. Therefore, there are numerous studies on the potential of these vehicles. However, research shows that many of these studies examine these potentials qualitatively or rely on survey results. This study aims to take a critical stance on these identified potentials by comparing LEV solutions to other existing mobility solutions in specific use cases and investigating which solutions look favorable from a user perspective.

The goal is to create a more precise understanding of these identified potentials and to assist LEV developers and policy makers in their future work.

To achieve this goal, this study is structured as follows:

- Chapter 2 introduces the definition of LEVs and defines to which type of vehicles this study is limited.
- Chapter 3 presents the knowledge of LEV in the literature. This chapter describes the categories of LEVs as well as some current vehicle examples, the advantages and disadvantages of LEVs, and their potential use cases. The information presented here also serves as input for the analysis in the upcoming Chapter 4.
- Chapter 4 introduces the analysis of selected use cases with different mobility options from the user's perspective. After presenting the chosen methodology and the relevant inputs for this analysis, the results of the analysis are described in detail. Lastly, these results are compared with the results of a separate expert interview.
- Chapter 5 discusses the results of this analysis, proposes some solution ideas for increasing the acceptance of LEVs, and gives an outlook for further studies.

2 Definition of LEV

At the beginning of this study, it is important to clarify what the term "small and light electric vehicles" stands for. A review of the literature shows that the boundaries that this term encompasses vary from one source to another. In addition, there are different categorizations by different regulatory organizations at national and international levels, which further complicates the definition of these vehicles.

In this study, the definition of light electric vehicles is limited to three-wheeled and four-wheeled L-class vehicles (L2e, L5e, L6e and L7e) according to EU Regulation No. 168/2013 [9]. Two-wheeled L-class vehicles, which include motorcycles but also micromobiles such as e-scooters or pedelecs, are not considered in this study because they have significantly different characteristics compared to the three- and four-wheeled vehicles in terms of driving, range and safety. Furthermore, the focus of this study is on passenger transportation. Therefore, commercial vehicles used for transporting goods aren't considered either.

The classification criteria for type admission according to EU Regulation 168/2013 are summarized in Table 1 below (the original classification criteria from the regulation are presented at the beginning of each corresponding subchapter in Chapter 3.1). To be admitted, each vehicle should meet specific requirements according to its chosen classification (a vehicle can meet the criteria of more than one category, and the manufacturer can choose which category its vehicle should be admitted to), which are detailed in the same regulation. The admission requirements of the LEV categories are generally less demanding than those of the M1 category (the category for conventional passenger cars).

Table 1: Type-admission criteria for L2e, L5e, L6e and L7e vehicles according to the EU Regulation Nr. 168/2013 [9, 10, p. 16]

Category	**L2e**		**L5e**		**L6e**		**L7e**				
Subcategory	L2e-P Passenger transport	L2e-U Transport of goods	L5e-A Mainly passenger transport	L5e-B Commercial use	L6e-A Light road-quad	L6e-B (BP/BU) Light four-wheel-mobile	L7e-A (A1/A2) Heavy road-quad	L7e-B Heavy off-road quad		L7e-C Heavy four-wheeled mobile	
Sub-subcategory								L7e-B1 Off-road quad	L7e-B2 Side-by-side buggy	L7e-CP Passenger transport	L7e-CU Transport of goods
Maximum design speed	≤ 45 km/h		-		≤ 45 km/h		-	≤ 90 km/h	-	≤ 90 km/h	
Maximum continuous rated power	≤ 4 kW		-		≤ 4 kW	≤ 6 kW	≤ 15 kW	-	≤ 15 kW	≤ 15 kW	
Maximum unladen weight*	≤ 270 kg		≤ 1000 kg		≤ 425 kg		≤ 450 kg	-	≤ 450 kg	≤ 450 kg	≤ 600 kg
Length	≤ 4000 mm		≤ 4000 mm		≤ 4000 mm	≤ 3000 mm	≤ 4000 mm			≤ 3700 mm	
Width	≤ 2000 mm		≤ 2000 mm		≤ 2000 mm	≤ 1500 mm	≤ 2000 mm			≤ 1500 mm	
Height	≤ 2500 mm		≤ 2500 mm		≤ 2500 mm		≤ 2500 mm				
Seating	≤ 2		≤ 5	≤ 2	≤ 2		≤ 2	≤ 2	≤ 3 (2 of them arranged side-by-side)	≤ 4	≤ 2
Number of wheels	3		3		4		4				

* Weight in running order, without batteries

In Europe, different LEV categories require different licenses. The L2e and L6e categories require an AM category license. L7e vehicles require a category B license, just like conventional passenger cars. For the L5e category, the license required depends on the continuous rated or net power of the vehicle. If the L5e vehicle has up to 15kW of power, it can be driven with an A1 category license. If it has more than 15kW of power, it requires a category A license. As a result of these different license requirements, the minimum driving age also changes depending on the category. While L2e and L6e vehicles and L5e vehicles with less than 15kW of power can be driven from the age of 16, L7e vehicles require the age of 18 and L5e vehicles with more than 15kW of power require the age of 21 (the age requirements may be subject to further details in different countries, such as the example of the category B driver's license with accompanied driving in Germany). The relevant driver's license categories for three-wheeled and four-wheeled LEVs and their respective requirements are shown in Table 2 below. The specifications of these categories for two-wheeled vehicles are not included in this table.

Table 2: Driving license categories for three- and four-wheeled LEVs and their conditions [9, 11]

Driving license category	Conditions	Minimum age	Relevant vehicle categories
AM	3 wheeled vehicles with maximum design speed ≤ 45km/h, maximum continuous rated power ≤ 4kW, mass in running order ≤ 270kg and maximum two seating positions (L2e) 4 wheeled vehicles with maximum design speed ≤ 45km/h, maximum continuous rated power ≤ 6kW (≤ 4kW if L6e-A), mass in running order ≤ 425kg and maximum two seating positions (L6e)	16*	L2e, L6e
A1	3 wheeled vehicles with maximum design speed > 45km/h and maximum continuous rated power ≤ 15kW	16	L5e
A	3 wheeled vehicles with maximum design speed > 45km/h and maximum continuous rated power > 15kW	21*	L5e
B	4 wheeled vehicles with maximum authorized mass < 3500kg and designed and constructed for the carriage of no more than eight passengers in addition to the driver	18*	L7e

* Susceptible to further details

3 LEV state-of-art

This chapter presents the current knowledge about LEVs in the literature. Chapter 3.1 introduces the general characteristics of the LEV categories mentioned in Chapter 2 above and presents some vehicle examples from these categories. Chapters 3.2 and 3.3 summarize the identified advantages and disadvantages of LEVs. Chapter 3.4 brings together the anticipated potential use cases.

Most of the reviewed literature on LEVs relies on one or more of the following methods for information: analytical studies of vehicle characteristics, expert interviews, survey results, and data from demonstration project participants. From these literature, information on the advantages, disadvantages and potential use-cases of LEVs are collected. The advantages are included to provide a baseline knowledge for why the adoption of these vehicles should be pursued and to present the arguments for why users might want to use these vehicles in a given use case. The disadvantages are included to acknowledge where the shortcomings of these vehicles are and to understand why users might choose another alternative to LEVs in a given real-world situation. The use cases are included to show where the current state of knowledge sees the highest potentials for these vehicles. This information is also used to select the use cases to be analyzed in Chapter 4. Information on the LEV categories and current offerings is presented at the beginning of this chapter to provide a basis for understanding the current state of the market and the general characteristics of these vehicles. Some of the vehicles presented in this chapter are also used in the analysis of the use cases in Chapter 4.

3.1 LEV categories and examples

The idea of LEVs on European streets can be traced back several decades with examples such as the Hotzenblitz (1989-1996) and City EL (1987-1991). These vehicles didn't succeed in establishing themselves in the market. However, the decade of the 2010s has seen a resurgence of interest in the idea of LEVs, as evidenced by the number of new concept and production vehicles entering the market. It can be hypothesized that developments in the field of lithium-ion batteries and the increased focus on more climate-friendly and city-friendly alternative mobility solutions have played a role in this development [10, pp. 24-25]. The following subchapters provide a brief overview of the current LEV offerings in each vehicle category.

3.1.1 L2e vehicles

L2e vehicles are the smallest and lightest of the categories considered in this study. As can be seen in Table 3 and Table 4, the L2e-P vehicles, which are the L2e vehicles for personal transport, are limited to the dimensions of 4000 mm/2000 mm/2500 mm (length/width/height), have a maximum mass of 270 kg and seat a maximum of 2 people. This relatively low maximum weight limit and the maximum speed limit of 45 km/h make the vehicles in this category most suitable for mobility needs in urban areas. To maximize the benefits in this context, many current vehicles in this category have adopted a short and narrow design to achieve this low weight limit. This maximizes their practicality by reducing the amount of space they require. However, this design also results in a more upright and higher seating position for the occupants and a higher center of gravity. Since these vehicles cannot counteract this higher center of gravity with a wider track width, due to their goal of being as narrow as possible, this design is usually more prone to tipping. To solve this problem and also to increase agility, many vehicles in this category have a tilt mechanism for cornering. In addition to increased agility, this feature gives these vehicles a more "motorcycle-like" driving characteristic, which can be perceived as more dynamic and fun by some users. However, it also results in higher costs due to the more complex mechanisms required. Another common feature of these vehicles is partial weather protection. Some current L2e vehicles choose not to include doors in their designs. The reason for this is to stay within the weight limit, but also to allow for unobstructed entry and exit, and to not confine the user to a space that is too small and cramped. These vehicles provide a windshield and roof to protect against wind and direct rain, but don't provide an isolated driver's compartment.

Table 3: Classification criteria for categories L1e-L7e (extract from the EU regulation on two- and three-wheeled vehicles and quadricycles) [9, p. 94]

Category	Category name	Common classification criteria
L1e-L7e	All L-category vehicles	(1) length ≤ 4 000 mm or ≤ 3 000 mm for a L6e-B vehicle or ≤ 3 700 mm for a L7e-C vehicle, and (2) width ≤ 2 000 mm, or ≤ 1 000 mm for a L1e vehicle, or ≤ 1 500 mm for a L6e-B or a L7e-C vehicle and (3) height ≤ 2 500 mm and

Table 4: Classification criteria for category L2e (extract from the EU regulation on two- and three-wheeled vehicles and quadricycles) [9, p. 95]

Category	Category name	Common classification criteria
L2e	Three-wheel moped	(4) three wheels and powered by a propulsion as listed under Article 4(3) and (5) engine capacity ≤ 50 cm^3 if a PI internal combustion engine or engine capacity ≤ 500 cm^3 if a CI combustion engine forms part of the vehicle’s propulsion configuration and (6) maximum design vehicle speed ≤ 45 km/h and (7) maximum continuous rated or net power ≤ 4 000 W and (8) mass in running order ≤ 270 kg and (9) equipped with a maximum of two seating positions, including the seating position for the driver and
Sub-categories	**Subcategory name**	**Supplemental sub-classification criteria**
L2e-P	Three-wheel moped for passenger transport	(10) L2e vehicle other than those complying with the specific classification criteria for a L2e-U vehicle.
L2e-U	Three-wheel moped for utility purposes	(10) exclusively designed for the carriage of goods with an open or enclosed, virtually even and horizontal loading bed that meets the following criteria: (a) $length_{loading\ bed} \times width_{loading\ bed} \geq 0{,}3 \times Length_{vehicle} \times maximum\ Width_{vehicle}$ or (b) an equivalent loading bed area as defined above in order to install machines and/or equipment and

	(c) designed with a loading bed area which is clearly separated by a rigid partition from the area reserved for the vehicle occupants and
	(d) the loading bed area shall be able to carry a minimum volume represented by a 600 mm cube.

Roo (or BICAR by its old name) and Toyota iRoad are two current example vehicles for the L2e category that are introduced in this chapter.

Figure 1: BICAR (2. Gen) [12]

Model name	BICAR (2. gen)
Width	800 mm
Length	1500 mm
Height	1836 mm
Maximum design speed	45 km/h
Maximum continuous rated power	not specified
Mass in running order	120 kg
Battery capacity	3,7 kWh
Range	40 - 60 km
Energy consumption	4,8 kWh/100 km
Trunk capacity	not specified

Table 5: BICAR (2. Gen) technical specifications [12]

Roo is a vehicle that first emerged as a development project at the Zurich University of Applied Sciences in Switzerland in 2014 under the name BICAR. The second generation of this vehicle was approved for road use in Switzerland in 2020, and the third generation is now planned for a pilot project in 2022 [13]. This vehicle is designed for individual users to cover short and medium distances in urban areas [12, p. 158]. A unique feature of this vehicle is its very compact design to enable a very small footprint (1,2 m^2) and low weight (120 kg). The small footprint allows 6 Roos to be parked in a conventional parking space (2 m * 5 m). The light weight of the vehicle allows a low energy consumption (4,8 kWh/100km), which allows a range of up to 60km with its 3,7 kWh battery. According to the developers, 75%

of all materials used in this vehicle are recyclable [12, p. 160]. The specially designed windshield and roof aim to keep the user dry on a rainy day, despite the partially open design of the vehicle. To keep weight to a minimum, non-essential features such as audio systems and design elements aren't built into the vehicle. Instead, the vehicle offers smartphone connectivity, and functions such as navigation are expected to be provided by the customer's own device. For safety, the vehicle has a tubular frame around the driver's zone and offers a three-point seat belt. For transporting goods, the vehicle has a bag holder in front of the handle and a storage box in the rear. The vehicle has a tilt mechanism that can tilt up to 35° when cornering for increased maneuverability and stability. The vehicle is steered by a motorcycle-style handlebar [14].

Figure 2: Toyota iRoad [17]

Model name	Toyota iRoad
Width	870 mm
Length	2345 mm
Height	1455 mm
Maximum design speed	45 km/h
Maximum continuous rated power	3,8 kW
Mass in running order	≤ 300 kg
Battery capacity	5,5 kWh
Range	50 km
Energy consumption	Not specified
Trunk capacity	-

Table 6: Toyota iRoad technical specifications [15, 16]

Toyota iRoad was first introduced as a concept vehicle at the 2013 Geneva Motor Show, and a street-legal version made its debut at the 2014 Paris Motor Show. Toyota stated the goals of this vehicle as providing greater flexibility in urban mobility while reducing urban congestion and harmful emissions [18]. As of today, Toyota iRoads are offered as sharing vehicles to be used in combination with public transport as pilot projects in the cities of

Toyota City, Grenoble and Tokyo [19]. The vehicle's uniqueness lies in the fact that it offers a fully enclosed cabin and vehicle functions such as heating and audio systems, yet it weighs less than 300 kg (the exact weight has not been disclosed by the manufacturer) and qualifies for the L2e category. Like the Roo, the Toyota iRoad has two front wheels, one rear wheel and a tilt mechanism. This mechanism allows the vehicle to tilt when cornering for increased maneuverability, but also keeps the vehicle straight on uneven surfaces. Unlike conventional vehicles, the iRoad is steered by its rear wheel. The iRoad is as narrow as the Roo, with a maximum width of 870 mm between the two side mirrors, but the fully enclosed cabin, additional features and the seat for a second person result in a relatively higher weight and a longer vehicle length (2345 mm). With these dimensions it is possible to park up to 5 iRoads in a conventional parking space. Unlike the Roo, the Toyota iRoad has a steering wheel like a conventional car and, as mentioned above, has heating, adjustable windows, an audio system and interior lighting. These give the user a more car-like interior. The vehicle doesn't have any dedicated storage space, but the back seat can be used to transport goods when there is no second passenger. For safety, the vehicle offers a three-point seat belt, but doesn't have an airbag [15].

3.1.2 L5e vehicles

The L5e category differs from the L2e category by not having a maximum speed limit and by allowing more seats and higher maximum mass. As can be seen in Table 3 and Table 7, L5e-A vehicles, which are the L5e vehicles for passenger transport, are limited to dimensions of 4000 mm/2000 mm/2500 mm (length/width/height), have a maximum weight of 1000 kg and seats for a maximum of 5 people. The lack of a maximum speed limit distinguishes these vehicles from L2e vehicles by allowing them to be suitable for non-urban roads. As wind resistance begins to play a more important role at higher speeds, an aerodynamic design with less wind resistance becomes more important in L5e vehicles. In addition, they require increased stability against tipping at higher speeds, which is a disadvantage of the three-wheeled design. To achieve these goals, L5e vehicles tend to have a wider track width and a lower center of gravity, which is achieved with a lower and longer vehicle design. They also tend to offer fully enclosed driver cabins. The longer and wider dimensions, as well as the fully enclosed design, allow these vehicles to offer more dedicated storage space. The wheel arrangements of two front wheels and a single rear wheel as well as a single front wheel and two rear wheels can be found in this category, such as the examples of Twike 5 and SAM. It is also possible to find ICE vehicles which do not offer weather protection and are more similar to motorcycle designs, such as the Piaggio MP3, in this category. However, these vehicles are not included in this study because they are not electric and do not count as LEVs.

Table 7: Classification criteria for category L5e (extract from the EU regulation on two- and three-wheeled vehicles and quadricycles) [9, p. 98]

Category	**Category name**	**Common classification criteria**
L5e	Powered tricycle	(4) three wheels and powered by a propulsion as listed under Article 4(3) and (5) mass in running order ≤ 1 000 kg and (6) three-wheel vehicle that cannot be classified as a L2e vehicle and
Sub-categories	**Subcategory name**	**Supplemental sub-classification criteria**
L5e-A	Tricycle	(7) L5e vehicle other than those complying with the specific classification criteria for a L5e-B vehicle and (8) with a maximum of five seating positions, including the seating position of the driver.
L5e-B	Commercial tricycle	(7) designed as a utility vehicle and characterised by an enclosed driving and passenger compartment accessible by maximum three sides and (8) equipped with a maximum of two seating positions, including the seating position for the driver and (9) exclusively designed for the carriage of goods with an open or enclosed, virtually even and horizontal loading bed that meets the following criteria: (a) $\text{length}_{\text{loading bed}} \times \text{width}_{\text{loading bed}} \geq 0{,}3 \times \text{Length}_{\text{vehicle}} \times \text{maximum Width}_{\text{vehicle}}$ or (b) an equivalent loading bed area as defined above designed to install machines and/or equipment and (c) designed with a loading bed area which is clearly separated by a rigid partition from the area reserved for the vehicle occupants and (d) the loading bed area shall be able to carry a minimum volume represented by a 600 mm cube.

The Twike 5 is introduced in this chapter as an example L5e vehicle.

Figure 3: Twike 5 [20]

Model name	Twike 5
Width	1552 mm
Length	3327 mm
Height	1235 mm
Maximum design speed	130/ 190 km/h
Maximum continuous rated power	45 kW
Mass in running order	ca. 600 kg
Battery capacity	18/36 kWh
Range	250/500 km
Energy consumption	7,2 kWh/100 km
Trunk capacity	300l

Table 8: Twike 5 technical specifications [20]

Twike 5 is a vehicle with a single front wheel and two rear wheels which is currently in the prototype-phase and is expected to enter series-production by the end of the first half of 2023. Like its predecessor, the Twike 3, which was launched in 1996, the Twike 5 has the unique feature that its electric powertrain can be assisted by the driver through pedaling. The energy generated by pedaling is sent to the vehicle's battery and can be used to reduce the vehicle's power consumption or increase its range. The manufacturer promotes this feature as a way to exercise while driving. Other unique features of this vehicle are its steering controls and its high top speed and range. The vehicle is steered by a sidestick steering system, which the manufacturer claims allows for precise and fatigue-free steering. This steering system also allows for an ergonomic seating position that allows for comfortable pedaling. Depending on the battery configuration, the Twike 5 has different ranges and top speeds. The smaller 18 kWh battery provides a range of 250 km and a top speed of 130 km/h, while the 36 kWh battery provides a range of 500 km and a top speed of 190 km/h. These ranges and top speeds differentiate the Twike 5 from other LEVs in this study and make it suitable for non-urban roads and longer trips. However, the Twike 5 is also significantly more expensive than the other examples, with expected prices ranging from

€39.900 to €49.900. The dashboard is equipped with a 7-inch touch display. For storage, there is a dedicated space in the back of the vehicle that can accommodate packages up to 90x50x50 cm. For larger items, the passenger seat can be removed to create more storage space. For safety, the Twike 5 has a 3-point seat belt and a fiber composite roll cage in addition to its aluminum chassis [20].

3.1.3 L6e and L7e vehicles

The L6e and L7e categories cover the 4-wheeled light electric vehicles. As shown in Table 3 and Table 9, the L6e-BP vehicles, which are the L6e vehicles for personal transport, are limited to the dimensions of 3000 mm/1500 mm/2500 mm (length/width/height), have a maximum weight of 425 kg, a maximum continuous rated or net power of 6 kW, a maximum speed of 45 km/h, and a maximum seating capacity of 2 people. The L7e-CP vehicles, which are the L7e vehicles for passenger transport, differ from the L6e-BP category by a longer length (3700 mm vs. 3000 mm), a slightly higher maximum weight (450 kg vs. 425 kg), a higher maximum continuous rated or net power (15 kW vs. 6 kW), a higher maximum speed (90 km/h vs. 45 km/h) and more seats (4 vs. 2). The longer length and higher weight limit are to allow the additional seating, while the higher power is to allow the higher top speed. With a top speed of 45 km/h, the L6e vehicles are mostly suitable for urban use. The increased top speed of the L7e vehicles allows them to be used on non-urban roads. However, as they are still below the maximum speeds of intercity roads and highways, they can be considered as urban vehicles with some additional flexibility. Unlike the L2e and L5e categories, L6e-BP and L7e-CP vehicles require an at least partially enclosed driver's cabin. With their 4-wheel configuration and enclosed driver's cabin, L6e and L7e vehicles feature a design more similar to conventional M1 vehicles. To emphasize their advantage over M1 vehicles in urban environments, but also to meet the relatively low weight limit, typical vehicles in this category aim for very compact designs. They also typically offer a limited number of additional features to save weight and keep costs down. Currently, Renault (Twizy) and Citroen/Opel (Ami/Rocks-e) are the OEMs that have a vehicle in the European market. However, models from smaller companies such as Microlino and Aixam are also available.

Table 9: Classification criteria for category L6e (extract from the EU regulation on two- and three-wheeled vehicles and quadricycles) [9, p. 99]

Category	Category name	Common classification criteria
L6e	Light quadricycle	(4) four wheels and powered by a propulsion as listed under Article 4(3) and (5) maximum design vehicle speed ≤ 45 km/h and (6) the mass in running order ≤ 425 kg and (7) engine capacity ≤ 50 cm^3 if a PI engine or engine capacity ≤ 500 cm^3 if a CI engine forms part of the vehicle's propulsion configuration and (8) equipped with a maximum of two seating positions, including the seating position for the driver and
Sub-categories	**Subcategory name**	**Supplemental sub-classification criteria**
L6e-A	Light on-road quad	(9) L6e vehicle not complying with the specific classification criteria for a L6e-B vehicle and (10) maximum continuous rated or net power ≤ 4 000 W.
L6e-B	Light quadri-mobile	(9) enclosed driving and passenger compartment accessible by maximum three sides and (10) maximum continuous rated or net power ≤ 6 000 W and
Sub-sub-categories	**Sub-subcategory name**	**Sub-sub-classification criteria in addition to the sub-classification criteria of a L6e-B vehicle**
L6e-BP	Light quadri-mobile for passenger transport	(11) L6e-B vehicle mainly designed for passenger transport and (12) L6e-B vehicle other than those complying with the specific classification criterion for a L6e-BU vehicle.
L6e-BU	Light quadri-mobile for utility purposes	(11) exclusively designed for the carriage of goods with an open or enclosed, virtually even and horizontal loading bed that meets the following criteria: (a) $\text{length}_{\text{loading bed}} \times \text{width}_{\text{loading bed}} \geq 0{,}3 \times \text{Length}_{\text{vehicle}} \times \text{maximum Width}_{\text{vehicle}}$ or (b) an equivalent loading bed area as defined above in order to install machines and/or equipment and (c) designed with a loading bed area which is clearly separated by a rigid partition from the area reserved for the vehicle occupants and (d) the loading bed area shall be able to carry a minimum volume represented by a 600 mm cube.

Table 10: Classification criteria for category L7e (extract from the EU regulation on two- and three-wheeled vehicles and quadricycles) [9, p. 101]

Category	Category name	Common classification criteria
L7e	Heavy quadricycle	(4) four wheels and powered by a propulsion as listed under Article 4(3) and (5) mass in running order: (a) ≤ 450 kg for transport of passengers; (b) ≤ 600 kg for transport of goods. And (6) L7e vehicle that cannot be classified as a L6e vehicle and
Sub-categories	**Subcategory name**	**Supplemental sub-classification criteria**
L7e-A	Heavy on-road quad	(7) L7e vehicle not complying with the specific classification criteria for a L7e-B or a L7e-C vehicle and (8) vehicle designed for the transport of passengers only and (9) maximum continuous rated or net power ([1]) ≤ 15 kW and
Sub-sub-categories	**Sub-subcategory name**	**Sub-sub-classification criteria in addition to the sub-classification criteria of a L6e-B vehicle**
L7e-A1	A1 heavy on-road quad	(10) maximum two straddle seating positions, including the seating position for the rider and (11) handlebar to steer.
L7e-A2	A2 heavy on-road quad	(10) L7e-A vehicle not complying with the specific classification criteria for a L7e-A1 vehicle and (11) maximum two non-straddle seating positions, including the seating position for the driver.
Sub-categories	**Subcategory name**	**Supplemental sub-classification criteria**
L7e-B	Heavy all terrain quad	(7) L7e vehicle not complying with the specific classification criteria for a L7e-C vehicle and (8) ground clearance ≥180 mm and
Sub-sub-categories	**Sub-subcategory name**	**Sub-sub-classification criteria in addition to the sub-classification criteria of a L6e-B vehicle**
L7e-B1	All terrain quad	(9) maximum two straddle seating positions, including the seating position for the rider and (10) equipped with a handlebar to steer and (11) maximum design vehicle speed ≤ 90 km/h and

		(12) wheelbase to ground clearance ratio ≤ 6.
L7e-B2	Side-by-side buggy	(9) L7e-B vehicle other than a L7e-B1 vehicle and (10) maximum three non-straddle seats of which two positioned side-by-side, including the seating position for the driver and (11) maximum continuous rated or net power ≤ 15 kW and (12) wheelbase to ground clearance ratio ≤ 8.
Sub-categories	**Subcategory name**	**Supplemental sub-classification criteria**
L7e-C	Heavy quadri-mobile	(7) L7e vehicle not complying with the specific classification criteria for a L7e-B vehicle and (8) maximum continuous rated or net power ≤ 15 kW and (9) maximum design vehicle speed ≤ 90 km/h and (10) enclosed driving and passenger compartment accessible via maximum three sides and
Sub-sub-categories	**Sub-subcategory name**	**Sub-sub-classification criteria in addition to the sub-classification criteria of a L6e-B vehicle**
L7e-CP	Heavy quadri-mobile for passenger transport	(11) L7e-C vehicle not complying with the specific classification criteria for a L7e-CU vehicle and (12) maximum four non-straddle seats, including the seating position for the driver.
L7e-CU	Heavy quadri-mobile for utility purposes	(11) exclusively designed for the carriage of goods with an open or enclosed, virtually even and horizontal loading bed that meets the following criteria: (a) $length_{loading\ bed} \times width_{loading\ bed} \geq 0{,}3 \times Length_{vehicle} \times Width_{vehicle}$ or (b) an equivalent loading bed area as defined above designed to install machines and/or equipment and (c) designed with a loading bed area which is clearly separated by a rigid partition from the area reserved for the vehicle occupants and (d) the loading bed area shall be able to carry a minimum volume represented by a 600 mm cube and (12) maximum two non-straddle seats, including the seating position for the driver.

The Renault Twizy 45 and Microlino 2.0 are presented in this chapter as example vehicles for the L6e and L7e categories.

Figure 4: Renault Twizy [21]

Model name	Renault Twizy 45
Width	1237 mm
Length	2335 mm
Height	1454 mm
Maximum design speed	45 km/h
Maximum continuous rated power	4 kW
Mass in running order	548 kg
Battery capacity	7 kWh
Range	100 km
Energy consumption	5,8 kWh/100 km
Trunk capacity	156l

Table 11: Renault Twizy 45 technical specifications [21, 22]

The Renault Twizy was launched in 2012 as the first four-wheeled LEV vehicle to be mass-produced by a major OEM in Europe in the 2000s. As a vehicle with a partially enclosed passenger cabin without doors (scissor doors are an optional feature), the vehicle differs from conventional vehicles not only by its compact size, but also by its design. To achieve this narrow width, the vehicle places the passenger seat directly behind the driver's seat, similar to the Toyota iRoad. This compact size allows the vehicle to be cross parked and, as mentioned earlier in this study, three Twizys can be parked in a conventional parking space. There are two versions of the Twizy: One with a top speed of 45 km, which qualifies for the L6e category, and one with a top speed of 80 km, which qualifies for the L7e category. These vehicles differ only in their built-in motors and are otherwise identical. As a vehicle launched in the early days of lithium-ion battery technology, the Twizy offers a range of 90 or 100 km, depending on the motor configuration. This range is made possible by the relatively low power consumption of 5,8-6,3 kW/100 km, which partially negates the disadvantages of the vehicle's earlier technology. The battery of the vehicle is not bought together with the vehicle. Instead, it is leased and can be replaced when the older battery begins to lose performance. Like the other examples in this study, the Twizy can be recharged using a standard household socket and takes 3,5 hours to fully recharge. The Renault Twizy is driven with a conventional steering wheel and pedals. For safety, the Twizy is equipped with a four-point seat belt and an airbag for the driver and a three-point seat belt for the rear passenger. For storage, the Twizy has two glove compartments with a total capacity of 8 liters and a lockable box under the rear seat with a capacity of 31 liters. The price of the Renault Twizy starts at €11.450 in Germany in 2022 [21–23].

Figure 5: Microlino 2.0 [24]

Model name	Microlino 2.0
Width	1473 mm
Length	2519 mm
Height	1501 mm
Maximum design speed	90 km/h
Maximum continuous rated power	12,5 kW
Mass in running order	496/513/530 kg
Battery capacity	6/ 10,5/ 14 kWh
Range	90/171/230 km
Energy consumption	7,8 kWh/100 km
Trunk capacity	230l

Table 12: Microlino technical specifications [24, 25]

Microlino 2.0 is the second iteration of the L7e vehicle from a Swiss startup, which unveiled the first version of this vehicle at the 2016 Geneva Motor Show. According to the manufacturer, this vehicle is inspired by the bubble cars of the 1950s and has a similar layout to some of these vehicles [26]. The front of the vehicle serves as a door, allowing the driver and passenger to enter the vehicle. A single bench seat serves both the driver and passenger, who sit side by side. This seating arrangement allows the Microlino to offer much more storage space than the other LEV examples shown in this study (excluding the Twike 5), as it offers 230 liters of storage behind this bench, which can be accessed from the rear. The door at the front of the vehicle allows passengers to get out directly onto the pavement when the vehicle is cross-parked. Like the Twizy, the Microlino can be cross parked and 3 Microlinos can fit into a conventional parking space. The vehicle has three Li-ion battery options of 6kWh, 10,5kWh and 14kWh, giving 91, 177 and 230km range respectively, according to the manufacturer. Depending on the battery size, the vehicle can be fully charged in 3 or 4 hours, and it is possible to charge Microlino using a standard household outlet. The vehicle has a 12,5 kW electric motor and can reach a top speed of 90 km/h. Like the Twizy, the Microlino is steered by a conventional steering wheel and has a digital dashboard. However, the fully enclosed driver's cabin provides the same weather protection as a conventional vehicle, and Microlino has a heater. For safety, Microlino has three-point seat belts for both driver and passenger. A unibody chassis made of pressed steel and aluminum parts, instead of the more typical tubular frame seen in these categories of vehicles, contributes to the safety of the vehicle and the driving characteristics. The starting price of the Microlino is expected to be €12.500 in Germany [24].

3.2 Advantages

The advantages of LEVs can be examined from two different perspectives: the advantages compared to larger vehicles and the advantages compared to smaller vehicles. This study focuses on the advantages over larger vehicles because, as noted earlier, the main goal of promoting the adoption of LEVs is to replace such vehicles for the environmental and space benefits. The advantages over the smaller vehicles are still briefly mentioned at the end of the chapter to state why users might want or need to choose these vehicles over the smaller alternatives and active transportation modes.

Most of the advantages of LEVs over larger vehicles result from the following three characteristics of these vehicles (or combinations of them) that are part of their definition:

- Small size and footprint
- Light weight
- Electric powertrain

The benefits that can be derived from these characteristics are discussed in the following chapters.

3.2.1 Use of space/parking

A key benefit of the small footprint of LEVs is in terms of parking. As shown in Figure 6, a category L7e LEV such as the Renault Twizy has only 41% of the footprint compared to the average footprint of vehicles registered in Germany in 2017. L2e vehicles can be even more advantageous in this regard: for example, a BICAR has a footprint of 1,2 m^2 and occupies only 17% of this average [12, p. 159]. Thanks to this small size, it is possible to park 3 Renault Twizys or even 5 BICARs in a conventional parking space 5 m long and 2,5 m wide.

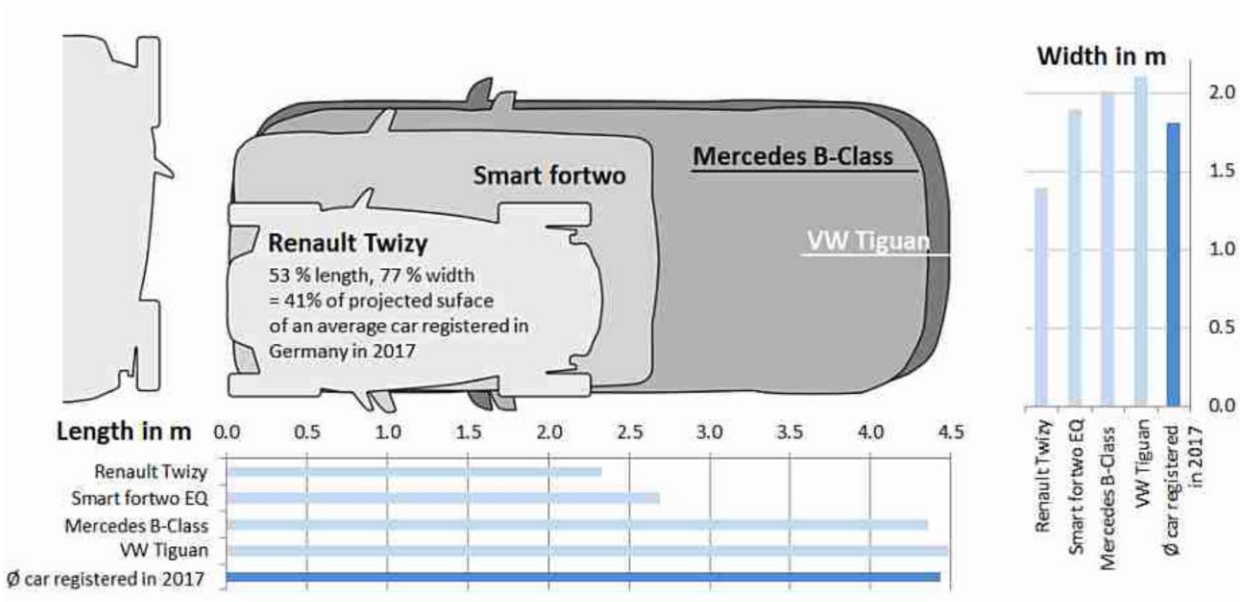
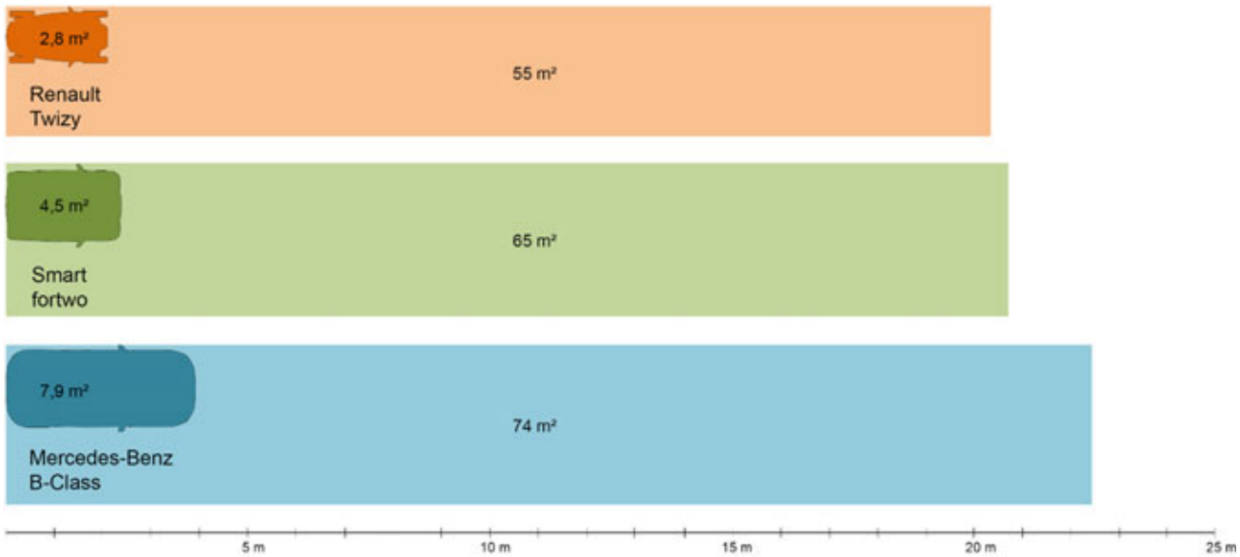


Figure 6: Comparison of different car and LEV dimensions [27, p. 9]

When in use, the small footprint of these vehicles allows them to be parked in small spaces where a conventional vehicle would not fit. Short-length LEVs can also be parked perpendicular to the street. These allow the user to find a parking space more easily, to spend less time looking for a parking space, and to park closer to his or her destination. In addition, the short wheelbase of these vehicles makes them more maneuverable. This makes them easier to park.

Widespread adoption of LEVs may allow cities to reduce the number of parking spaces or create smaller parking spaces specifically for these vehicles, for example in mobility hubs. How these reallocated spaces can be used is discussed in Chapter 3.2.9.

LEVs also use less space in operation. Figure 7 compares the space requirements of an LEV with those of a small category M1 car and a large category M1 car, taking into account stopping and reaction distances at a speed of 30 km/s. Under these conditions, a Renault Twizy requires about 20 m² less space than a Mercedes B-class car. The visualization shows that this space gain is relatively small compared to the space gain during parking, when considered as a percentage of the total space required for the mentioned case. However, the smaller footprint during driving also has a positive effect on congestion. According to [28, p. 3657], drivers tend to adapt their speed to the perceived density of traffic around them: if it feels congested, they slow down; if they perceive more space, they speed up again. Moreover, with the same number of drivers, congestion is reduced when vehicles take up less space. Therefore, the positive effects of LEVs on traffic flow should not be overlooked when considering the benefits of LEVs.



*Road width and dimension of parking spaces are not taken into account. Areas are determined by the dimensions of the vehicles, as in most EU countries defined by law, for driving 1,5m lateral clearing distance to single track vehicles, stopping distance and reaction distance. Date: Renault 2020, Mercedes-Benz AG 2020

Figure 7: Visualization of land use in parking position and operation at 30 km/h [29, p. 10]

3.2.2 Energy consumption and efficiency

LEVs generally have lower energy consumption than conventional electric vehicles due to their lighter weight. While energy consumption cannot be directly correlated to vehicle weight due to the influence of several other factors, a comparison of vehicle examples shows that LEVs have significantly lower consumption than conventional electric vehicles (see Table 13). Lower energy consumption means lower operating costs for the user and less impact on the environment (especially if the electricity used isn't 100% from renewable sources). Lower energy consumption also means more range per kWh of battery capacity, allowing smaller batteries. Moreover, LEVs put less strain on the electrical grid per vehicle [30, p. 123].

Table 13: Energy consumption of LEV and M1-class vehicle examples [22, 31–33]

Model	Energy consumption (WLTP) [kwh/100km]
Renault Twizy 45	5,8
Microlino	7
Smart EQ fortwo	17,4
Volkswagen ID.3	14,9

The topic of energy consumption and efficiency of electric vehicles compared to internal combustion engine (ICE) vehicles is an already widely studied topic [34] and therefore is not discussed further in this study.

In theory, a conventional electric vehicle can have a similar or even lower energy consumption per person when all the seats are occupied (in the example of Microlino vs. Volkswagen ID.3: 3,5 vs. 3 kWh/100km per person). However, when the average occupation rate of passenger cars is considered (in Germany, the occupancy rate of a passenger car is about 1,5 people per vehicle [7]), LEVs show a significant advantage over the conventional electric vehicles.

3.2.3 Use of resources

The lower weight of LEVs due to their smaller size means that less resources are used per vehicle (if the vehicles use similar materials), which is a clear environmental benefit. However, in addition to the general use of less material per vehicle, LEVs also have further advantages in this regard compared to conventional electric vehicles due to their smaller batteries. Current battery technologies, such as lithium-ion batteries, require some rare raw materials which have significant environmental and sometimes also social impacts on the places where they are mined. Many of these materials are also only mined in a few specific countries, which means they have to be transported over long distances, causing further CO_2 emissions. The ability to use smaller batteries allows these vehicles to use less of these materials, resulting in lower CO_2 emissions over their cradle-to-grave lifecycle. For example, the Renault Twizy uses a 6,1 kWh battery for a range of 100 km, while a Smart EQ fortwo uses a 17,6 kWh battery for a range of 133 km [22, 32].

3.2.4 Air quality

Battery electric powertrains do not produce tailpipe emissions such as CO_2 or NO_x like conventional ICE powertrains. Therefore, replacing ICE vehicles with LEVs (or any battery electric vehicle for that matter) eliminates local emissions of these gases and helps improve air quality in the cities. For example, a gasoline-powered VW Golf 8 1.0 TSI emits 120g CO_2 per km and a diesel-powered VW Golf 8 2.0 TDI SCR emits an additional 15mg NO_x per km on top of its 110g CO_2 emission [35, 36]. Because of the high traffic density in cities, vehicle tailpipe emissions create locally higher concentrations of these gases in the air. In large numbers, this can lead to noticeably more polluted air in the city. Replacing ICE vehicle trips with LEVs can reduce this effect and may be a possible measure for cities struggling with high levels of air pollution.

The air pollution benefits of LEVs are not solely in comparison to internal combustion engines, either. When battery electric vehicles aren't charged with 100% renewable energy, their energy still causes a certain amount of CO_2 emissions (and further emissions) depending on the energy mix. For example, Germany's energy mix (including prechain emissions) was 473g CO_2 per kWh in 2019 [37]. This means that vehicles using less energy offer an emissions advantage, even if both vehicles don't produce tailpipe emissions. As explained in Chapter 3.2.2, LEVs have significantly lower energy consumption than conventional electric vehicles and therefore cause lower emissions. Furthermore, vehicle production is also a source of emissions, as manufacturing, shipping, and processing materials all require energy and generate further emissions. Therefore, a heavier vehicle requires more materials and causes more emissions than a lighter vehicle produced by the same company in similar facilities. As a result, LEVs cause fewer emissions in the "cradle-to-tank" phase of their lifecycle.

There are some LEV vehicle concepts, such as the SLRV [38], which are not battery-electric vehicles and instead use fuel-cell-technology. These vehicles use hydrogen instead of fossil-fuels and emit only water vapor instead of CO_2, NO_x, and other pollutants. Thus, these vehicles also provide similar benefits as the battery-electric LEVs compared to ICE vehicles.

When it comes to air quality, there's another issue that isn't addressed in the literature reviewed, but where LEVs can provide additional benefits: fine particle emissions from brakes and tires. Fine particle emissions are caused by the abrasion of these components during use. Because LEVs are lighter than conventional vehicles, they have less kinetic energy at a given speed, so the brakes of an LEV are less stressed than those of conventional vehicles and emit less particles. Lighter weight also reduces tire wear [39, 40]. Therefore, it can be said: LEVs have the potential to reduce fine particle emissions from tires and brakes.

3.2.5 Noise

Vehicles with electric powertrains have significantly lower engine noise compared to ICE vehicles [41, 42]. For conventional ICE vehicles, the dominant components of vehicle noise at urban speeds (0-50 km/h) are engine noise and tire noise, as shown in Figure 8. As can be seen in this graph, engine noise is dominant at lower speeds, while tire noise becomes more important as speed increases. In addition, the engine noise of ICE vehicles increases significantly during acceleration. Therefore, especially in cities with high congestion and resulting frequent speed changes, engine noise accounts for a significant portion of vehicle noise. Replacing ICE vehicles with LEVs can help reduce noise levels and improve the quality of life in these cities. The engine noise of electric vehicles is also lower than that of ICE vehicles at higher speeds. However, as tire noise becomes the dominant factor in vehicle noise at high speeds, this reduction becomes more negligible in this range.

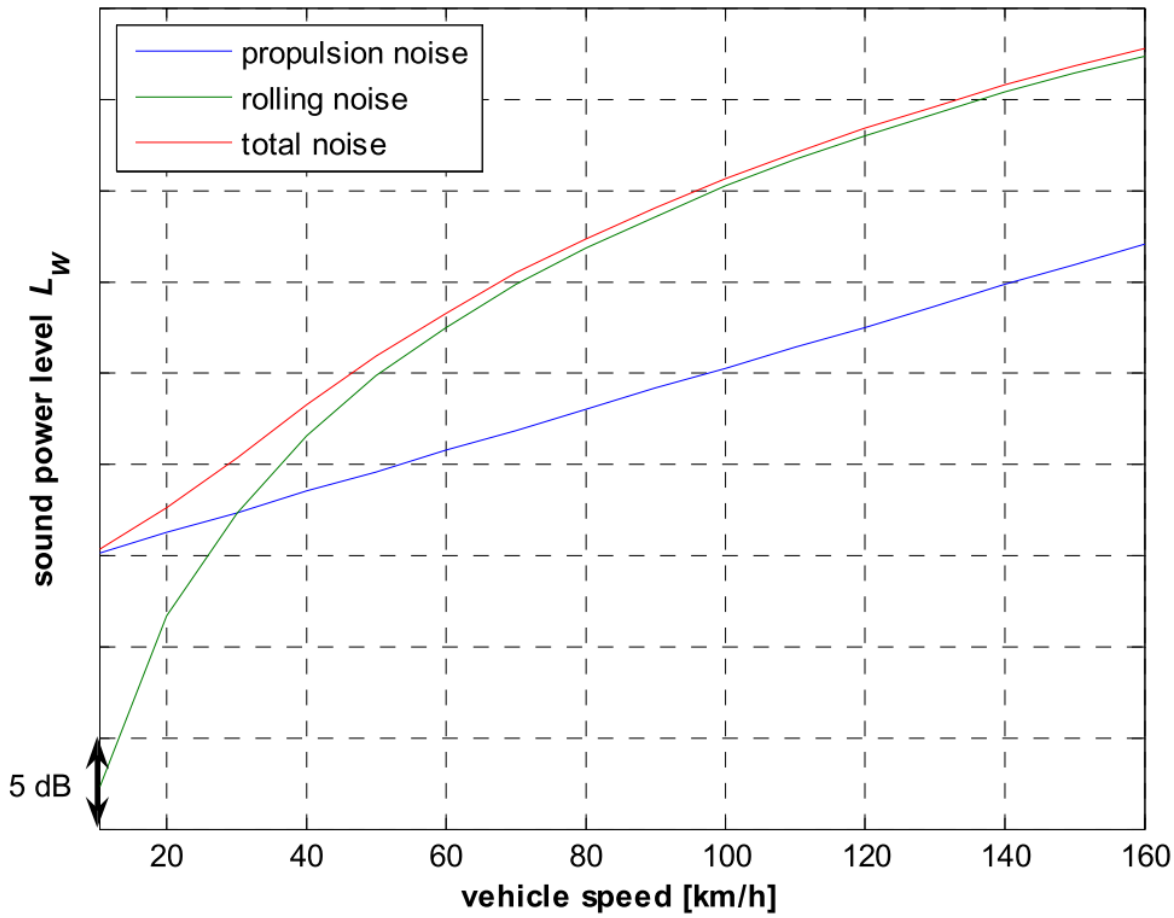


Figure 8: Propulsion, rolling and total noise levels in relevance to vehicle speed [43]

In addition to their powertrain, the lighter weight of LEVs also contributes to lower noise levels. As a result of various factors, increased vehicle weight results in increased tire noise [44, pp. 195-198]. While this advantage is not as great as the noise reduction of the electric powertrain over ICE, it can still contribute to noise reduction in both urban and suburban environments.

3.2.6 Costs

The selling prices of LEVs are considered both an advantage and a disadvantage in the literature. LEV prices are generally lower than conventional BEV prices, but it is possible to find some ICE models at similar prices (Figure 9). As battery technology develops and battery prices come down, there is potential for the prices of these vehicles to come down as well. However, when making this comparison, it is important to remember that LEVs offer less functionality and less flexibility in transporting people and goods compared to conventional vehicles. Therefore, in the eyes of customers, whether or not the prices of these vehicles are expensive is a subjective issue. However, if this issue is considered only in the context of battery electric vehicles, LEVs offer a lower entry point for customers who want to buy an electric vehicle.

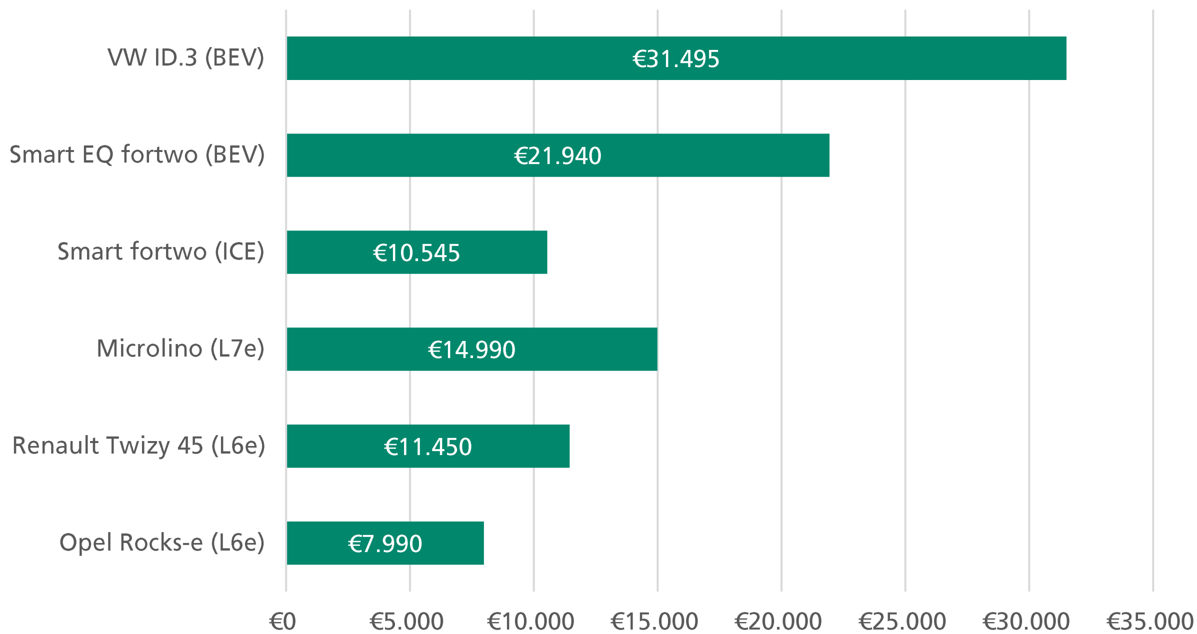


Figure 9: Examples of vehicles and their prices in Germany in 2022 [45]

In terms of operating costs, LEVs have an advantage in energy consumption as mentioned in Chapter 3.2.2, which leads to lower energy costs. Another possible advantage of these vehicles can be lower parking costs, as they take up much less space. However, this advantage cannot be realized if there are no special regulations for LEVs or if there are no LEV-specific parking spaces with adjusted prices.

The topics maintenance and total cost of ownership are not included in this study because it was not possible to find information of the quality required for a comparison within the limits of this study. The topics of value depreciation and second-hand vehicle market are also not included either because of the different focus point of the study.

3.2.7 Optical benefits

The small size of LEVs allows them to take up less visual space and provide functional and aesthetic benefits. LEVs generally have a much shorter length than conventional vehicles - resulting in more frequent gaps between moving or parked vehicles - and a lower height (see Figure 10). This results in less restricted visibility. Less restricted visibility increases road safety. For example, more vulnerable road users, such as pedestrians, can see oncoming vehicles more easily and can also be seen by drivers when they emerge from between vehicles. It also improves the line of sight for drivers in traffic. In addition to safety, a less restricted view also creates a more open atmosphere and a more pleasant feeling of space. [27, p. 10]. This is particularly evident to pedestrians walking on sidewalks next to on-street parking spaces. In general, wider adoption of LEVs in cities can reduce the visual dominance of cars in cities and contribute to a more people-oriented cityscape.

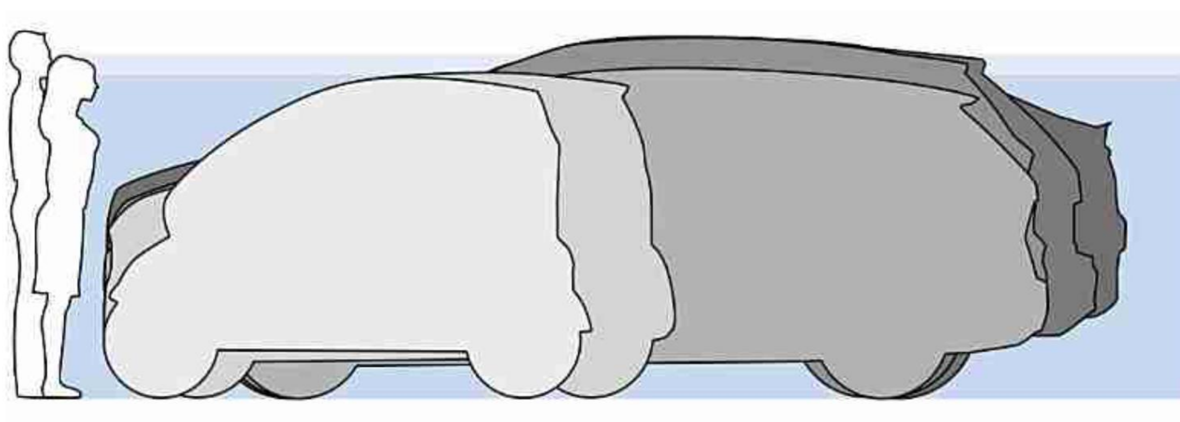


Figure 10: Height of different vehicle types depending on the eye level of women and men (50th percentile) [27, p. 11]

3.2.8 Advantages during usage

The characteristics of LEVs also give their users some advantages during use. For example, the small size and electric powertrain of these vehicles give them greater agility in urban traffic. They can also enter and maneuver in narrow streets more easily than conventional vehicles. This advantage becomes especially important in cities with old city centers where the streets weren't designed for cars. As mentioned in Chapter 3.2.1, it is also easier to find a parking space for these vehicles, as they can fit into spaces that conventional cars cannot.

This allows users to park closer to their destinations and increases the attractiveness of these vehicles in cities with limited parking space.

Another possible advantage of these vehicles is that they can be exempt from bans in restricted zones (depending on local legislation). The electric powertrain of these vehicles exempts them from ICE bans and allows them to enter low emission zones in cities. However, since these vehicles aren't officially considered as cars, there is also a possibility that these vehicles might be allowed to enter some other restricted zones where conventional vehicles (including BEVs) are not allowed.

The different driver's license requirements for some of these vehicles allow them to be driven at a younger age than 18, providing an earlier flexible mobility option for younger people.

3.2.9 Further advantages for the city

The broader the range of mobility solutions, the better the overall transportation system can evolve and adapt to people's needs. Including LEVs in the mobility mix can complement public transport and active transport modes such as walking and cycling, and support intermodal and multimodal mobility by increasing diversification. [29, p. 13].

The reduced space requirements of LEVs can give cities the opportunity to reallocate some of the public space currently used for vehicular traffic and parking. When these vehicles make up a significant portion of the vehicles in the city, a portion of public parking spaces can be planned according to the size of these vehicles, allowing cities to repurpose these freed-up spaces. Figure 11 shows the potential amount of space that can be freed up by adapting parking for conventional vehicles to LEVs in different configurations. One possible use of this reallocation could be to create more infrastructure for more active modes, such as more bike lanes, and to increase the attractiveness of these modes in the city. This may help more people to switch to these modes and further increase the environmental benefits as a secondary effect. If these vehicles become widely adopted, the increased amount of public space that is reclaimed can allow for more people-oriented urban planning and, together with improved multimodal transportation systems, new neighborhood structures may be possible. [10, p. 12].

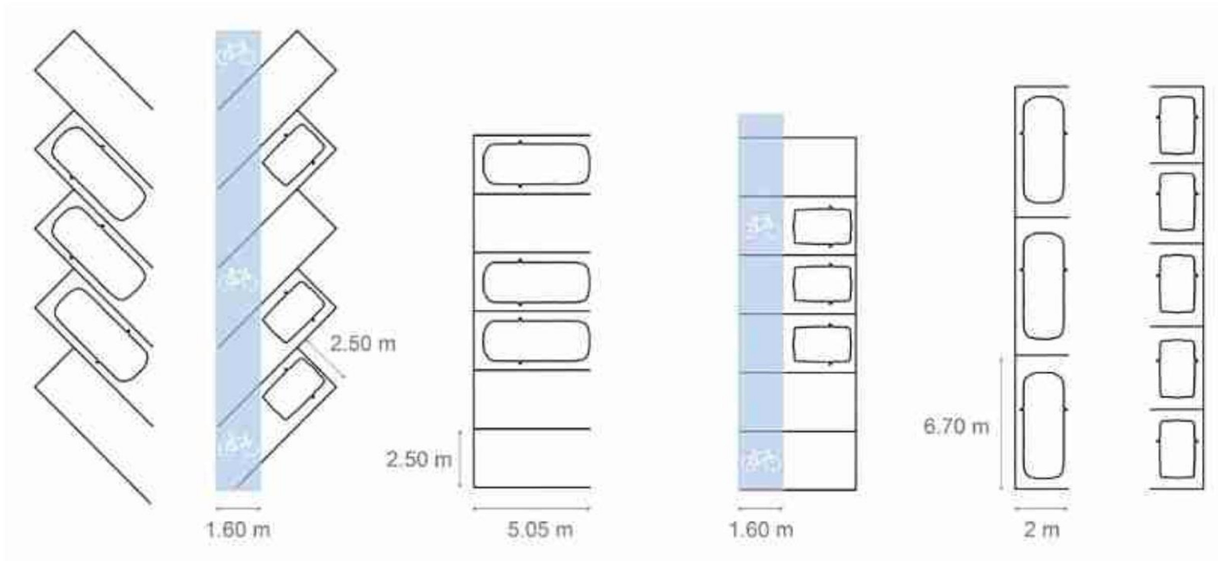


Figure 11: Possibility to reduce space allocated to parking by rededicating parking bays to smaller vehicles (The arrangement of the lanes for cyclists is only intended to illustrate that space for active modes can be allocated here and serve as a suggestion) [27, p. 10]

LEVs also pose less risk to vulnerable road users than conventional cars. Although this issue depends on many other factors, such as vehicle design and crash structures, etc., their light weight and limited top speed mean that they carry less kinetic energy than conventional cars and produce less crash impact than a heavier vehicle of similar design at the same speed.

LEVs can reduce the impact of increased electric vehicle adoption on the electric grid. This is due to the smaller battery sizes, lower energy consumption, and lower peak loads of these vehicles compared to conventional BEVs [30, p. 123].

Adopting LEVs can also help reduce urban heat islands and de-seal hard surfaces for stormwater infiltration. Parking lots, such as those made of concrete, have a high heat capacity and don't allow rainwater to infiltrate. Converting these spaces to green spaces can help cities with both of these issues. In addition, LEVs have lower heat emissions than conventional ICE vehicles due to their electric powertrains. In this way, LEVs further contribute to the reduction of heat islands. [27, pp. 10-11].

3.2.10 Advantages over smaller vehicles

Some of the selected advantages of LEVs compared to smaller vehicles are as follows:

Self-balancing: Two-wheeled vehicles such as bicycles and motorcycles require the rider to balance the vehicle while riding, which must be learned. 3-wheel and 4-wheel LEVs don't share this characteristic. This makes them accessible to more users.

More safety: Especially in the L6e and L7e categories, most LEVs have an enclosed cabin for the driver, which provides additional safety compared to vehicles such as bicycles, motorcycles, and scooters where the rider is in the open. Most LEVs also have seat belts (although this is not a requirement for approval).

Weather protection: Many LEVs in the L6e and L7e categories offer partial or full weather protection.

Speed and range: LEVs typically have higher top speeds and ranges than pedelecs and e-scooters. As a result, they can make longer one-way trips and cover distances faster. (Some s-pedelecs and e-bikes can also reach the top speeds of the L2e and L6e LEVs, up to 45 km/h. Motorcycles are generally faster and can offer longer ranges than LEVs).

Transport capacity for goods: LEVs offer more space for carrying goods than 2-wheeled vehicles. They also don't have the balance problem that limits how goods can be carried on 2-wheeled vehicles.

More comfort: Most LEVs offer a full seat for drivers and passengers, while e-scooter riders must stand, and bicycles offer only a saddle. As mentioned above, most LEVs also offer partial or full weather protection and don't require balancing to ride. In addition, riding a vehicle with an enclosed passenger cabin may allow passengers to feel more comfortable while sharing the same lanes with larger vehicles.

Theft: Unlike bicycles, pedelecs, and e-scooters, most LEVs have a vehicle weight that cannot be carried by a single person without outside assistance. As a result, they don't need to be locked in place like bicycles and are harder to steal.

3.3 Disadvantages

While some of the disadvantages of LEVs are a direct or indirect result of their definitional characteristics, others are caused by the lack of regulations favoring LEVs, the lack of infrastructure, or the current state of the LEV market. These disadvantages are described in the following chapters.

3.3.1 Safety

The safety of LEVs is generally inferior to that of conventional passenger vehicles for a number of reasons. The first is a direct result of the weight of these vehicles. In vehicle-to-vehicle crashes, the risk of injury and death is higher for the lighter vehicle due to the physical laws of mass and inertia [46, p. 614]. In today's traffic, most vehicles on the road (which share the same lanes with LEVs) are significantly heavier than the LEVs. As long as the majority of traffic consists of heavier vehicles, LEVs will be at a disadvantage in terms of occupant safety.

The second reason is design. To achieve their small size and weight, most LEVs have a short overhang. This, however, limits the crush structures and the total amount of material that can absorb the energy of a crash. Therefore, LEVs are at a disadvantage compared to conventional vehicles in terms of how their crush structures can be designed.

The third reason is a combination of regulations, cost and vehicle weight. Unlike conventional passenger cars, there are no regulations (at least in the EU) that require LEVs to be crash-tested. Also, while there are some minimum standards to be met, many safety features are optional in LEVs that are otherwise mandatory in conventional passenger cars [9]. This means that manufacturers may choose not to include some safety features in order to reduce the cost or weight of the vehicle. As a result, the active and passive safety features included in LEVs vary by vehicle manufacturer/model, and the minimum standard is lower than for conventional vehicles.

3.3.2 Range and charging

In the Fraunhofer user survey, 29,8% of respondents who don’t want to use LEVs cited range as one of their reasons [47, pp. 29-30].

Typically, LEVs have a range of 40-230 km, depending on the category, model, and battery size. However, these ranges can vary depending on driving style, topography, and climate. Driving style can have both a positive and negative impact on range. Topographies with large changes in elevation increase energy consumption, and high and low temperatures decrease the effective capacity of the batteries, resulting in shorter ranges.

Considering that most LEVs aren't suitable for freeways, and therefore their main use case is not long-distance travel, these ranges are sufficient to cover most LEV trips. In the aforementioned Fraunhofer study, when the same participants were asked about their daily trips, the results showed that about 90% of these people's trips were less than 50 km. Thus, LEVs can indeed cover these trips without range problems. This leads to the conclusion that better informing users about the range of LEVs can reduce some of the resistance to these vehicles [47, p. 30]. However, it must also be taken into account that it is neither possible nor desirable for users to recharge their vehicles after every trip.

As with BEVs, charging infrastructure plays an important role in the successful deployment of LEVs. In both the DLR studies and the ELVITEN project, users and expert interviews indicated that they consider sufficient charging infrastructure to be an important issue for the advancement of LEVs [48, p. 6, 49, p. 296]. According to the ICCT report, most areas in Germany have less than 20% of the charging capacity they will need by 2025, and only about 5 to 10% of what will be needed by 2030 [50, p. i]. However, given the importance of this issue for the transition to BEVs, it can be expected that there will be a gradual improvement in the situation over the next few years. There are already plans in place in Germany, such as the expansion of the charging infrastructure network to 1 million publicly accessible charging points by 2030 [50, p. i].

Typically, LEVs are equipped with onboard charging systems and can be connected to a power source without the need for an additional charger. Most LEVs use single-phase charging (max 3,7 kW via household outlets or 7,2 kW via dedicated chargers). Three-phase charging (max 11 kW or 22 kW, depending on the type of charger) and DC charging (high-voltage charging at supporting charging stations from 50 kW to 350 kW), which allow faster charging speeds and are typically found in modern BEVs, are often not implemented in LEVs due to higher costs. The smaller power consumption and battery sizes compared to conventional BEVs make single-phase charging plausible in LEVs, but it is still slower in comparison (Table 14). This lack of quick charging can be a barrier for people who can't charge their vehicles regularly and want to take advantage of short stops along their routes to charge their vehicles. On the other hand, the ability to use household outlets for charging in still reasonable times is an advantage for LEVs over conventional BEVs, which require significantly longer times to charge from household outlets and therefore require the installation of a wallbox for plausible charging times at home.

Table 14: Charging times of different vehicle models with different charging types [45]

Modell	**Battery**	**Charging type**	**Time**
Opel Rocks-e	5,5 kWh	AC single phase 2,3kW (household socket) 100%	210 minutes
Renault Twizy 45	6,1 kWh	AC single phase 2,3kW (household socket) 100%	210 minutes
Microlino (medium battery)	10,5 kWh	AC single phase 2,6kW (household socket) 100%	180 minutes
smart EQ fortwo	17,6 kWh	AC single phase 2,3kW (household socket) 100%	420 minutes
		AC single phase 3,7 kW (wallbox/ charging station) 100%	360 minutes
		AC three phase 22 kW (wallbox/ charging station) 100%	60 minutes
Volkswagen ID.3	45 kWh	AC single phase 7,2 kW (wallbox/ charging station) 100%	450 minutes
		DC charging station 50 kW 80%	41 minutes
		DC charging station 100 kW 80%	31 minutes

3.3.3 Maximum speed

As mentioned in Chapter 2, the regulations allow a maximum speed of 45 km/h for vehicles classified in categories L2e and L6e. This limits the roads on which these vehicles can be operated. Having a lower maximum speed than the allowed speed limit of a road can disrupt the flow of traffic and also make the driver of the said vehicle feel uncomfortable. The latter is particularly noticeable to the driver and passengers of LEVs, as these vehicles are relatively smaller than other faster vehicles on the road. The limited safety of these vehicles can also contribute to this sense of unease. As a result, L2e and L6e LEVs are not well suited for non-urban roads with speed limits above 50 km/h. They are better suited for urban use. However, the 50 km/h speed limit on main roads is still slightly higher than their top speed and can also cause some discomfort. These vehicles are also not allowed on highways, as these roads require a minimum speed of over 60 km/h in most countries.

L5e and L7e vehicles are less disadvantaged in this regard, as they have a maximum speed limit of 90 km/h or no limit at all, depending on the category.

3.3.4 Flexibility for additional passengers and transport of goods

One advantage of passenger cars for individual mobility is the flexibility they offer. Even if they are not needed regularly, extra passenger seats and luggage space allow users to use their vehicles for irregular occasions when the need arises. These vehicles are suitable for most conventional road types. This allows users to consider their vehicles as a solution for a variety of situations. It can bring a feeling of ease as it allows them to be prepared for simultaneous needs and have a vehicle that is familiar to them in different situations. With their limited number of passenger seats, limited space for transporting goods, and not being suitable for all road types, LEVs don't offer the same flexibility as a conventional vehicle for different needs.

3.3.5 Comfort

Due to their price point and the goal of being as light as possible, most typical LEVs have fewer driver assistance systems and features than conventional vehicles. For the same reasons, they also integrate simpler steering, axle, and suspension systems. Some LEVs have only partial or no weather protection. On the other hand, LEVs with enclosed passenger cabins typically have limited interior space due to the size of the vehicle. As a result, the ride quality and overall comfort of a typical LEV can be expected to be inferior to that of a typical conventional vehicle.

Driving a small vehicle on a road with larger vehicles can also negatively affect the comfort of the driver and passengers. When road traffic is dominated by larger vehicles, the limited safety of these vehicles compared to conventional cars can create a further sense of discomfort when traveling at higher speeds on rural roads or highways (for L5e and L7e vehicles) next to larger and heavier vehicles.

3.3.6 Infrastructure and regulations

To date, there aren't many regulations specifically designed to support LEVs. The lack of such regulations detracts from some of the benefits of these vehicles. For example, as mentioned in Chapter 3.2.6, in the absence of specific regulations for LEVs, these vehicles pay the same price for parking even though they take up significantly less space. This reduces the parking benefit of LEVs for users. The issue of subsidies puts LEVs at a disadvantage compared to conventional BEVs. As of today, BEVs in Germany are eligible for a subsidy of up to €9000 at the time of purchase (€6000 from the government and €3000 from the manufacturer) [51]. However, there is no similar subsidy for LEVs at the national level (In some regions of Germany, there are subsidies for purchasing an LEV, but these are much lower and often limited to specific groups of purchasers, such as businesses or municipalities). This difference closes the price gap between conventional BEVs and LEVs and puts LEVs at a disadvantage. The lack of this subsidy for LEVs also creates a subjective disadvantage for these vehicles, as potential buyers may question why an LEV doesn't get a subsidy while a conventional BEV does. This question can make buyers uncertain about their knowledge of the differences between LEVs and conventional vehicles, leading to a purchase decision in favor of a conventional vehicle as the more familiar option. [52].

The literature reviewed also indicate that current regulations are mostly designed for conventional vehicles. They state that, in order to encourage the development of LEVs, regulations are needed that favor LEVs. Some suggestions are to allow the use of special lanes such as bus lanes to give some time advantage to these vehicles and to reduce the overall speed limit in cities to 30 km/h to increase the safety and comfort for these vehicles [27].

3.3.7 Available models

To date, LEVs represent a very small share of all vehicles on the road. In 2019, only 2816 four-wheeled light electric vehicles were sold in Europe [1]. Due to the small volume of this market, there aren't many companies developing vehicles for this segment. Of the major car manufacturers, only Renault, Citroen and Opel currently have models on sale, and most of the other available vehicles are from small and medium sized companies. The small number of available models makes it harder for customers to find a model that fits their personal preferences and needs compared to conventional cars.

3.4 Use-cases

The researched literature suggest the following possible use cases for LEVs:

- Commuting
- Shopping
- First-/last-mile
- Free-time activities
- Tourism
- Company- and campus fleets
- Conditional use cases (such as use in car-restricted areas or cities with narrow streets)

In the Fraunhofer user survey, shopping (and daily chores) was the most frequently cited potential use case for LEVs (81,9% of 925 respondents) by the participants who said they could see themselves using an LEV (925 of 2000 respondents). This was followed by leisure activities (75,4%) and commuting (57%), while first/last mile vehicle and "on vacation" were cited by less than half of the respondents (47,2% and 34,8% respectively) (Figure 12) [47, p. 35].

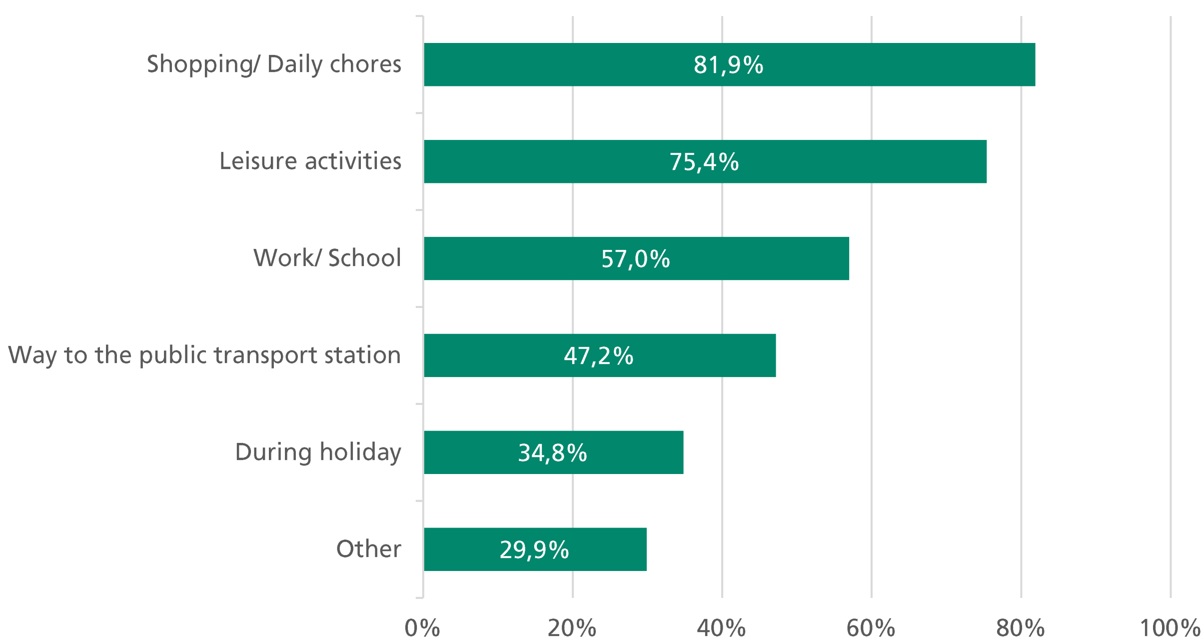


Figure 12: Potential use cases for the users [47, p. 35]

In the user survey of the ELVITEN project, respondents were asked about their willingness to use 3- or 4-wheeled LEVs (together with the willingness to use 2-wheeled light electric vehicles and bicycles) for the trip purposes of work or education trips, shopping trips, and leisure trips. The detailed results of this survey can be found in [53, pp. 71-73] for each of these use cases and cities separately (the results are not shown here due to the large number of graphs).

While not directly comparable, both surveys yield similar results, with 27-39% of total respondents seeing themselves as potentially using LEVs for the use cases mentioned.

In order to keep the size of the study within limits, three use cases were selected for further analysis in this study. The shopping use case was chosen because it received the highest ranking in both surveys. Commuting is the second selected use case due to its high share in daily mobility and its regularity. The use case "first/last mile vehicle" was selected as the third use case because of its specific importance for the envisaged intermodal mobility solutions.

4 Analysis of LEV potentials for specified use cases

This chapter presents an analysis that aims to provide a better understanding of the user's perspective on LEVs and the role of these vehicles in the mix of possible mobility options. Chapter 4.1 describes the methodology used and the rationale behind this choice. Chapter 4.2 introduces the personas used in this analysis and explains how they were created. The alternative mobility options that are compared to LEVs and their selection are described in Chapter 4.3. Chapter 4.4 presents the results of the analysis for each use case individually. Chapter 4.5 presents the results of the expert interviews conducted in parallel with this study and compares them with the results of Chapter 4.4.

4.1 Methodology

For the LEVs to be accepted by users and gain traction, these vehicles need to meet their needs and expectations. As mentioned in Chapter 3, studies in the form of surveys have been carried out to gain an understanding of the acceptance and preferences of the users. The Fraunhofer study with 2024 participants [47, p. 16] and the ELVITEN project with 6988 participants from various countries [54] provide a well-acceptable knowledge base in this regard. However, user surveys as a method have some limitations and disadvantages, such as:

- Depending on the question (for example leading questions) or the environment, the answers can be distorted (also unconsciously), which means that the results may be inconclusive.
- There is often a discrepancy between the answers and the actual behavior of the participants, because there is a tendency to go along with certain positive expectations. [55]

In order to gain a better understanding of how well LEVs can meet the needs and expectations of users, a different approach was taken. The methodology, which is a modified version of the methodology proposed in [56, pp. 84-85] for a similar goal in a different topic, focuses on the analysis of daily use cases of LEVs and is presented in the following Figure 13:

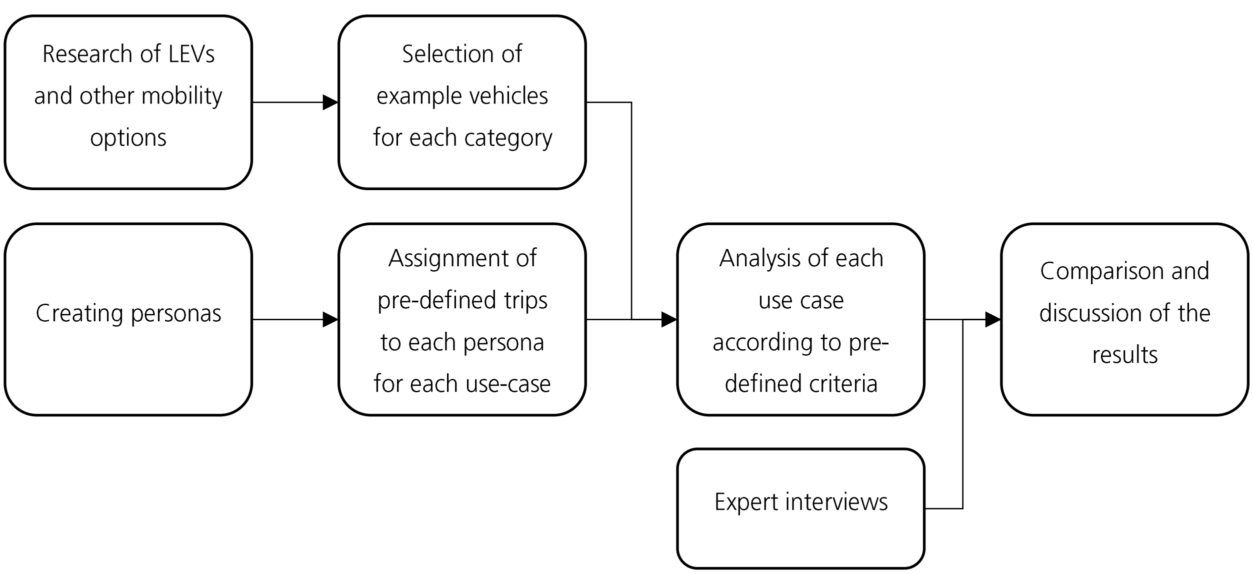


Figure 13: Steps of the proposed methodology

In this approach, the first step is the creation of personas [57, 58] for selected user groups. A certain number of trips are assigned to these personas. These trips include defined start and end points, a trip purpose, and some other details such as items to be carried or time of day. In parallel, information about LEVs and other possible mobility options are collected. For each category, a sample vehicle is selected and its specifications noted. Then, each trip for each persona is analyzed for each vehicle type according to pre-specified criteria, and key findings are commented and explained. In another parallel, expert interviews are conducted on the topic of user acceptance, needs and expectations. The results of these interviews are then compared with the results of the analysis and the findings are discussed.

The main goal of this approach is to analyze the use of LEVs from the perspective of the users, rather than treating it as an isolated topic. Typically, in the course of their daily lives, people do not directly face the question of whether or not they want to have an LEV. Instead, they have mobility needs and are looking for solutions that best meet those needs and desires, given their conditions and constraints. For them, LEVs are just one possible option among many other mobility solutions. This study aims to recognize this perspective and analyze LEVs accordingly.

The use of personas allows for the analysis of the topic with limited resources and time. This was particularly relevant for this study due to the limitations of the COVID-19 pandemic during the preparation of this study. In addition, personas allow the situations to be considered closer and on a more personal level, which can help to elicit more specific and precise details compared to generalized statements derived from more abstract criteria. This aspect is further strengthened by the use of specific travel examples in this methodology.

A disadvantage of using personas is their subjectivity. To compensate for this, expert interviews were included in this analysis. While not a direct way to verify the results of the persona analysis, these interviews provide a second source of information, allow for comparison of results, and provide a basis for discussion of the results. A more direct verification of these results can be done through targeted user surveys, interviews, or real-world testing in further studies.

4.2 Personas

To create the personas, first, a set of attribute categories were defined to provide a structure on which to base these personas. These categories and their classifications are a modified version of the categories mentioned in [56] and are shown in the Table 15 below. The spatial typology category is classified according to RegioStar7 [59, p. 8]. The classification of the economic status is taken from [60, p. 21].

Table 15: Attribute categories for the personas

Age	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80+
Gender	Male	Female							
Spatial typology	Metropole	Regiopole/ Big city	Middle-sized city/ Urban area of an urban region	Small city/ Village of an urban region	Central city of a rural region	Middle-sized city/ Urban area of a rural region	Small city/ Village of a rural region		
Economic status	Very low	Low	Middle	High	Very high				
Education level	Primary education	Secondary education	High school	University					

The number of personas was limited to three in order to keep the size of the study manageable. The persona attributes were assigned with the following two goals in mind:

- If possible, to cover a wide range of classifications
- Consistency between the attributes and a realistic profile

In addition, the selection of attributes was focused on user categories that showed a more positive attitude towards the use of LEVs in the Fraunhofer Institute's user survey [47, pp. 26-27]. Using personas that represent the more reluctant user groups could be a valid strategy for identifying and highlighting the shortcomings of LEVs. However, the very low number of LEVs on European roads compared to the relatively high acceptance rate of the survey participants led to the decision to focus on the user groups that show a higher acceptance of these vehicles in order to better understand this situation.

Since the user groups between the ages of 18 and 25 and over the age of 56 showed a lower level of acceptance for LEVs compared to the other age groups in the Fraunhofer study, the personas in this study were selected between the ages of 26 and 56. Similarly, the spatial typologies with populations under 5000 were not assigned to the personas. The resulting attribute table for the three personas is shown in Table 16 below. It should be noted that the assignment of these attributes has been done in a deliberately random way, while paying attention to the criteria mentioned above, so that they can represent possible types of real people. Other combinations of attributes would be equally valid.

Table 16: Chosen attributes for the personas

Age	0-9	10-19	⬟ 20-29	■ 30-39	40-49	● 50-59	60-69	70-79	80+
Gender	⬟ Male	■ ● Female							
Spatial typology	■ Metropole	⬟ Regiopole/ Big city	Middle-sized city/ Urban area of an urban region	● Small city/ Village of an urban region	Central city of a rural region	Middle-sized city/ Urban area of a rural region	Small city/ Village of a rural region		
Economic status	Very low	⬟ Low	■ Middle	High	● Very high				
Education level	Primary education	Secondary education	■ High school	⬟ ● University					

Persona 1 ⬟ Persona 2 ■ Persona 3 ●

The next step after selecting persona attributes was to detail the personas by selecting a representative image, basic information, and descriptive text. Basic information includes the persona's age, location, income level, and education level. The goal behind using a picture and descriptive text is to help personalize the profile and visualize the persona as a real person in the given scenarios. The descriptive texts consist of three parts: A general information text, a description of the planned example trips, and a further characteristics part. The general information text describes the persona's background and talks about some of their motivations. The text about the trips gives some details about the planned trips for the later analysis. The further characteristics part contains information that is not part of the first general information text, but may still be relevant to visualize the persona as a real person or to better understand his/her needs in the given situation. Some of the information included here is the persona's hobbies, time management characteristics, fitness level, and relationship with technology.

The three created personas are shown below.

Figure 14: Max Neuer [61]

MAX NEUER

AGE: 26

RESIDANCE: Karlsruhe

ECONOMIC STATUS: low

EDUCATION LEVEL: university degree

Max moved to Karlsruhe from Saxony a few days ago for his master's degree and is getting to know the city. He left his hometown to specialize in a field related to the environment. This is a topic that is very close to his heart, and he wants to contribute his part to it. His father is a climate scientist, so growing up, Max was especially informed and involved in the subject. To get to know new people at the university, he has signed up for some sports classes that take place on campus in the evenings after classes. He is not an early riser, introverted and prefers a quiet atmosphere on his way to lectures. In his free time, he likes to travel and explore new cities.

TRIPS

Although he arrived in Karlsruhe only a few days ago, Max's semester has already started. His classes start at 8 a.m. most days of the week. Twice a week he carries an extra bag for the swimming class in the evening. Max usually goes grocery shopping once a week, but sometimes he needs to make an impromptu trip to the store when he forgets something or when his recipes require an unplanned ingredient. This weekend, Max is going on a multi-day trip to Milan and has planned to take a small luggage with him.

FURTHER CHARACTERISTICS

- He is interested in photography, movies and sustainable fashion.
- He prefers advance planning to spontaneity, but is not always punctual and has to live with the consequences.
- He has an above average level of fitness.
- He owns a smartphone and is tech-savvy.

Figure 15: Anne Schäfer [62]

ANNE SCHÄFER

AGE: 39

RESIDANCE: Stuttgart

ECONOMIC STATUS: middle

EDUCATION LEVEL: high-school degree

Anne works part-time as a secretary for an engineering firm. With her two children now at an age where they both attend school, she has more time to pursue her own needs. During this time, she has taken up yoga and started a healthy eating blog. These interests awakened her environmental awareness, which led Anne to adjust her habits accordingly. She is a native of Stuttgart, and currently lives in an apartment building with her husband and children.

TRIPS

Most days, Anne leaves early for work and returns around noon. She carries only a backpack on these trips. Because she needs to shop for a family of four, she goes grocery shopping several times a week. All members of the family drink bottled water, so water bottles regularly make up a significant portion of her groceries. This week, she is visiting a friend after work for a small celebration and brings a large cake that she made herself.

FURTHER CHARACTERISTICS

- She is interested in yoga and blogging.
- As a mother of two active children, flexible and short-term planning is a necessity for her. She also tends to be impatient and does not like long waits.
- Her fitness level is average.
- She owns a smartphone and uses it occasionally.

Figure 16: Vivienne Gallant [63]

VIVIENNE GALLANT

AGE: 55

RESIDANCE: Bad Herrenalb

ECONOMIC STATUS: very high

EDUCATION LEVEL: university degree

Vivienne is a manager in an energy company, and a few months ago she was given the task of leading the implementation of two new sustainability projects for her company. She lives in a single-family home surrounded by nature in the northern Black Forest and has been driving a large sedan most of the time. In her new position, she wants to set an example for others and has decided to use more sustainable means of transportation from now on when possible.

TRIPS

She drives to work three times a week and works from home the rest of the time. When she does, she carries a light bag with her work laptop and a few documents. Since her children have moved out, she only cooks for two at home, but she enjoys trying new recipes with fresh ingredients, so she goes shopping several times a week. She also stops at the farmer's market and the bakery on some of her shopping trips. This weekend, she is planning a brunch with her college friends and hopes to meet them in Ettlingen.

FURTHER CHARACTERISTICS

- She is interested in literature and Japanese culture.
- She likes to have a routine, plans ahead, and pays attention to detail.
- She used to exercise occasionally to keep fit, but her stamina is slowly declining.
- She owns a smartphone and is technologically savvy.

4.3 Vehicle examples for comparison

For the vehicles, the first step was to identify which mobility options represent an alternative to LEVs in the given use cases. This was followed by researching the available vehicles in these categories. As a result, a vehicle example was selected for each category to be used in the analysis.

Electric (kick) scooters, bicycles, pedelecs, M1 class vehicles and public transport were identified as the most viable mobility alternatives to LEVs for this comparison. Important criteria for this selection were (among others): Meeting the trip purpose, providing sufficient range for the given use cases, and being commonly used and recognized mobility options for ordinary people. For example, velomobiles were not included because they are rare on the roads and are not considered a standard mobility option for many people. Motorcycles were also excluded from this comparison because they have different riding characteristics, require different types of licenses, and are not considered suitable by everyone due to safety concerns. Cargo bikes were not included because they would only be suitable for the shopping use case and not the other two.

The main goal of the selection of example vehicles is to represent each category with a vehicle that exhibits its general characteristics. Due to the very different characteristics of the selected mobility options and the differences in data availability, a common set of selection criteria for all example vehicles wasn't feasible. Therefore, each category was examined individually. However, the selection criteria were still based on the main objective mentioned above.

For e-scooters, the best-selling model on Amazon Germany [64] was selected, which is the Xiaomi Mi Electric Scooter 1S as of June 2022. For bicycles and pedelecs, the Giant brand was selected as one of the top-selling bicycle brands worldwide, and from its product portfolio, Giant Tourer GTS and Giant Entour E+0 were selected as representative bicycles and pedelecs, respectively, for their categories.

For the L2e category of LEVs, the Toyota iRoad was selected as the only vehicle from a major OEM currently on the market in this category. The lack of publicly available technical details of the Roo also contributed to this decision. For the L5e category, the Twike 5 was the only currently available example, although it is also currently in prototype status. For the L6e category, Renault Twizy was selected as the model that significantly boosted the number of LEV sales in the year of its introduction (2012) and accounted for a large share of LEV sales in its category in the following years [10, p. 30]. For the L7e category, the Microlino was chosen as the example vehicle because it is a new model scheduled for launch in 2022 and represents the current available standards of its category, while still being in a similar price range to other examples in this category.

For the M1 vehicles, one battery electric vehicle (BEV) and one internal combustion engine (ICE) vehicle were selected from each of the A- and C-Class vehicles. Class A vehicles were selected because they are the smallest vehicles in the M1 category, and therefore the closest to LEVs in terms of size and function. C-Class vehicles were chosen because they represent the more common vehicle type on the road [65], but are still not as large as the SUVs and therefore not too far away from the LEVs in comparison. The ICE vehicles were included in this comparison to demonstrate the resulting differences between the LEV electric powertrains and the ICE vehicles.

The Smart fortwo EQ was chosen as the example electric vehicle for the M1 category of the A-Class because of its significantly compact size, which comes close to the dimensions of LEVs, especially in terms of length. The fact that there is also an ICE version of this vehicle, which was on sale until 2019, also made the choice of this vehicle appealing, as the differences between these vehicles in the comparison can be limited to their different powertrains. For the ICE C-Class, the Volkswagen Golf was selected as the example vehicle because it is the best-selling model in Germany in 2022 [65] and therefore represents the most common vehicle. For the C-Class electric, the Volkswagen ID3 was chosen as the example vehicle because it is the most sold electric vehicle in the C-Class in Germany in 2022 [65].

After the example vehicles were selected, the following information about the vehicles were collected:

- Energy consumption
- Dimensions
- Maximum speed
- Range
- Trunk volume
- Weather protection
- Air conditioning
- Heating
- Price (if available)

The energy consumption information was collected to calculate the energy cost and resulting CO_2 equivalent emissions of the example trips made with these vehicles. The dimensions were used to estimate how easily these vehicles can be parked and how easily they can navigate through narrow urban spaces and traffic. Maximum design speed was relevant for calculating the estimated duration of trips and on which roads these vehicles can be used. Range information was important to assess whether a given trip can be made with the vehicle without recharging breaks and whether it can be part of a multi-destination chain trip. The availability of weather protection, air conditioning and heating were relevant for subjective passenger comfort during the trip in different weather conditions.

It should be noted that while the energy consumption of conventional passenger cars is measured using a standardized test cycle (WLTP [66]), there is no similar standardized formal test cycle for micromobiles and LEVs. If a WLTP energy consumption value was not specified for a vehicle, this value was calculated by dividing the range specified for the vehicle by the net battery capacity. This is only a rough estimate, but should still be enough to give an accurate picture, as the main goal here is to assess how these vehicles compare.

The information collected on the example vehicles are brought together in the Table 17 below.

Table 17: Technical specifications of example vehicles for comparison

Modell	Xiaomi Mi Electric Scooter 1S	Giant Tourer GTS	Giant Entour E+0	Toyota iRoad	Twike 5	Renault Twizy 45	Microlino 2.0	Smart fortwo (2019)	Smart EQ fortwo	Volkswagen Golf	Volkswagen ID.3
Category	E-Scooter	Bike	Pedelec	L2e	L5e	L6e	L7e	M1 Class A (ICE)	M1 Class A (BEV)	M1 Class C (ICE)	M1 Class C (BEV)
Energy consumption [l/100km or kWh/100km]	0,9 kWh/100km (calculated value)	-	0,4 kWh/100km (calculated value)	11 kWh/100km (calculated value)	7,2 kWh/100km (WLTP)	5,8 kWh/100km (WLTP)	7,8 kWh/100km (WLTP)	6,2l/100km (WLTP)	17,4 kWh/100km (WLTP)	5,3l/100km (WLTP)	14,9 kWh/100km (WLTP)
Dimensions [w/l/h in mm]	430/ 1080/ 1140	Not specified	670/ ca. 1850/ ca. 1000	870/ 2345/ 1455	1552/ 3327/ 1235	1237/ 2335/ 1454	1473/ 2519/ 1501	1663/ 2695/ 1555	1663/ 2695/ 1555	1789/ 4284/ 1491	1809/ 4261/ 1568
Maximum design speed [km/h]	20	-	25	45	130/190	45	90	151	130	188	160
Range [km]	30	-	125	50	250-500	100	91/177/230	452	133	849	351
Trunk volume [l]	-	- (optional basket, ca. 13l [67])	- (optional basket, ca. 13l [67])	Not specified (back seat with cargo net)	300-600	39 (+ back seat space)	230	260-350	260/350	381-1237	385-1267
Weather protection	no	no	no	yes	yes	partial	yes	yes	yes	yes	yes
Air conditioning	no	no	no	no	no	no	no	yes	yes	yes	yes
Heating	no	no	no	yes	yes	no	yes	yes	yes	yes	yes
Price [€]	449	749	2.549	Not yet on sale	from 39.990	from 11.450	from 14990	from 11.165	from 21.940	from 29.560	from 31.495
Further details to mention	Can be folded			Can tilt with active lean technology Steering via rear wheel	Unique steering system Driver can supplemen-tarily power the vehicle by pedaling	No doors as standard, partial doors are optional	Door on the front side	Not available since 2019			€6000 + €3000 environment bonus available
Data source	[68]	[69]	[70]	[15, 16]	[20, 71, 72]	[21, 22, 73]	[24, 31, 74]	[75, 76]	[32, 77]	[35, 78]	[79, 80]

4.4 Analysis of the use cases

As mentioned in Chapter 4.1, after creating the personas and selecting the example vehicles, the selected use cases were analyzed for each persona with the selected mobility options. The focus of this analysis was the user's perspective, meaning: This analysis examined the parameters and factors that a user would pay attention to and that would affect the user's experience while using the given vehicle for the given use case. The goal of this focus was to show if and how LEVs are different from existing mobility options in the eyes of the users, and if they are a viable alternative in the given use cases.

As part of this analysis, each persona was assigned a specific start and end address for their trips. The selection of these addresses was done on a random basis, but attention was still paid to the plausibility of the selected addresses. For example, when assigning home addresses to the personas, it was important that the selected addresses were in residential areas. The work addresses for the commute trips were also randomly selected, but the selection was limited to places that fit the descriptions given in the persona profiles. For the shopping trips, the closest relevant supermarkets/shops to the home addresses were selected. The aim of this random sampling approach was to test the viability of the analyzed mobility options in each situation, while remaining as close to reality as possible within the given limitations of the study.

The assignment of specific addresses to the respective trips allowed the quantification of the specific details of these trips. In this analysis, trip duration, energy consumption, energy costs, and the resulting CO_2 emissions were calculated as quantifiable parameters of the trips. Trip duration and energy costs were included because they are directly relevant to the user. They can be considered as the price the user pays for this trip in terms of time and money. Therefore, they have a significant impact on the choice of mobility option for a given use case. Energy consumption and the resulting CO_2 emissions were included because they can also be deciding criteria for environmentally sensitive users. This information can also be important to assess the impact of a trip with a given vehicle for further studies.

For the time estimations and the optimal routes, Google Maps© was used. Google Maps© was chosen because it is a fast and free way to make these estimates, taking into account the real time traffic situation, without the need for simulation or paid software. Furthermore, it is a navigation tool that is widely used by people in their daily lives for estimation of their upcoming travel time and navigation. Therefore, it was appropriate for the analysis here in this context. Google Maps© allows a direct estimation for a trip by car, bicycle or public transport. For the estimation of e-scooters, pedelecs and LEVs, some correction factors were implemented. According to [81], the average speed of a pedelec-rider is 2 km/h faster than that of a cyclist, while the average speed of a cyclist is about 16 km/h. The average speed of e-scooters is similar to that of bicycles [82, p. 4]. Based on these information, the estimated times for the e-scooter trips were set to the same values as for the bicycle trips, and the times for the pedelec trips were corrected by the factor of 0,89. For the L2e and L6e vehicles, the estimates were based on a car trip. However, the parts of their roads where the speed limit is higher than 50 km/h were examined separately and corrected to the maximum speed of 45 km/h. Since L5e and L7e vehicles have relatively comparable speeds to M1 vehicles, they were given the same estimates as M1 vehicles.

The energy consumption was calculated from the length of the trips, again taken from Google Maps©, and the average consumption of the vehicles. The energy costs were calculated from the energy consumption and the average prices of fuel (1,405 EUR/l [83]) and electricity (0,304 EUR/kWh [84]) in year 2019. In order not to take into account the extraordinary effects of the Corona pandemic and the Russian invasion of Ukraine on prices, the average prices were taken from the year 2019. The CO_2-equivalent emissions were calculated from the energy consumption and either the constant of 2,370 kgCO_2/l for ICE vehicles [85] or the average emitted CO_2-emissions per kWh of electricity in Germany in the year 2019 for electric vehicles, which was 0,473 kgCO_2/kWh [86] (the reason for choosing 2019 was the same as for the prices). The CO_2-emissions of public transport trips were taken from the KVV.regiomove app [87].

In addition to the quantitative details, qualitative factors were also examined. Factors related to driving, comfort, functionality and safety were identified as qualitative factors important for the users during their trip with the given vehicles. Driving characteristics of the vehicle, ease of driving the vehicle through traffic and its agility, navigation during driving and parking are the factors considered under the topic of driving. Weather protection and temperature inside the vehicle, ergonomics, ride quality, interior size, noise, comfort in traffic and entertainment are considered under ride comfort. Functionality refers to how well the vehicle enables the user to meet the needs of the trip, such as having enough storage space for the items being carried. Charging/refueling is also considered under this factor. Safety includes the conceptual safety of the vehicle type as well as the passive and active safety measures of the vehicles. The focus here is on the safety of the user and not on how safe the vehicle is for other road users. This is because the focus of the analysis is placed on the user's perspective.

In the following chapters, the results of this analysis are presented in tables for each persona. The qualitative factors are presented under the titles positive subjective factors and negative subjective factors. For LEVs, all identified qualitative relevant factors are listed for the given use case and persona. For the other mobility options, their positive and negative subjective points compared to LEVs are identified and listed. The reason for this separation is to focus on where LEVs differ from the other mobility options. The e-scooters, bicycles and pedelecs are compared to the L2e vehicle, while the M1 vehicles and public transport options are compared to the L7e vehicle. The goal here is to identify how these options differ from the closest LEV example to their category. In general, if a factor is not important for the given use case, it's not explicitly listed in the table. For example, if the user doesn't carry anything, a smaller or larger trunk capacity is not listed as a negative or positive factor. These factors are also explained and discussed in the texts that follow the tables.

Among the qualitative factors of the vehicles, some factors apply only to specific use cases or personas, while others apply generally. To make it easier to identify these, they are marked accordingly in the tables. If a factor is generally applicable to this vehicle in the given use case category, it is marked with a solid black square bullet. If a factor is specific to the requirements of a persona in the given example, it is marked with a white circle bullet. In addition, the plausibility of the vehicles for the given use cases is also marked. If the analysis shows that a vehicle is not plausible for a given use case, the category and reason are marked with a red lightning bolt in the table. If there is a factor that doesn't completely rule out a vehicle, but could still cause some users to not consider that vehicle as a viable option, those vehicles and the corresponding reason are marked with an orange exclamation mark. Viable vehicles are marked with a green check mark.

In the descriptive texts, to avoid repetition, points already explained in a previous chapter are not repeated in the following use case chapters, and only their differences are pointed out.

This analysis is done in the form of a thought experiment, meaning: Each persona is imagined as a character going through the trip with the given vehicles, and the predicted experiences of the personas are noted. The results should not be directly related to the general characteristics of the user groups to which the persona belongs, but should be seen as specific to the persona itself.

4.4.1 Use case 1: Commuting

The first use case to be analyzed is commuting. In this study, commuting is considered as the trips between a person's place of residence and his/her place of work, study, or the like, which are made on a regular basis.

In the case of commuting trips, the importance of comfort and inconveniences becomes more apparent, because the user experiences them on a regular basis. This regularity also makes the duration of the trip a very important factor from the user's point of view in the choice of the mobility option. Costs become more important because of the frequent repetition of these trips. A secure availability of the vehicle and a reliable planning of the trip are further important aspects of a commute trip due to the general purpose of these trips.

The three trips analyzed for the personas are as follows:

- Max goes to the university (Karlsruhe/Innenstadt-Ost) to attend a lecture at 8 o'clock in the morning on a weekday. On his way to the lecture, he stops at his newly discovered favorite café for coffee and a small breakfast (Karlsruhe/Innenstadt-West). Because of his swim practice in the evening, he carries a gym bag in addition to his normal bag for the lectures.

- Anne goes to work (Stuttgart/Leinfelden-Echterdingen) on a weekday at 8 o'clock in the morning. She carries a backpack.
- Vivienne goes to work (Ettlingen) on a weekday at about 8:30 in the morning. She carries a laptop bag.

The results of the analysis for the three personas for each mobility option are shown below.

Table 18: Analysis of use cases - Max/Commuting

Vehicle	Public transport ⚠	Bike ✓	E-Scooter ✓	Pedelec ✓
Trip length [km]	Not specified	4,3	4,3	4,3
Trip time [min]	26 min (19 min walk, tram every 7 mins) ⚠	15	15	13
Energy consumption	-	0	0,039	0,017
Energy costs [€]	-	0,00	0,01	0,01
CO_2-equivalent [gCO_2]	323	0	18	8
Positive subjective arguments	▪ no active driving, time can be used for other activities ▪ no parking	▪ can use bike roads ▪ can go through traffic ▪ quick to get on and off ▪ no parking maneuvers ▪ very easy to find a place to park, can be parked directly at the destination ▪ no charging/refueling	▪ can use bike roads ▪ can go through traffic ▪ quick to get on and off ▪ no parking maneuvers ▪ many options for a place to park, can be parked directly at the destination ▪ can be charged at a charging point without the need for a free parking spot	▪ can use bike roads ▪ can go through traffic ▪ quick to get on and off ▪ no parking maneuvers ▪ many options for a place to park, can be parked directly at the destination ▪ rider decides how much help he gets from the electric motor (option for using the ride as a chance for sport) ▪ portable battery can be taken with for charging
Negative subjective arguments	▪ no freedom with timing, trip time need adjustment to the schedule of public transport, extra time need to be planned to catch the tram ▪ exposed to weather conditions before and after taking the tram ▪ shared space with other people ▪ no seating guaranteed ▪ parts of the trip require walking ▪ carrying the bags ▪ potentially louder environment	▪ no motorized ride, rider uses his own energy, resulting tiredness and sweating ▪ fully exposed to weather conditions ▪ fully exposed to the noise of the environment ▪ no safety elements in case of an accident o only limited space for the bags, the rider might need to carry the bags by himself, the bags can cause an imbalance ▪ rider experiences the deformities of the road more directly ▪ less comfortable seating and ergonomics ▪ susceptible to theft (light enough to be carried away by a person unless fixed to a place)	▪ fully exposed to weather conditions ▪ fully exposed to the noise of the environment ▪ no safety elements in case of an accident o no space for the bags, so the bags should be carried by the rider and can cause imbalance by riding ▪ rider experiences the deformities of the road very directly ▪ not very comfortable to ride, no seating, the rider stands up the whole ride ▪ susceptible to theft (light enough to be carried away by a person unless fixed to a place)	▪ fully exposed to weather conditions ▪ fully exposed to the noise of the environment ▪ no safety elements in case of an accident o only limited space for the bags, the rider might need to carry the bags by himself, the bags can cause an imbalance ▪ rider experiences the deformities of the road more directly ▪ less comfortable seating and ergonomics ▪ very susceptible to theft (light enough to be carried away by a person unless fixed to a place and expensive), so extra effort is needed to find a secure place to lock the bike

Vehicle	L2e ✓	L5e ✓	L6e ✓	L7e ✓
Trip length [km]	7,0	7,0	7,0	7,0
Trip time [min]	17	17	17	17
Energy consumption	0,770	0,511	0,406	0,546
Energy costs [€]	0,23	0,16	0,12	0,17
CO_2-equivalent [gCO_2]	364	242	192	258
Positive subjective arguments	▪ effortless ride ▪ fun to drive with motorcycle-like driving characteristic ▪ low noise through fully enclosed drivers cabin and electric drivetrain ▪ full weather protection against rain and wind, no jacket required ▪ listening to music without headphones possible o easy to find a parking place thanks to the possibility of vertical parking and narrow width of the vehicle ▪ (limited) space to leave personal belongings in the vehicle o bags can be placed to the back seat	▪ effortless ride ▪ low noise through fully enclosed drivers cabin and electric drivetrain ▪ full weather protection against rain and wind, no jacket required ▪ listening to music without headphones possible ▪ space to leave personal belongings in the vehicle ▪ bags can be placed in the trunk ▪ optionally the ride time can be used as a sport exercise time	▪ effortless ride ▪ protection against direct wind and rain o easy to find a parking place thanks to the possibility of vertical parking ▪ bags can be placed to the back seat	▪ effortless ride ▪ low noise through fully enclosed drivers cabin and electric drivetrain ▪ full weather protection against rain and wind, no jacket required ▪ listening to music without headphones possible o easy to find a parking place thanks to the possibility of vertical parking ▪ space to leave personal belongings in the vehicle ▪ bags can be placed in the trunk
Negative subjective arguments	o no integrated navigation, no place to fix smartphone to use it for navigation ▪ narrow interior space ▪ driver might feel uncomfortable near bigger vehicles in the traffic ▪ vulnerable against heavier vehicles in case of a collision o no designated space for the second bag ▪ if charging is wanted, a parking spot next to a charging point is required	▪ relatively low seating position ▪ driver might feel uncomfortable near bigger vehicles in the traffic ▪ vulnerable against heavier vehicles in case of a collision ▪ if charging is wanted, a parking spot next to a charging point is required	o no integrated navigation, no place to fix smartphone to use it for navigation ▪ driver is exposed to the external temperature and weather conditions, additional clothing might be required ▪ no voice isolation ▪ listening to music without headphones disturbs the environment ▪ personal items can't be left in the vehicle securely ▪ driver might feel uncomfortable near bigger vehicles in the traffic ▪ vulnerable against heavier vehicles in case of a collision o no designated space for second bag ▪ if charging is wanted, a parking spot next to a charging point is required	▪ small interior space ▪ driver might feel uncomfortable near bigger vehicles in the traffic ▪ vulnerable against heavier vehicles in case of a collision ▪ if charging is wanted, a parking spot next to a charging point is required

Vehicle	M1-A BEV ✔	M1-A ICE ✔	M1-C BEV ✔	M1-C ICE ✔
Trip length [km]	7,0	7,0	7,0	7,0
Trip time [min]	17	17	17	17
Energy consumption	1,218	0,434	1,043	0,371
Energy costs [€]	0,37	0,61	0,32	0,52
CO_2-equivalent [gCO_2]	576	1029	493	879
Positive subjective arguments	▪ slightly improved ride comfort ▪ slightly bigger interior space ▪ improved safety	▪ slightly improved ride comfort ▪ slightly bigger interior space ▪ improved safety ▪ no charging	▪ improved ride comfort ▪ bigger interior space ▪ improved safety	▪ improved ride comfort ▪ bigger interior space ▪ improved safety ▪ no charging
Negative subjective arguments	▪ vertical parking not possible	▪ vertical parking not possible ▪ engine noise	▪ vertical parking not possible	▪ vertical parking not possible ▪ engine noise

▪ factor applicable generally

○ factor specific to the persona’s trip

✔ vehicle is plausible

⚠ there are factors that bring the plausibility of the vehicle in question

⚠ vehicle is not plausible

Table 19: Analysis of use cases - Anne/Commuting

Vehicle	Public transport ⚠	Bike ⚠	E-Scooter ⚠	Pedelec ⚠
Trip length [km]	Not specified	10,9	10,9	10,9
Trip time [min]	44 min (9 min walk, tram every 20 mins, 1 transfer) ⚠	48 ⚠	48 ⚠	43 ⚠
Energy consumption	-	0	0,099	0,044
Energy costs [€]	-	0,00	0,03	0,01
CO_2-equivalent [gCO_2]	323	0	47	21
Positive subjective arguments	▪ no active driving, time can be used for other activities ▪ no parking	▪ can use bike roads ▪ can go through traffic ▪ quick to get on and off ▪ no parking maneuvers ▪ very easy to find a place to park, can be parked directly at the destination ▪ no charging/refueling	▪ can use bike roads ▪ can go through traffic ▪ quick to get on and off ▪ no parking maneuvers ▪ easy to find a place to park, can be parked directly at the destination ▪ can be folded and taken inside for charging	▪ can use bike roads ▪ can go through traffic ▪ quick to get on and off ▪ no parking maneuvers ▪ easy to find a place to park, can be parked directly at the destination ▪ rider decides how much help she gets from the electric motor (option for using the ride as a chance for sport) ▪ portable battery can be taken with for charging
Negative subjective arguments	▪ no freedom with timing, the trip needs to be planned according to the schedule of public transport, extra time is needed as a buffer to catch the tram ▪ transfer ▪ exposed to weather conditions at the beginning and end of the trip ▪ shared space with other people seating is not guaranteed ▪ parts of the trip require walking potentially louder environment	▪ no motorized ride, rider uses her own energy, resulting tiredness and sweating. Intensified by the very long trip duration and elevation changes ▪ fully exposed to weather conditions ▪ fully exposed to the noise of the environment ▪ not all roads are suitable for bikes and pose a safety risk ▪ no safety elements in case of an accident ▪ only limited space for the bags, the rider might need to carry the bags by himself, the bags can cause an imbalance ▪ rider experiences the deformities of the road more directly less comfortable seating and ergonomics ▪ susceptible to theft (light enough to be carried away by a person unless fixed to a place)	▪ fully exposed to weather conditions ▪ fully exposed to the noise of the environment ▪ not all roads are suitable for e-scooters and pose a safety risk ▪ no safety elements in case of an accident ▪ no space to transport goods, so the bag should be carried by the rider ▪ rider experiences the deformities of the road very directly ▪ not very comfortable to ride, no seating, the rider stands up the whole ride, intensified by the trip duration ▪ susceptible to theft (light enough to be carried away by a person unless fixed to a place)	▪ fully exposed to weather conditions ▪ fully exposed to the noise of the environment ▪ not all roads are suitable for bikes and pose a safety risk ▪ no safety elements in case of an accident ▪ only limited space for the bag, the rider might need to carry the bag by herself ▪ rider experiences the deformities of the road more directly ▪ less comfortable seating and ergonomics ▪ very susceptible to theft (light enough to be carried away by a person unless fixed to a place and expensive), so extra effort is needed to find a secure place to lock the bike

Vehicle	L2e ✓	L5e ✓	L6e ✓	L7e ✓
Trip length [km]	12,7	12,7	12,7	12,7
Trip time [min]	20	18	20	18
Energy consumption	1,397	0,927	0,737	0,991
Energy costs [€]	0,42	0,28	0,22	0,30
CO_2-equivalent [gCO_2]	661	439	348	469
Positive subjective arguments	▪ effortless ride ▪ fun to drive with motorcycle-like driving characteristic o agile and easy to navigate in the traffic through very narrow and short body of the vehicle ▪ low noise through fully enclosed driver's cabin and electric drivetrain ▪ full weather protection against rain and wind, no jacket required ▪ listening to music without headphones possible ▪ (limited) space to leave personal belongings in the vehicle ▪ bag can be placed to the back seat	▪ effortless ride ▪ low noise through fully enclosed driver's cabin and electric drivetrain ▪ full weather protection against rain and wind, no jacket required ▪ listening to music without headphones possible ▪ space to leave personal belongings in the vehicle ▪ the bag can be placed in the trunk or on the second seat ▪ optionally the ride time can be used as a sport exercise time	▪ effortless ride ▪ protection against direct wind and rain ▪ bag can be placed to the back seat	▪ effortless ride ▪ low noise through fully enclosed drivers cabin and electric drivetrain ▪ full weather protection against rain and wind, no jacket required ▪ listening to music without headphones possible space to leave personal belongings in the vehicle ▪ bags can be placed in the trunk
Negative subjective arguments	▪ narrow interior space ▪ ride comfort not too high on bumpy roads ▪ driver might feel uncomfortable near bigger vehicles in the traffic and faster moving vehicles o driver might feel compelled to choose the route with slower streets instead of the main road ▪ vulnerable against heavier vehicles in case of a collision ▪ if charging is wanted, a parking spot next to a charging point is required	▪ relatively low and unusual seating position ▪ ride comfort not too high on bumpy roads ▪ driver might feel uncomfortable near bigger vehicles in the traffic ▪ vulnerable against heavier vehicles in case of a collision ▪ if charging is wanted, a parking spot next to a charging point is required	▪ driver is exposed to the external temperature and weather conditions, additional clothing might be required ▪ ride comfort not too high on bumpy roads no voice isolation ▪ listening to music without headphones disturbs the environment ▪ personal items can't be left in the vehicle securely ▪ driver might feel uncomfortable near bigger vehicles in the traffic and faster moving vehicles ▪ vulnerable against heavier vehicles in case of a collision ▪ if charging is wanted, a parking spot next to a charging point is required	▪ small interior space ▪ ride comfort not too high on bumpy roads ▪ driver might feel uncomfortable near bigger vehicles in the traffic ▪ vulnerable against heavier vehicles in case of a collision ▪ if charging is wanted, a parking spot next to a charging point is required

Vehicle	M1-A BEV	M1-A ICE	M1-C BEV	M1-C ICE
Trip time [min]	22	22	22	22
Energy consumption	3,393	1,209	2,906	1,034
Energy costs [€]	1,03	1,70	0,88	1,45
CO_2-equivalent [gCO_2]	1605	2865	1374	2449
Positive subjective arguments	▪ slightly improved ride comfort ▪ slightly bigger interior space o more space to leave personal belongings in the vehicle ▪ improved safety	▪ slightly improved ride comfort ▪ slightly bigger interior space o more space to leave personal belongings in the vehicle ▪ improved safety ▪ no charging	▪ improved ride comfort ▪ bigger interior space ▪ driver feels more comfortable on the main roads o more space to leave personal belongings in the vehicle ▪ improved safety	▪ improved ride comfort ▪ bigger interior space ▪ driver feels more comfortable on the main roads o more space to leave personal belongings in the vehicle ▪ improved safety ▪ no charging
Negative subjective arguments	▪ vertical parking not possible	▪ vertical parking not possible ▪ engine noise	▪ vertical parking not possible	▪ vertical parking not possible ▪ engine noise

▪ factor applicable generally

o factor specific to the persona's trip

✓ vehicle is plausible

⚠ there are factors that bring the plausibility of the vehicle in question

⚠ vehicle is not plausible

Table 20: Analysis of use cases - Vivienne/Commuting

Vehicle	Public transport	Bike	E-Scooter	Pedelec
Trip length [km]	not specified	18,7	18,7	18,7
Trip time [min]	60 min (11 min walking, 2 transfers)	55	55	49
Energy consumption	-	0	0,168	0,075
Energy costs [€]	-	0, 00	0,05	0,02
CO_2-equivalent [gCO_2]	1222	0	80	35
Positive subjective arguments	▪ no active driving, time can be used for other activities ▪ no parking	▪ can use bike roads ▪ can go through traffic ▪ quick to get on and off ▪ no parking maneuvers ▪ very easy to find a place to park, can be parked directly at the destination ▪ no charging/refueling	▪ can use bike roads ▪ can go through traffic ▪ quick to get on and off ▪ no parking maneuvers ▪ easy to find a place to park, can be parked directly at the destination ▪ can be folded and taken inside for charging	▪ can use bike roads ▪ can go through traffic ▪ quick to get on and off ▪ no parking maneuvers ▪ easy to find a place to park, can be parked directly at the destination ▪ rider decides how much help she gets from the electric motor (option for using the ride as a chance for sport) ▪ portable battery can be taken with for charging
Negative subjective arguments	▪ no freedom with timing, the trip needs to be planned according to the schedule of public transport, extra time is needed as a buffer to catch the tram and the bus, busses are prone to traffic and can cause delays as well as missing of connections ▪ transfers ▪ exposed to weather conditions at the beginning and end of the trip as well as during the transfers ▪ shared space with other people ▪ seating is not guaranteed ▪ parts of the trip require walking potentially louder environment	o no motorized ride, rider uses his own energy, resulting tiredness and sweating (intensified by the very long trip duration and elevation changes) ▪ fully exposed to weather conditions ▪ fully exposed to the noise of the environment o not all roads are suitable for bikes and pose a safety risk ▪ no safety elements in case of an accident o only limited space for the bags, the rider might need to carry the bags by himself, the bags can cause an imbalance ▪ less comfortable seating and ergonomics ▪ rider experiences the deformities of the road more directly susceptible to theft (light enough to be carried away by a person unless fixed to a place)	▪ fully exposed to weather conditions ▪ fully exposed to the noise of the environment o not all roads are suitable for e-scooters and pose a safety risk ▪ no safety elements in case of an accident o no space for the bags, so the bags should be carried by the rider and can cause imbalance by riding ▪ rider experiences the deformities of the road very directly o not very comfortable to ride, no seating, the rider stands up the whole ride (intensified by the long trip duration) ▪ susceptible to theft (light enough to be carried away by a person unless fixed to a place)	▪ fully exposed to weather conditions ▪ fully exposed to the noise of the environment o not all roads are suitable for bikes and pose a safety risk ▪ no safety elements in case of an accident o only limited space for the bags, the rider might need to carry the bags by himself, the bags can cause an imbalance ▪ less comfortable seating and ergonomics ▪ rider experiences the deformities of the road more directly ▪ very susceptible to theft (light enough to be carried away by a person unless fixed to a place and expensive), so extra effort is needed to find a secure place to lock the bike

Vehicle	L2e ✓	L5e ✓	L6e ✓	L7e ✓
Trip length [km]	19,5	19,5	19,5	19,5
Trip time [min]	27	22	27	22
Energy consumption	2,145	1,424	1,131	1,521
Energy costs [€]	0,65	0,43	0,34	0,46
CO_2-equivalent [gCO_2]	1015	673	535	719
Positive subjective arguments	▪ effortless ride ▪ low noise through fully enclosed drivers cabin and electric drivetrain ▪ full weather protection against rain and wind, no jacket required ▪ listening to music without headphones possible ▪ (limited) space to leave personal belongings in the vehicle ▪ bag can be placed to the back seat	▪ effortless ride ▪ low noise through fully enclosed drivers cabin and electric drivetrain ▪ full weather protection against rain and wind, no jacket required ▪ listening to music without headphones possible ▪ space to leave personal belongings in the vehicle ▪ the bag can be placed in the trunk or on the second seat ▪ optionally the ride time can be used as a sport exercise time	▪ effortless ride ▪ protection against direct wind and rain ▪ bag can be placed to the back seat	▪ effortless ride ▪ low noise through fully enclosed drivers cabin and electric drivetrain ▪ full weather protection against rain and wind, no jacket required ▪ listening to music without headphones possible ▪ space to leave personal belongings in the vehicle ▪ bags can be placed in the trunk
Negative subjective arguments	▪ narrow interior space ▪ ride comfort not too high on bumpy roads ▪ tilting might not feel comfortable for the driver o driver might feel uncomfortable near bigger vehicles in the traffic and faster moving vehicles ▪ vulnerable against heavier vehicles in case of a collision ▪ if charging is wanted, a parking spot next to charging point is required	▪ relatively low and unusual seating position ▪ ride comfort not too high on bumpy roads ▪ driver might feel uncomfortable near bigger vehicles in the traffic ▪ vulnerable against heavier vehicles in case of a collision ▪ if charging is wanted, a parking spot next to a charging point is required	▪ driver is exposed to the external temperature and weather conditions, additional clothing might be required ▪ ride comfort not too high on bumpy roads ▪ no voice isolation ▪ personal items can't be left in the vehicle securely o driver might feel uncomfortable near bigger vehicles in the traffic and faster moving vehicles ▪ vulnerable against heavier vehicles in case of a collision ▪ if charging is wanted, a parking spot next to a charging point is required	▪ small interior space ▪ ride comfort not too high on bumpy roads o driver might feel uncomfortable near bigger vehicles in the traffic ▪ vulnerable against heavier vehicles in case of a collision ▪ if charging is wanted, a parking spot next to a charging point is required

Vehicle	M1-A BEV ✔	M1-A ICE ✔	M1-C BEV ✔	M1-C ICE ✔
Trip length [km]	19,5	19,5	19,5	19,5
Trip time [min]	22	22	22	22
Energy consumption	3,393	1,209	2,906	1,034
Energy costs [€]	1,03	1,70	0,88	1,45
CO_2-equivalent [gCO_2]	1605	2865	1374	2449
Positive subjective arguments	▪ slightly improved ride comfort ▪ slightly bigger interior space ○ more space to leave personal belongings in the vehicle ▪ improved safety	▪ slightly improved ride comfort ▪ slightly bigger interior space ○ more space to leave personal belongings in the vehicle ▪ improved safety ▪ no charging	▪ improved ride comfort ▪ bigger interior space ▪ driver feels more comfortable on the main roads ○ more space to leave personal belongings in the vehicle ▪ improved safety	▪ improved ride comfort ▪ bigger interior space ▪ driver feels more comfortable on the main roads ▪ more space to leave personal belongings in the vehicle ▪ improved safety ▪ no charging
Negative subjective arguments	▪ vertical parking not possible	▪ vertical parking not possible ▪ engine noise	▪ vertical parking not possible	▪ vertical parking not possible ▪ engine noise

▪ factor applicable generally

○ factor specific to the persona’s trip

✔ vehicle is plausible

⚠ there are factors that bring the plausibility of the vehicle in question

⚠ vehicle is not plausible

Time:

Comparing the times in different examples shows different results. In Max's example, the micromobiles (bike/pedelec/e-scooter) offer the fastest option. The advantage of the micromobiles in this example comes from the fact that they are allowed to use the bike roads and therefore have a more direct route. The LEVs and M1 vehicles are 2 minutes (13%) slower than the bike/e-scooter and 4 minutes (30%) slower than the pedelec. On the other hand, in the examples of Anne and Vivienne, the micromobiles' trip durations are much longer than the trips with LEVs and M1 vehicles. In these examples, it is safe to say that these 40+ minute trip durations with the micromobiles fall outside the plausible window. The trip durations of the L2e and L6e vehicles, despite their lower top speeds, remain similar to the faster vehicles in Anne's example, as they are only 2 minutes (11%) slower than the faster vehicles. However, in Vivienne's example, where most roads allow a higher top speed, the difference increases to 5 minutes (23% slower). Public transport takes at least twice as long as the fastest alternatives in all examples and shows a significant disadvantage in this topic.

When it comes to total trip duration, however, there are a couple of other things to pay attention to that aren't accounted for in these trip duration estimates. The first is parking. Both the search for a parking space and the parking maneuver take some additional time. Finding a parking space is situation and vehicle dependent and can be different on each occasion. In general, it can be said that if there isn't a designated parking space and the vehicle must be parked on the streets, the smaller vehicles can find a parking space easier and faster. Especially the vehicles that can park vertically get a bigger advantage, because they can use the narrow spots that normally wouldn't be enough for the length of a conventional car, and they can use the extra space for the necessary maneuvers to get the vehicles in and out of that position. The distance from the parking spot to the actual destination is also something to consider, as the additional walking distance adds to the total time. The easier it is for a vehicle to find a parking space, the shorter this time can be. Micromobiles have an advantage here because they can be parked directly at the destination in most cases. Another factor to consider is the preparation time at the beginning and end of a trip, which is slightly longer for an LEV and M1 vehicle than for a micromobile. If users want to charge their electric vehicles, this is also an additional time to consider. In addition to connecting the vehicle to the charging station and the payment process, the location of the charging station, which may be farther away from the final destination than a normal parking spot, is another factor that adds time. For public transportation, an additional buffer time should be factored in to ensure that the bus/train can be reached. There is also the discrepancy between the traveler's desired time of departure and the available scheduled times of public transport. Especially if the frequency of the used connections is not high, the exact time of the traveler's departure may not be optimally in line with the schedule, and the waiting time may increase. It is not easy to assign a specific duration to these mentioned factors, as they can vary from situation to situation and from person to person, but they should be considered in the total duration of the trip, even if only qualitatively.

When these points are taken into account, the advantage of micromobiles in Max's example becomes even greater. They take less time to prepare, can be parked right at the coffee shop and later at his lecture hall, and require almost no time for parking maneuvers. Parking at the lecture hall doesn't make much of a difference between LEVs and M1s. However, the LEVs (especially the L2e, L6e, and L7e examples) have an advantage over the M1 vehicles at the coffee shop stop. Public transport has a high frequency on this route (every 3 minutes in the first part and every 7 minutes in the second part), so its disadvantage is minimal. In the examples of Anne and Vivienne, the effects of these qualitative advantages of the micromobiles over the LEVs/M1 vehicles are minimal, and the LEVs don't bring any additional advantage over the M1 vehicles because they are parked in parking garages at the workplaces. For public transport, in the case of Anne, the frequencies are lower than Max (every 20 minutes) and may therefore add some additional waiting time, but the effect is still moderate. In the case of Vivienne, however, the buses on her route don't run on a regular pattern, and the time between the two buses is close to 1 hour, which can either make the waiting time much longer or force her to plan her travel time accordingly.

In summary, it can be said that LEVs don't provide much of a time advantage over micromobiles if the commute is happening in the city or over short distances. However, for longer commutes, they allow travel times similar to those of M1 vehicles. Public transport is at a disadvantage in all three examples.

Energy consumption and costs:

When the energy consumption and the resulting energy costs are considered, the L5e, L6e and L7e vehicles have a significant advantage over the M1 category vehicles. The L2e vehicle has a closer energy consumption level to the M1 vehicles, but this can be seen as a result of the older technology and the active leaning system of the vehicle. When it comes to the cost of energy, a trip with the M1 C-class BEV vehicle costs 1,9 times as much as a trip with the L7e vehicle. This factor increases to 4,1 times when comparing the M1 A-class ICE vehicle with the L7e vehicle. Therefore, it can be said that the LEVs bring considerable savings in terms of energy consumption and energy costs compared to the M1 vehicles. On the other hand, the energy consumption and costs of the micromobiles are negligibly small and show a great advantage over all other mobility options considered. The results of these comparisons don't differ between personas because they are calculated with averages and therefore their ratios don't change between personas. If these values were measured with real-life tests, they could show slightly different results, but it's safe to assume that these differences would not be too large to invalidate the statements made here.

CO_2 emissions:

Since CO_2 emissions are directly related to energy consumption, the same conclusions can be drawn for electric vehicles. However, the disadvantage of ICE vehicles over electric vehicles becomes even more apparent in this regard, as they produce about 80% more CO_2 emissions than their comparable electric counterparts. This difference is also likely to increase in the coming years, as countries continue to make the transition to more environmentally friendly sources of energy and reduce the CO_2-equivalent emissions of their electricity generation. In a direct comparison, the L7e example vehicle produces only 23% and 26% of the CO_2 emissions of the M1 examples in the A- and C-class, respectively. On the other hand, the micromobiles again have negligible CO_2 emissions and show a great advantage in this area as well. The emissions of public transport depend strongly on whether the trip is made by tram or bus, as can be seen in the comparison of Anne and Vivienne, and on how direct the route is compared to the individual mobility options, as in the comparison of Max and Anne.

In general, it can be said that the emissions of public transport fall between those of LEVs and M1 electric vehicles.

Driving:

By the driving characteristics aspect, the active leaning system of the L2e vehicle sets this vehicle apart. With its motorcycle-like driving style and agility, this can be a positive aspect for the younger users such as Max and Anne, but can also be a negative aspect for the older users such as Vivienne due to the excessive movement. (Of course, this doesn't necessarily apply to all younger users and vice versa). The L5e vehicle also has a unique steering system, but it is assumed that users can get used to it once they own the vehicle. However, this aspect would become an obstacle if the analysis were based on shared vehicles instead of privately owned ones. The L6e and L7e vehicles have conventional steering and should therefore not differ much from the M1 vehicles. Their smaller motors are compensated by the agility of their electric drivetrains and their light weight, allowing them to keep up with larger vehicles on urban roads. On the other hand, the lack of power and the limited top speed in the case of L2e and L6e vehicles can still be felt as a negative point on non-urban roads. This doesn't apply to Max, but may apply to Anne and especially to Vivienne.

In the case of the micromobiles, the bicycle is again not plausible for Anne and Vivienne because of the long distance of their trips, as it relies on the rider's own power. Max's journey has an optimal distance for a bicycle ride. However, on a windy or hot day, it can still be exhausting for him. A pedelec offers more comfort in such conditions with its power-assisting electric motor. In terms of driving characteristics, the more rigid and uncomfortable handling of e-scooters (compared to bikes and pedelecs) could prove a negative point for Max when it comes to using them for commuting.

The possibility to use the bicycle lanes and therefore the freedom to have a nicer and more direct route is another positive point for the micromobiles in the example of Max. Taking a greener route without the noise of car traffic can add a positive aspect to his morning commute.

All three examples have designated parking spaces at their destinations, so parking doesn't play a big role at the destination. However, in the case of Max, parking during his short stop for coffee could significantly affect his experience. This is where the micromobiles have the biggest advantage, as they can be parked on the spot without any problems. The ability to park vertically also gives the L2e, L6e, and L7e examples a noticeable advantage over the M1 vehicles, as such spots are much easier to find. The M1 vehicles may take longer to find a suitable parking space, and require additional walking if the parking space found isn't very close to the store. This walking and parking search add stress and time to Max's commute, which is especially negative during a morning commute.

Comfort:

When it comes to ride comfort, weather protection is a topic that applies to all three personas. The L2e, L5e and L7e vehicles, as well as the M1 vehicles, offer a fully enclosed driver's cabin for full weather protection. This allows the drivers to dress up more to their liking and comfort, as they will only be exposed to the outside weather for a short period of time. This can be seen as a positive for comfort not only during the ride, but also for the rest of the day. The partial weather protection of the L6e vehicle requires appropriate clothing for the outside temperature. The longer waiting times and transfers by public transport also expose all three personas more to the outside weather and may influence their choice of clothing. Not only do the micromobiles provide no protection from the weather, but they also expose the riders to additional wind during the ride. This may not only actively influence their choice of clothing, such as picking up a windproof coat, but also require them to purchase additional accessories, such as gloves. This situation is worst for bikes, where the rider has to balance protection against cold and wind with lightness and breathability against perspiration. Especially in the case of Vivienne, the effect on the choice of clothing can be seen as a strong negative point, because she may want to give priority to dressing appropriately for her managerial role at work.

In terms of ergonomics, the L2e, L6e and L7e vehicles offer similar driver seats to the conventional M1 vehicles, and their feel can be considered comparable to those vehicles. The L5e vehicle has a lower and more reclined seating position, which can take some time to adjust. This effect may be less for Max and more for Vivienne. The bicycle and pedelec seats are less comfortable than a driver's seat in LEVs and M1 vehicles. On public transport, passenger comfort depends on how crowded the tram or bus is. In a relatively empty vehicle, the ride comfort may be similar to a car, but riders may have to sit on narrower seats next to other passengers, or even stand if no seats are available. The e-scooter offers no seating and is therefore the worst option in this topic. Standing while riding may be less of a problem for Max, but may bother Anne and Vivienne more.

The relatively inferior ride quality of LEVs on bad roads compared to M1 vehicles may not affect Max too much on his shorter urban route, but may become more important for Anne and Vivienne. Bicycles and pedelecs offer even less comfort, and the e-scooter is the worst in this comparison.

The interiors of the L2e, L5e and L7e vehicles can feel too small and therefore can give all 3 personas a feeling of being cramped. The L6e vehicle has a more positive feeling here thanks to the only partially enclosed driver's cabin. The M1 C-class vehicles are more advantageous with their more spacious interior. The micromobiles, on the other hand, leave the drivers out in the open and are the most advantageous with the feeling of openness. Public transport vehicles with their large interiors are also advantageous in this regard, as long as the vehicles aren't overcrowded.

When it comes to noise, the L2e, L5e, L7e and M1 vehicles once again gain a positive point against the L6e vehicle and the micromobiles with their fully enclosed driver's cabins. This point is important for Max because of his personal preferences and for Anne and Vivienne because of their longer trips. At the same time, it affects the topic of entertainment for each persona through its effect on listening to music (or podcasts/audiobooks). While the personas can freely listen to music in the vehicles with enclosed cabins, the other mobility options only allow them to listen to music with headphones. Listening to music through headphones is also a safety risk because it impairs the driver's perception of the environment and is discouraged [88]. In the case of public transportation, the personas still need to listen to music through headphones, but they can do so without worrying about the additional safety risk. Since they are not driving, they also have more options for using this time other than listening to music.

The discomfort of being in a smaller vehicle for LEVs may not be too noticeable for Max in slow urban traffic, but it may be more noticeable on non-urban roads, as in the case of Anne and Vivienne. For the L2e and L6e vehicles, this inconvenience may be even greater on non-urban roads where the speed limit is over 50 km/h, as they will be slower than the other vehicles around them and will be overtaken frequently. Micromobiles are even more disadvantaged than LEVs in this regard.

Functionality:

All of the given LEVs meet most of the travel needs of the three personas. For Max, the L2e, L6e, and L7e vehicles offer easy parking during his coffee stop with the ability to park vertically, allowing him to plan his trip duration accurately. The L5e vehicle cannot park vertically, but its compact size still allows him to find a parking space more easily than a conventional car. They also all provide enough space for him to carry his two bags. However, the LEVs don't offer a cup holder, so he can't comfortably drink coffee on the go. For Anne, the L2e and L6e vehicles aren't allowed on the highway, so they cost her a possible route, but she has a comparable alternative and doesn't lose much other than a few extra minutes of driving time. All LEVs meet the requirements of Vivienne's commute. The M1 vehicles may cause Max to spend extra time looking for parking, as explained above, so he needs to plan for some buffer time. The micromobiles don't offer Max the space to carry his two bags, and while they don't make his commute impossible, they do make it more difficult. The bike and the pedelec can be fitted with a basket so that he can carry one of his bags in the basket and the other on his back. With the e-scooter, he has to carry both bags on his back, which can be uncomfortable and disturb his balance while riding. Because of the length of their trips, the micromobiles aren't plausible for Anne and Vivienne. For Max, public transportation requires him to arrive at stations on time, which may cause him stress or require him to arrive a few minutes early as a buffer. In the case of Vivienne, arriving at work in an electric vehicle can support the image of sustainability she wants to build. Arriving at work in an LEV instead of a conventional M1 vehicle can further reinforce this image by promoting not only electric vehicles, but also the importance of smaller cars for efficiency and saving space and resources.

Charging is of moderate importance in this use case. Except for the e-scooter for Anne and Vivienne and the L2e vehicle for Vivienne, all vehicles have enough range to make a round trip if they start with a full charge. So the ability to charge the vehicle is not a necessity, but can be seen as an optional opportunity. This should be the general case, as these vehicles have the opportunity to charge overnight before the trip. However, if the vehicle is on a low charge or the commute is to be continued with a longer chained trip, the long stay at the university/office may provide a suitable opportunity for charging. The opportunity for free charging, sometimes offered by companies or public institutions as an incentive to encourage the electrification of vehicles, can also be an attractive point for the personas to charge their vehicles at these places.

The bicycle has a clear advantage over other vehicles because it does not need to be charged or refuelled. The e-scooter has the advantage of being small and foldable, allowing Anne and Vivienne to take it into their offices and charge it at any power outlet. Because he changes classrooms frequently during the day, this option isn't very practical for Max, and he would have to find a place on campus to charge his e-scooter. On the other hand, his commute is short enough to allow him to make a round trip without recharging, so this need is unlikely to arise for him. The pedelec has a removable battery, so all three personas can plug it into normal university/office outlets and charge it. The LEVs and BEVs face the challenge of finding a free space at a charging station. This requires them to park where the charging stations are, and because the number of charging stations is limited, there is a risk that they will not be able to charge their vehicles. This can be an inconvenience for all three personas if they have planned their trips with the idea of charging their vehicles at school/work. The ability to charge from household outlets doesn't give LEVs much of an advantage over conventional BEVs, because the only ways to charge outside at these locations are likely to be charging stations and wallboxes. However, if there are stations dedicated to micromobiles with conventional outlets, they can provide additional charging stations for LEVs. ICE vehicles refuel at gas stations en route, so their users aren't restricted in where they can park.

Another issue to consider is how to secure the vehicle during stops or at the end of the trip. In this regard, the micromobiles are generally at a slight disadvantage compared to the LEVs and M1 vehicles. While the LEVs and M1 vehicles are simply locked with a key, the micromobiles must be secured to a location by the user. In addition, the relatively easy disassembly of expensive components such as batteries on pedelecs creates an additional risk of theft. However, in these three examples, the importance of this issue is not too high as all personas park their vehicles either for very short periods of time or in relatively safe environments where the risk of theft is not too high, especially during the day. The L6e vehicle has one negative point compared to other LEVs and M1 vehicles. Since the vehicle doesn't have an enclosed driver's cabin, the personas have no way to safely leave their personal belongings in the vehicle. The small locked box in the back seat allows some items to be left in the vehicle, but due to the size of the box, it is relatively limited and not as convenient as in the other LEV and M1 examples.

Safety:

In general, as explained in Chapter 3.3.1, the LEVs offer less safety to their occupants in a collusion with a heavier vehicle. While this risk is lower for Max, it becomes more significant for Anne and Vivienne as they travel on roads with higher speed limits. For L2e and L6e vehicles, this risk becomes greater because they cannot exceed 45 km/h and are significantly slower than the other vehicles on these roads. However, in the examples of Anne and Vivienne, micromobiles are at an even greater disadvantage. In both cases, some of the roads on their routes don't have dedicated bicycle infrastructure, and this poses a major safety risk for riders because the other vehicles travel at much higher speeds than the micromobiles. This is another reason why commuting by a micromobile is implausible for these two personas.

4.4.2 Use case 2: Shopping

A shopping trip refers to a trip to any type of store for the purpose of purchasing goods. Since the type and quantity of goods can vary greatly depending on the purpose of the trip, it is not easy to make general statements that can be applied to all types of shopping trips.

This study focuses on grocery shopping as an example because it is a common and recurring type of shopping trip that applies to most user groups.

In the case of shopping trips, the focus lies on function, as it is a trip to fulfill a need. It is important that the vehicle can carry the goods in a comfortable way and that the trip can be made quickly and easily. Since the trip is often made to the nearest store that fulfills the user's needs, the duration and length of the trip are usually short. This reduces the importance of driving characteristics and ride comfort and puts more emphasis on functionality. It can be said that the shopping trips have a semi-regular character, as they do not take place every day, but are repeated when necessary.

The three trips analyzed for the personas are as follows:

- Max goes to the discount store closest to his home to do his weekly shopping after returning home from the university, at the beginning of the week. He carries a full backpack and a large shopping bag because of his trip.
- Anne goes around noon, after work, to her favorite supermarket where she can find the vegan products she wants, which, thanks to living in the city, is still a plausible distance from her house. Because she is shopping for a family of four, she has two large bags of groceries to carry, plus a six-pack of bottled water.
- Vivienne goes to the supermarket in the evening after returning from work and leaving her things at home. After leaving the supermarket, she also stops at the farmer's market and the bakery, which are close by. Because she often shops to cook with fresh ingredients, she only has a medium-sized bag of groceries from the supermarket. Afterwards, she picks up a few additional items from the farmer's market and the bakery, which aren't too large in size either.

The results of the analysis for the three personas for each mobility option are shown below. It should be noted that these results are not for one-way trips, but for round trips, unlike the other two use cases.

Table 21: Analysis of use cases - Max/Shopping

Vehicle	Public transport ✓	Bike ⚠	E-Scooter ⚠	Pedelec ⚠
Trip length [km]	not specified	1,1	1,1	1,1
Trip time [min]	6 (walk)	4	4	4
Energy consumption	-	0	0,010	0,004
Energy costs [€]	-	0,00	0,00	0,00
CO_2-equivalent [gCO_2]	0	0	5	2
Positive subjective arguments	▪ not losing time with getting on or off a vehicle and parking	▪ quick to get on and off ▪ no parking maneuvers ▪ can be parked directly at the destination	▪ quick to get on and off ▪ no parking maneuvers ▪ can be parked directly at the destination	▪ quick to get on and off ▪ no parking maneuvers ▪ can be parked directly at the destination
Negative subjective arguments	▪ actively carrying the bags ▪ fully exposed to weather conditions	▪ no motorized ride, rider uses his own energy ▪ fully exposed to weather conditions ▪ no safety elements in case of an accident ○ only limited space for the bags, ⚠ the rider needs to carry the second bag either on his shoulder or hang it to the handlebar, which causes imbalance	▪ fully exposed to weather conditions ▪ no safety elements in case of an accident ○ no space for the bags, the rider ⚠ needs to carry the second bag either on his shoulder or hang it to the handlebar, which causes imbalance	▪ fully exposed to weather conditions ▪ no safety elements in case of an accident ○ only limited space for the bags, ⚠ the rider needs to carry the second bag either on his shoulder or hang it to the handlebar, which causes imbalance

Vehicle	L2e	L5e	L6e	L7e
Trip length [km]	1,20	1,20	1,20	1,20
Trip time [min]	5	5	5	5
Energy consumption	0,132	0,088	0,070	0,094
Energy costs [€]	0,04	0,03	0,02	0,03
CO_2-equivalent [gCO_2]	62	41	33	44
Positive subjective arguments	▪ effortless ride ▪ full weather protection against rain and wind, no jacket required ▪ (limited) space to leave personal belongings in the vehicle ○ goods can be placed to the back seat	▪ effortless ride ▪ full weather protection against rain and wind, no jacket required ▪ space to leave personal belongings in the vehicle ▪ goods can be placed in the trunk comfortably	▪ effortless ride ▪ protection against direct wind and rain ▪ goods can be placed to the back seat	▪ effortless ride ▪ full weather protection against rain and wind, no jacket required ▪ space to leave personal belongings in the vehicle ▪ goods can be placed in the trunk comfortably
Negative subjective arguments	○ no trunk, it is not comfortable placing a bag and a second open grocery bag to the back seat with the cargo net	-	▪ driver is exposed to the external temperature and weather conditions, additional clothing might be required ▪ personal items can't be left in the vehicle securely ○ no trunk, it is not comfortable placing a bag and a second open grocery bag to the back seat with the cargo net	-

Vehicle	M1-A BEV	M1-A ICE	M1-C BEV	M1-C ICE
Trip length [km]	1,20	1,20	1,20	1,20
Trip time [min]	5	5	5	5
Energy consumption	0,209	0,074	0,179	0,064
Energy costs [€]	0,06	0,10	0,05	0,09
CO_2-equivalent [gCO_2]	99	176	85	151
Positive subjective arguments	-	-	-	-
Negative subjective arguments	-	-	-	-

▪ factor applicable generally

○ factor specific to the persona's trip

vehicle is plausible

there are factors that bring the plausibility of the vehicle in question

vehicle is not plausible

Table 22: Analysis of use cases - Anne/Shopping

Vehicle	Public transport ⚠	Bike ⚠	E-Scooter ⚠	Pedelec ⚠
Trip length [km]	not specified	2,6	2,6	2,6
Trip time [min]	21 min (19 min walk, tram every 7 mins) ⚠	16	16	14
Energy consumption	-	0	0,023	0,010
Energy costs [€]	-	0,00	0,01	0,00
CO_2-equivalent [gCO_2]	25	0	11	5
Positive subjective arguments	▪ no active driving ▪ no parking	▪ quick to get on and off ▪ no parking maneuvers ▪ can be parked directly at the destination	▪ quick to get on and off ▪ no parking maneuvers ▪ can be parked directly at the destination	▪ quick to get on and off ▪ no parking maneuvers ▪ can be parked directly at the destination
Negative subjective arguments	▪ no freedom with timing, trip time need adjustment to the schedule of public transport ▪ parts of the trip require walking ▪ actively carrying the goods ▪ fully exposed to weather conditions during walking	▪ no motorized ride, rider uses his own energy ▪ fully exposed to weather conditions ▪ not all roads are suitable for bikes ▪ no safety elements in case of an accident ○ the amount of goods are too much for carrying with a bike ⚠	▪ fully exposed to weather conditions ▪ not all roads are suitable for e-scooters ▪ no safety elements in case of an accident ○ the amount of goods are too much for carrying with an e-scooter ⚠	▪ fully exposed to weather conditions ▪ not all roads are suitable for bikes ▪ no safety elements in case of an accident ○ the amount of goods are too much for carrying with a bike ⚠

Vehicle	L2e	L5e	L6e	L7e
Trip length [km]	2,80	2,80	2,80	2,80
Trip time [min]	9	9	9	9
Energy consumption	0,308	0,204	0,162	0,218
Energy costs [€]	0,09	0,06	0,05	0,07
CO_2-equivalent [gCO_2]	146	97	77	103
Positive subjective arguments	▪ effortless ride ▪ full weather protection against rain and wind, no jacket required ▪ (limited) space to leave personal belongings in the vehicle ○ goods can be placed to the back seat	▪ effortless ride ▪ full weather protection against rain and wind, no jacket required ▪ space to leave personal belongings in the vehicle ▪ goods can be placed in the trunk comfortably	▪ effortless ride ▪ protection against direct wind and rain ▪ goods can be placed to the back seat	▪ effortless ride ▪ full weather protection against rain and wind, no jacket required ▪ space to leave personal belongings in the vehicle ▪ goods can be placed in the trunk comfortably
Negative subjective arguments	▪ the space on the back seat not enough for all the goods, creative placements might be needed	-	▪ driver is exposed to the external temperature and weather conditions, additional clothing might be required ▪ personal items can't be left in the vehicle securely ▪ the space on the back seat not enough for all the goods, creative placements might be needed. In addition, not enclosed space requires a fixed placement of the goods	-

Vehicle	M1-A BEV ✓	M1-A ICE ✓	M1-C BEV ✓	M1-C ICE ✓
Trip length [km]	2,80	2,80	2,80	2,80
Trip time [min]	9	9	9	9
Energy consumption	0,487	0,174	0,417	0,148
Energy costs [€]	0,15	0,24	0,13	0,21
CO_2-equivalent [gCO_2]	230	411	197	352
Positive subjective arguments	-	-	-	-
Negative subjective arguments	-	-	-	-

- ▪ factor applicable generally
- ○ factor specific to the persona's trip
- ✓ vehicle is plausible
- ⚠ there are factors that bring the plausibility of the vehicle in question
- ⚠ vehicle is not plausible

Table 23: Analysis of use cases - Vivienne/Shopping

Vehicle	Public transport ⚠	Bike ⚠	E-Scooter ⚠	Pedelec ⚠
Trip length [km]	not specified	10,3	10,3	10,3
Trip time [min]	56 min (25 min walk, with 5 buses) ⚠	48 ⚠	48 ⚠	43 ⚠
Energy consumption	-	0	0,093	0,041
Energy costs [€]	-	0,00	0,03	0,01
CO_2-equivalent [gCO_2]	113	0	44	19
Positive subjective arguments	▪ no active driving ▪ no parking	▪ quick to get on and off ▪ no parking maneuvers ▪ very easy to find a place to park, can be parked directly at the destination	▪ quick to get on and off ▪ no parking maneuvers ▪ many options for a place to park, can be parked directly at the destination	▪ quick to get on and off ▪ no parking maneuvers ▪ many options for a place to park, can be parked directly at the destination
Negative subjective arguments	▪ no freedom with timing, trip time need adjustment to the schedule of public transport, busses prone to traffic and can cause delays, missing of connections ▪ transfers ▪ exposed to weather conditions at the beginning and end of the trip and also during the transfers ▪ parts of the trip require walking ▪ actively carrying the goods	o no motorized ride, rider uses his own energy, resulting tiredness and sweating. Intensified by the very long trip duration and elevation changes ▪ fully exposed to weather conditions o not all roads are suitable for bikes and pose a safety risk ▪ no safety elements in case of an accident ▪ carrying the goods in the bike-basket not as comfortable as by the LEVs or cars	▪ fully exposed to weather conditions o not all roads are suitable for e-scooters and pose a safety risk ▪ no safety elements in case of an accident ▪ no place for carrying the goods, the rider needs to carry them by herself	▪ fully exposed to weather conditions o not all roads are suitable for bikes and pose a safety risk ▪ no safety elements in case of an accident ▪ carrying the goods in the bike-basket not as comfortable as by the LEVs or cars

Vehicle	L2e ✓	L5e ✓	L6e ✓	L7e ✓
Trip length [km]	10,40	10,40	10,40	10,40
Trip time [min]	19	19	19	19
Energy consumption	1,144	0,759	0,603	0,811
Energy costs [€]	0,35	0,23	0,18	0,25
CO_2-equivalent [gCO_2]	541	359	285	384
Positive subjective arguments	▪ effortless ride ▪ full weather protection against rain and wind, no jacket required ▪ (limited) space to leave personal belongings and the previously bought goods in the vehicle ▪ easy to find a parking place thanks to the possibility of vertical parking and narrow width of the vehicle ▪ goods can be placed to the back seat	▪ effortless ride ▪ full weather protection against rain and wind, no jacket required ▪ space to leave personal belongings and the previously bought goods in the vehicle ▪ goods can be placed in the trunk	▪ effortless ride ▪ protection against direct wind and rain ▪ easy to find a parking place thanks to the possibility of vertical parking ▪ goods can be placed to the back seat	▪ effortless ride ▪ full weather protection against rain and wind, no jacket required ▪ space to leave personal belongings and the previously bought goods in the vehicle ▪ easy to find a parking place thanks to the possibility of vertical parking ▪ goods can be placed in the trunk
Negative subjective arguments	▪ if cannot be parked directly at the destination, extra walking while carrying the goods ○ driver might feel uncomfortable near bigger vehicles in the traffic and faster moving vehicles ▪ vulnerable against heavier vehicles in case of a collision	▪ if cannot be parked directly at the destination, extra walking while carrying the goods ▪ driver might feel uncomfortable near bigger vehicles in the traffic ▪ vulnerable against heavier vehicles in case of a collision	▪ driver is exposed to the external temperature and weather conditions, additional clothing might be required ▪ personal items and previously bought goods can't be left in the vehicle securely ▪ if cannot be parked directly at the destination, extra walking while carrying the goods ○ driver might feel uncomfortable near bigger vehicles in the traffic and faster moving vehicles ▪ vulnerable against heavier vehicles in case of a collision	▪ if cannot be parked directly at the destination, extra walking while carrying the goods ○ driver might feel uncomfortable near bigger vehicles in the traffic ▪ vulnerable against heavier vehicles in case of a collision

Vehicle	M1-A BEV ✓	M1-A ICE ✓	M1-C BEV ✓	M1-C ICE ✓
Trip length [km]	10,40	10,40	10,40	10,40
Trip time [min]	19	19	19	19
Energy consumption	1,810	0,645	1,550	0,551
Energy costs [€]	0,55	0,91	0,47	0,77
CO_2-equivalent [gCO_2]	856	1528	733	1306
Positive subjective arguments	▪ driver feels slightly more comfortable on the main roads ▪ improved safety	▪ driver feels slightly more comfortable on the main roads ▪ improved safety	▪ driver feels more comfortable on the main roads ▪ improved safety	▪ driver feels more comfortable on the main roads ▪ improved safety
Negative subjective arguments	▪ finding a suitable parking spot slightly harder ▪ if cannot be parked directly at the destination, extra walking while carrying the goods	▪ finding a suitable parking spot slightly harder ▪ if cannot be parked directly at the destination, extra walking while carrying the goods	▪ finding a suitable parking spot harder ▪ if cannot be parked directly at the destination, extra walking while carrying the goods	▪ finding a suitable parking spot harder ▪ if cannot be parked directly at the destination, extra walking while carrying the goods

- ▪ factor applicable generally
- ○ factor specific to the persona's trip
- ✓ vehicle is plausible
- ⚠ there are factors that bring the plausibility of the vehicle in question
- ⚠ vehicle is not plausible

Time:

Comparing the three examples again shows different results in terms of trip duration. In Max's example, the distance to get where he wants to go is so short that the time difference between the modes is negligible. In Anne's example, the LEVs and M1 vehicles have a 5 to 7 minute advantage over the micromobiles, which is not a large difference considering that this is a round trip. Moreover, some of this difference is negated by the additional time required to park the LEVs and M1 vehicles. In these two examples, the public transport option consists mostly or entirely of walking. In the Vivienne example, however, the situation changes due to the longer distance to the shops as a result of the rural nature of the persona's residence. While the LEVs and cars make the round trip in 19 minutes, the micromobiles take over 40 minutes. This shows a significant travel time advantage for the LEVs and M1 vehicles over the micromobiles in this example. In addition, the LEVs gain an advantage over the M1 vehicles due to easier parking, especially at the second stop of this trip, and thus can result in the shortest trip duration. Public transit requires four transfers on this trip and takes a total of 56 minutes, with 25 minutes of walking, which is implausible when compared to the alternatives.

Energy consumption, energy costs and CO_2 emissions:

Since these results depend on the trip distance and not on the details of the trips, the same conclusions from the commuter trips can be applied here. The only additional point worth mentioning is the relatively low total energy cost of the trips. While the energy costs of an LEV and an M1 ICE still differ by a factor of 3-4, even the most expensive trip has an energy cost of 24 cents in Anne's example and 91 cents in Vivienne's example. Since these trips don't occur as often as the commute trips, it can be said that energy cost differences of this magnitude may play a smaller role in the choice of mobility option.

Driving:

On the driving side, most of the outtakes explained in the commuting examples apply here as well. As explained above, due to the shorter trip duration and the less regular nature of the trips, the importance of these items is lower in these examples. However, one part that plays an important role here is parking. While the destinations in Max's and Anne's examples have parking for their customers, the second stop in Vivienne's example doesn't have this option. As a result, Vivienne may have to search longer for a parking spot and end up parking farther away from her destination with the M1 vehicles. LEV vehicles may have the same need, but their ability to park vertically and their compact size give them a better chance of finding a suitable parking space than M1 vehicles. Parking far away when shopping causes an additional inconvenience compared to commuting, because the user has to carry what they bought for that extra distance. How big and significant this inconvenience is depends on the weight/size of the goods carried and how far the vehicle is parked.

Ride comfort:

In terms of ride comfort, as in the case of driving, the findings from commuting can be applied here to a lesser extent due to the shorter trip duration and the less regular nature of the trips.

Functionality:

In this use case, the storage spaces of the vehicles gain a major importance. The volume, geometry, and ease of use of the storage space affect how well and comfortable the trip is for the user. In the examples given, how well the LEVs meet the needs of the trips varies. The L2e vehicle offers the back seat as storage with a cargo net. This doesn't provide ideal geometry for open grocery bags, especially considering the vehicle's tilt, but it may be sufficient for Max and Vivienne's trips. For Anne, however, the L2e vehicle's storage space may prove too small, unless she can creatively arrange the goods to fit into the vehicle's available spaces. This is doable, but not a comfortable solution for the persona. The same can be said for the L6e vehicle. In this vehicle, the non-enclosed driver's cab actually limits the amount of goods that can be carried even more, because the poorly secured items can fall off the vehicle. Therefore, it's not possible to "stuff" the excess items into the empty spaces in the interior in the same way as in the L2e vehicle. This vehicle provides enough storage for Vivienne, but may be problematic for Max and not enough for Anne. The L5e and L7e vehicles, on the other hand, offer dedicated storage for all three personas and are suitable. The same can be said for the M1 vehicles, as they all have enough storage space for these examples as well. The micromobiles are the most disadvantaged of the three examples. Max can carry his backpack on his back, but the basket on the bike (if there is one) may be too small to hold a large grocery bag, so he may have to hang it on the handlebar of the bike or carry it himself on his shoulder. Although the trip isn't very long and this may be acceptable to him, the resulting imbalance is still uncomfortable and poses a certain safety risk. The e-scooter doesn't have a basket, so the same also applies here. For Anne, the amount of goods is too much to carry with the micromobiles without creating a major inconvenience and safety risk. For Vivienne, the amount of goods can be carried more comfortably on a bicycle/pedelec with a basket. However, the length of the trip also makes this implausible.

Charging is only a minor factor in this use case. Some supermarkets offer charging stations for BEVs and additional sockets for micromobiles, making it possible to charge while shopping. However, the generally short distances for this use case mean that these trips don't create a need for charging. So if there's an opportunity to charge while shopping, that can be seen as a positive, but the lack of that opportunity shouldn't be seen as a negative. Also, the short duration of stay means that only partial charging is possible. Taking these points into account, the pedelec and e-scooter again have an advantage because they can always be parked near the charging points and charged as long as there are free outlets. The LEVs can only use these outlets if they find a free parking space next to them. The BEVs have the least chance of using the charging opportunities because they need the charging stations to be unoccupied (if there are any).

For vehicle security, the general conclusions from the commuting use case also apply to this use case, but are less important here because of the relatively short duration of stays at the destinations.

Safety:

While the general advantages and disadvantages of vehicles in terms of safety apply to all use cases and persona examples, their importance changes (to some extent) depending on the situation. As mentioned in the section on functionality, the imbalance created by non-optimal ways of transporting goods with the micromobiles creates an additional safety risk due to the reduced control of the rider, and is especially true for the examples of Max and Anne. On the other hand, Max and Anne drive on relatively calm urban roads with good infrastructure and low speed limits, so the safety risks on these roads aren't too high, which is true for all types of vehicles. Vivienne, on the other hand, rides part of her trip on non-urban roads with higher speed limits and no dedicated bike lanes, so the risks are higher for her while riding the micromobiles.

4.4.3 Use case 3: First-/last-mile vehicle

First/last mile refers to the parts of trips between the traveler's starting point and the point where the traveler's first intended primary mode of transportation is taken (first mile), and between the point where the traveler's last intended primary mode of transportation is left and the traveler's final destination (last mile). While these terms are most often used to refer to the trip between the closest public transportation station and the starting point/end destination, they can also refer to the trip from a traveler's home to the location of a sharing vehicle, for example.

In some cases, when public transportation connections are not optimal (because of indirect routes, bad connection times, etc.), a vehicle can be used to go directly to a particular mode of transportation (and vice versa) to bypass the non-ideal intermediate steps. An example of this would be using a bicycle instead of a tram or bus to reach the main train station when traveling from home to another city. In this study, this type of use is also considered a first/last mile trip.

The main focus of first/last mile trips is to reach the main mode of transport conveniently. The assurance of arriving at the destination at a certain time to catch the connection is especially important for first mile trips (if it is a connection to public transport). Ease of transfer and short travel time are also important criteria for these trips. Due to the relatively short distance and duration of these trips and their primary function, driving characteristics and ride comfort may play a lesser role in the choice of mobility options compared to the criteria mentioned above. However, if the trip is made on a regular basis (for example, as part of a commute), these criteria may also gain more importance.

The three trips analyzed for the personas are as follows:

- Max goes to Basel on Saturday morning and has to go to Karlsruhe main station to catch a train. He has a small suitcase with him because he plans to stay there for the weekend. The first mile is the trip between his house and the main station instead of the tram station at Yorkstraße, because the tram takes an indirect route from this station to the main station.
- Anne goes to Vaihingen to visit a friend after she comes home from working. She carries a cake with her that needs to be held straight to stay intact. She wants to take the subway from Schwabstraße station, because the bus and train from the station near her home take an indirect route and have transfers.
- Vivienne goes to Ettlingen on Saturday morning to meet friends for brunch. To do so, she goes from her home to the Bad Herrenalb train station to take the tram. She carries only a small purse and is dressed up for the occasion.

The results of the analysis for the three personas for each mobility option are shown below.

Table 24: Analysis of use cases - Max/First mile vehicle

Vehicle	Public transport	Bike	E-Scooter	Pedelec
Trip length [km]	not specified	3	3	3
Trip time [min]	21 min (6 min walk, tram every 8 mins)	12	12	11
Energy consumption	-	0	0,027	0,012
Energy costs [€]	-	0,00	0,01	0,00
CO_2-equivalent [gCO_2]	207	0	13	6
Positive subjective arguments	▪ no active driving ▪ no parking	▪ quick to get on and off ▪ no parking maneuvers ▪ can be parked directly at the destination for free	▪ quick to get on and off ▪ no parking maneuvers ▪ fee for the bike-parking station cheaper than a parking garage for cars	▪ quick to get on and off ▪ no parking maneuvers ▪ fee for the bike-parking station cheaper than a parking garage for cars
Negative subjective arguments	▪ no freedom with timing, trip time need adjustment to the schedule of public transport, extra time need to be planned to catch the tram ▪ exposed to weather conditions before and after taking the tram ▪ parts of the trip require walking ▪ carrying the luggage	▪ no motorized ride, rider uses his own energy ▪ fully exposed to weather conditions ▪ no safety elements in case of an accident ○ a luggage cannot be carried with a bike ▪ susceptible to theft (light enough to be carried away by a person unless fixed to a place)	▪ fully exposed to weather conditions ▪ no safety elements in case of an accident ○ a luggage cannot be carried with an e-scooter ▪ susceptible to theft (light enough to be carried away by a person unless fixed to a place)	▪ fully exposed to weather conditions ▪ no safety elements in case of an accident ○ a luggage cannot be carried with a pedelec ▪ very susceptible to theft (light enough to be carried away by a person unless fixed to a place and expensive), so extra effort is needed to find a secure place to lock the bike

Vehicle	L2e	L5e	L6e	L7e
Trip length [km]	3,90	3,90	3,90	3,90
Trip time [min]	10	10	10	10
Energy consumption	0,429	0,285	0,226	0,304
Energy costs [€]	0,13	0,09	0,07	0,09
CO_2-equivalent [gCO_2]	203	135	107	144
Positive subjective arguments	▪ effortless ride ▪ full weather protection against rain and wind, no jacket required ▪ (limited) space to leave personal belongings in the vehicle ▪ the luggage can be placed to the back seat	▪ effortless ride ▪ full weather protection against rain and wind, no jacket required ▪ space to leave personal belongings in the vehicle ▪ the luggage be placed in the trunk comfortably	▪ effortless ride ▪ protection against direct wind and rain ▪ the luggage can be placed to the back seat	▪ effortless ride ▪ full weather protection against rain and wind, no jacket required ▪ space to leave personal belongings in the vehicle ▪ the luggage can be placed in the trunk comfortably
Negative subjective arguments	▪ fee for parking	▪ fee for parking	▪ driver is exposed to the external temperature and weather conditions, additional clothing might be required ▪ personal items can't be left in the vehicle securely ▪ fee for parking	▪ fee for parking

Vehicle	M1-A BEV ✅	M1-A ICE ✅	M1-C BEV ✅	M1-C ICE ✅
Trip length [km]	3,90	3,90	3,90	3,90
Trip time [min]	10	10	10	10
Energy consumption	0,679	0,242	0,581	0,207
Energy costs [€]	0,21	0,34	0,18	0,29
CO_2-equivalent [gCO_2]	321	573	275	490
Positive subjective arguments	-	-	-	-
Negative subjective arguments	-	-	-	-

- ▪ factor applicable generally
- ○ factor specific to the persona's trip
- ✅ vehicle is plausible
- ⚠ there are factors that bring the plausibility of the vehicle in question
- ⚠ vehicle is not plausible

Table 25: Analysis of use cases - Anne/First mile vehicle

Vehicle	Public transport	Bike	E-Scooter	Pedelec
Trip length [km]	not specified	1,3	1,3	1,3
Trip time [min]	16 min (walk)	6	6	5
Energy consumption	-	0	0,012	0,005
Energy costs [€]	-	0,00	0,00	0,00
CO_2-equivalent [gCO_2]	0	0	6	2
Positive subjective arguments	▪ planning an extra time for parking not necessary	▪ quick to get on and off ▪ no parking maneuvers ▪ very easy to find a place to park, can be parked directly at the destination, planning an extra time for parking not necessary	▪ quick to get on and off ▪ no parking maneuvers ▪ many options for a place to park, can be parked directly at the destination, planning an extra time for parking not necessary	▪ quick to get on and off ▪ no parking maneuvers ▪ many options for a place to park, can be parked directly at the destination, planning an extra time for parking not necessary
Negative subjective arguments	▪ exposed to weather conditions	▪ no motorized ride, rider uses his own energy ▪ fully exposed to weather conditions ▪ no safety elements in case of an accident ○ the cake cannot be carried with a bike properly	▪ fully exposed to weather conditions ▪ no safety elements in case of an accident ○ the cake cannot be carried with an e-scooter properly	▪ fully exposed to weather conditions ▪ no safety elements in case of an accident ○ the cake cannot be carried with a pedelec properly

Vehicle	L2e ✓	L5e ✓	L6e ✓	L7e ✓
Trip length [km]	1,40	1,40	1,40	1,40
Trip time [min]	5	5	5	5
Energy consumption	0,154	0,102	0,081	0,109
Energy costs [€]	0,05	0,03	0,02	0,03
CO_2-equivalent [gCO_2]	73	48	38	52
Positive subjective arguments	▪ effortless ride ▪ full weather protection against rain and wind, no jacket required ▪ (limited) space to leave personal belongings in the vehicle ▪ easy to find a parking place thanks to the possibility of vertical parking and narrow width of the vehicle ▪ free to park on the streets in Stuttgart	▪ effortless ride ▪ full weather protection against rain and wind, no jacket required ▪ space to leave personal belongings in the vehicle ▪ the luggage be placed in the trunk comfortably ▪ free to park on the streets in Stuttgart ▪ the cake can be carried in the trunk	▪ effortless ride ▪ protection against direct wind and rain ▪ the luggage can be placed to the back seat ▪ easy to find a parking place thanks to the possibility of vertical parking ▪ free to park on the streets in Stuttgart	▪ effortless ride ▪ full weather protection against rain and wind, no jacket required ▪ space to leave personal belongings in the vehicle ▪ easy to find a parking place thanks to the possibility of vertical parking ▪ free to park on the streets in Stuttgart ▪ The cake can be carried in the trunk
Negative subjective arguments	▪ securing a space to carry the cake properly ▪ need to plan an extra time for the search of a parking spot and walking	▪ need to plan an extra time for the search of a parking spot and walking	▪ driver is exposed to the external temperature and weather conditions, additional clothing might be required ▪ personal items can't be left in the vehicle securely ▪ securing a space to carry the cake properly ▪ need to plan an extra time for the search of a parking spot and walking	▪ need to plan an extra time for the search of a parking spot and walking

Vehicle	M1-A BEV	M1-A ICE	M1-C BEV	M1-C ICE
Trip length [km]	1,40	1,40	1,40	1,40
Trip time [min]	5	5	5	5
Energy consumption	0,244	0,087	0,209	0,074
Energy costs [€]	0,07	0,12	0,06	0,10
CO_2-equivalent [gCO_2]	115	206	99	176
Positive subjective arguments	-	-	-	-
Negative subjective arguments	▪ slightly harder to find a parking space on the streets	▪ slightly harder to find a parking space on the streets ▪ parking fee	▪ slightly harder to find a parking space on the streets	▪ slightly harder to find a parking space on the streets ▪ parking fee

▪ factor applicable generally

○ factor specific to the persona's trip

vehicle is plausible

there are factors that bring the plausibility of the vehicle in question

vehicle is not plausible

Table 26: Analysis of use cases - Vivienne/First mile vehicle

Vehicle	Public transport ⚠	Bike ✓	E-Scooter ✓	Pedelec ✓
Trip length [km]	not specified	4,4	4,4	4,4
Trip time [min]	16 min (with bus, 6 min walk) ⚠	13	13	12
Energy consumption	-	0	0,040	0,018
Energy costs [€]	-	0,00	0,01	0,01
CO_2-equivalent [gCO_2]	142	0	19	8
Positive subjective arguments	▪ no active driving ▪ no parking	▪ quick to get on and off ▪ no parking maneuver	▪ quick to get on and off ▪ no parking maneuver	▪ quick to get on and off ▪ no parking maneuver
Negative subjective arguments	▪ no freedom with timing, trip time need adjustment to the schedule of public transport, busses prone to traffic and can cause delays ▪ exposed to weather conditions while waiting at the station ▪ parts of the trip require walking	▪ no motorized ride, rider uses his own energy ▪ fully exposed to weather conditions ▪ not all roads are suitable for bikes and pose a safety risk ▪ no safety elements in case of an accident	▪ fully exposed to weather conditions ▪ not all roads are suitable for e-scooters and pose a safety risk ▪ no safety elements in case of an accident	▪ fully exposed to weather conditions ▪ not all roads are suitable for bikes and pose a safety risk ▪ no safety elements in case of an accident

Vehicle	L2e ✅	L5e ✅	L6e ✅	L7e ✅
Trip length [km]	4,70	4,70	4,70	4,70
Trip time [min]	8	8	8	8
Energy consumption	0,517	0,343	0,273	0,367
Energy costs [€]	0,16	0,10	0,08	0,11
CO_2-equivalent [gCO_2]	245	162	129	173
Positive subjective arguments	▪ effortless ride ▪ full weather protection against rain and wind, no jacket required ▪ (limited) space to leave personal belongings in the vehicle	▪ effortless ride ▪ full weather protection against rain and wind, no jacket required ▪ space to leave personal belongings in the vehicle	▪ effortless ride ▪ protection against direct wind and rain	▪ effortless ride ▪ full weather protection against rain and wind, no jacket required ▪ space to leave personal belongings in the vehicle
Negative subjective arguments	▪ driver might feel uncomfortable near bigger vehicles in the traffic and faster moving vehicles ▪ vulnerable against heavier vehicles in case of a collision ▪ if charging is wanted, a parking spot next to a charging point is required	▪ driver might feel uncomfortable near bigger vehicles in the traffic ▪ vulnerable against heavier vehicles in case of a collision ▪ if charging is wanted, a parking spot next to a charging point is required	▪ driver is exposed to the external temperature and weather conditions, additional clothing might be required ▪ personal items can't be left in the vehicle securely ▪ driver might feel uncomfortable near bigger vehicles in the traffic and faster moving vehicles ▪ vulnerable against heavier vehicles in case of a collision ▪ if charging is wanted, a parking spot next to a charging point is required	▪ driver might feel uncomfortable near bigger vehicles in the traffic ▪ vulnerable against heavier vehicles in case of a collision ▪ if charging is wanted, a parking spot next to a charging point is required

Vehicle	M1-A BEV	M1-A ICE	M1-C BEV	M1-C ICE
Trip length [km]	4,70	4,70	4,70	4,70
Trip time [min]	8	8	8	8
Energy consumption	0,818	0,291	0,700	0,249
Energy costs [€]	0,25	0,41	0,21	0,35
CO_2-equivalent [gCO_2]	387	691	331	590
Positive subjective arguments	▪ driver feels slightly more comfortable on the main roads ▪ improved safety	▪ driver feels slightly more comfortable on the main roads ▪ improved safety ▪ no charging	▪ driver feels more comfortable on the main roads ▪ improved safety	▪ driver feels more comfortable on the main roads ▪ improved safety ▪ no charging
Negative subjective arguments	-	-	-	-

- ▪ factor applicable generally
- ○ factor specific to the persona's trip
- vehicle is plausible
- there are factors that bring the plausibility of the vehicle in question
- vehicle is not plausible

Time:

Comparing the times in these examples gives a more consistent result than the commuting and shopping examples: The LEVs and M1 vehicles are slightly faster than the micromobiles, but the differences are not too large. While the differences in the cases of Max and Anne in the urban environments are only 1-2 minutes and therefore negligible (especially when the additional preparation and parking times for the LEVs and M1 vehicles are considered), the difference in the case of Vivienne goes up to 5 minutes due to the non-urban roads and the longer trip distance. All examples show a time advantage over walking/public transport for the same trips (in Vivienne's example, the time difference between cycling and public transport is also only 3 minutes, which looks small. However, when waiting times and the need to plan for a buffer time are taken into account, it becomes clear that all of these mobility options offer a clear time advantage over public transport in these examples).

Energy consumption, costs and CO_2 emissions:

The same outtakes from shopping can also be applied here.

Driving and ride comfort:

As in the case of shopping, the outtakes from commuting can also be applied here, but with less importance for the reasons explained above. One point to mention again is the possibly higher importance of weather protection for Vivienne as in the case of commuting. In this example, since she may want to dress up for the meeting with her friends, the vehicles that don't offer full weather protection, such as the micromobiles and the L6e vehicle, have a more obvious disadvantage over other options.

Parking is covered in the functionality section below, along with the topic of transfer.

Functionality:

As mentioned above, easy transfer is an important part of a first/last mile trip. Therefore, those vehicles that can be parked (or picked up) as close to the destination as possible, and require the least amount of extra effort to drop off/pick up, are more advantageous for these trips. In Max's example, the LEVs and M1 vehicles can be parked for a fee in the lots around the main train station. Since there are no dedicated parking spaces for the LEVs and no on-street parking, the LEVs do not have a significant advantage over the M1 vehicles in this regard. With both types of vehicles, Max must find a parking spot, perform a parking maneuver, retrieve his belongings from the vehicle, and lock the vehicle. The micromobiles can either be parked in the secured bike park for a (smaller) fee, or they can be locked up at a free place around the station. While it is much easier to find a place to park a micromobile than a LEV/car, Max needs to pay attention to locking his micromobile in a safe place (preferably to a fixed post or something similar) because of the increased risk of theft around such stations. For this reason, especially the pedelec should preferably be parked in the secured bike park. It should also be noted that bike parking around such stations is usually much more crowded than regular parking, so finding a space may still take a little longer than parking a micromobile normally. "Get off the micromobile, lock it in a safe place, start walking to the destination" is a slightly shorter and more streamlined process than parking an LEV/car. In Anne's example, the parking experience changes because a normal subway station in the city doesn't offer designated parking spaces. Therefore, she has to find a spot on the street (and pay a fee for ICE vehicles) or use the nearby parking garage for a (higher) fee (if it's not full). LEVs (especially the L2e, L6e and L7e vehicles) have an advantage here because they can more easily find street parking. LEVs and battery electric M1 vehicles also don't have to pay for on-street parking in Stuttgart. Micromobiles can be parked even more easily than in Max's example, because the bike racks aren't likely to be as full as they would be at a train station. In Vivienne's example, Park&Ride facilities at the station make it easy to park LEVs and M1 vehicles. Parking the micromobiles is also convenient with the bike parking at the station.

When it comes to carrying personal belongings, all LEVs and M1 vehicles provide enough space for Max to carry his luggage. On the other hand, it is not possible to carry a piece of luggage with the micromobiles, and therefore this trip becomes implausible. For Anne; L5e, L7e and M1 vehicles offer the necessary space to carry her cake safely. She might also be able to find a suitable place in the L2e and L6e vehicles. However, this becomes a more difficult task in these vehicles and may cause her more stress. With the micromobiles, carrying the cake becomes even more difficult and can be considered implausible. All vehicles meet Vivienne's storage requirements.

Similar to the shopping use case, these first/last mile trips do not generate a need for charging due to the short distances of the trips. Therefore, the lack of such an opportunity should not be seen as a negative. In addition, the additional steps and imprecise time needed to prepare the vehicle for charging are points against the desired simple transfer process. Thus, it can be argued that the user may not want to use these trips to charge their vehicles. In the case of Max, the long stay time makes it unfavorable to leave his vehicle at a public charging station. In the case of Anne, the station where she leaves her vehicle doesn't offer public charging. Vivienne can take advantage of the charging opportunities during her trip, and if she chooses to do so, the same advantages and disadvantages of the vehicles in the shopping use case can be applied here.

Safety:

The general conclusions from commuting and shopping can be applied here as well. While Max's and Anne's examples provide the appropriate infrastructure, such as bike lanes and speed limits below 50 km/h, Vivienne's route lacks these, creating a higher risk for the micromobiles.

4.5 Results of expert interviews

As mentioned in Chapter 4.1, expert interviews were conducted to compare and validate the results of the analysis in Chapter 4.4. These interviews were conducted and evaluated as part of a separate thesis [89]. In this chapter, the structure of the interviews is briefly introduced and their results regarding the use cases are discussed in relation with the results of Chapter 4.4. The detailed description of the interview methodology and the complete results, including further inputs of the experts regarding the chances of LEVs as well as the acceptance criteria of the users, can be found in [89].

The interviews conducted followed the characteristics of two of the three categories according to the categorization of [90, pp. 28-29]: Guideline-based interviews and exploratory interviews. The aim was to have a main structure for these interviews so that they could be evaluated methodically, while leaving room for additional information and being flexible enough to make best use of interviewees' expertise. The interviews followed a guideline based on the questions that emerged from a previous literature review. This guideline was divided into the main topics of application areas, user acceptance criteria, and challenges of LEVs. The questions were open-ended in order to obtain a wider range of statements and not to suggest answers. Neither the wording of the questions nor their order was mandatory. Due to the chosen survey instrument and the limited number of interviewees, a quantitative evaluation was not possible. Instead, the sum of the information gathered through the interviews represents the outcome of these interviews.

In total, 6 experts were interviewed. Two of these experts were from industry and the other four were researchers. The experts' work roles are shown in the Table 27 below:

Table 27: List of expert interview participants

Expert No.	Current Role
Expert 1	Managing partner of a platform for electromobility and electric micro vehicles
Expert 2	Researcher at a university in the field of "sociological mobility research" with the focus on mobility futures
Expert 3	Co-founder and chief marketing officer of a LEV start-up
Expert 4	Professor at a university in the field of "infrastructure management" and director of a mobility lab
Expert 5	Team leader of the vehicle concepts research group at the institute of automotive engineering at a university
Expert 6	Project manager at the institute for vehicle concepts at a research institute

Expert 1 is the managing partner of a platform that advises and informs users about electric mobility and electric micro vehicles. Expert 2's publications deal, among other things, with social acceptance of new forms of mobility and urban planning measures. Expert 3 is a co-founder of a start-up company that produces an LEV vehicle, and he deals with LEVs and their marketing or customer requirements in his daily work. Expert 4 is a professor of infrastructure management at a university and runs the university's mobility lab, which focuses on efficient transportation and innovative mobility concepts, with an emphasis on small electric vehicles. Expert 5's team has developed a concept car with the goal of efficiency in cities. During the registration process, they dealt with the question of whether their vehicle should be registered as an L7e vehicle or as a conventional passenger car. Expert 6's publications focus specifically on three- and four-wheeled LEVs and their user acceptance and potential.

In addition to their different fields of work and backgrounds, the interviewees also came from different German cities and German-speaking countries, which allowed for more perspectives to be incorporated into the results of these interviews.

Commuting:

According to the experts, the suitability of LEVs for commuting depends heavily on the type of road and the distance. If these two things are right, the experts see LEVs as very suitable for this purpose. Expert 6 cited 70 km as a guideline value for maximum commuting distances for LEVs in her studies. According to Expert 1, distances over 20 km on highways and country roads are not suitable for LEVs. At this point, Expert 2 also emphasized the role of safety.

In terms of the benefits of LEVs for this use case, weather protection played an important role in the responses. Expert 1 added not having to wear a helmet as an additional attraction for some users. Expert 3 mentioned not needing a wall box or charging station at the workplace (as LEVs can be charged from conventional sockets) as an additional advantage over conventional battery electric vehicles.

In addition to these benefits, two experts also mentioned the cost advantage compared to conventional cars, which they said is important because commuting makes up a large part of daily travel. At the same time, however, they warned that this advantage depends on whether the person is replacing his or her conventional car or still needs one. Expert 2 mentioned that the suitability of public transport and bicycles also plays an important role in this context, as they can be an even cheaper alternative.

Comparing the experts' statements with the analysis results of the examples in Chapter 4.4 shows that they are consistent in most areas. Max and Anne's examples were less than 20 km, and the analysis showed that LEVs are appropriate for these commutes. Vivienne's commute was close to 20km, and since her route was mostly on non-urban roads, it was considered less appropriate. Weather protection was also discussed in detail in this analysis for all personas. However, the helmet topic was an element that didn't come up in the analysis. This shows that even if the analysis was to examine the given examples in detail and document the relevant aspects of the trips with the given vehicles, an analysis through a thought experiment may fail to consider all elements of a trip and there may be other relevant aspects for these trips beyond the documented points.

The experts' statements on costs also seem to be in line with the results of Chapter 4.4, but it should be noted that the results of Chapter 4.4 were limited to energy costs, while the experts' statements considered this topic in a broader aspect.

Daily shopping:

Since "shopping" can mean a wide range of different types of shopping trips, this use case was specifically named "daily shopping" in the relevant questions. The experts found this use case to be very suitable for LEVs, as it mostly takes place close to the users, and the users need a place to store their goods in order to carry them.

However, two of the experts cautioned at this point that they were skeptical as to whether LEVs would provide any significant benefits in urban areas. They cited the very short distances to shops due to the high density of cities and the fact that most of these trips can actually be done on foot. They say that if LEVs are used for these trips, they will cause additional traffic and therefore active modes are more preferable from a sustainability perspective. For this reason, Expert 5 sees the benefits of LEVs stronger in the "belt" regions of the cities.

The most frequently cited advantage of LEVs was their storage space, which is often much larger than that of two-wheeled vehicles. They are also seen as suitable for chain routes and spontaneous shopping along the way. The ability to take a second person or a child was also mentioned as relevant. The ability to lock up and leave personal belongings in the vehicle was mentioned as an additional advantage by Expert 6.

Parking is another topic that was commented on. Here, LEVs were cited as being at a disadvantage compared to micromobiles. The experts pointed out that LEVs don't have an advantage if they are only parked in parking spaces for passenger cars. However, if the parking spaces are designed appropriately, LEVs could benefit. They also noted that in city centers, LEVs have a parking advantage over conventional passenger cars because of their smaller size.

Again, most of these statements are largely consistent with the findings in Chapter 4.4. While the LEVs with the more limited storage areas (L2e and L6e vehicles) fell short in the example of Anne’s large grocery shopping, the L5e and L7e vehicles still provided enough storage space for her trip and were suitable. In the other two examples, all LEVs provided enough space. The statement about urban areas can also be applied to Max's example, where the trip times for the vehicles and walking were almost the same. On the other hand, Anne's example showed two use cases where LEVs might still have a notable advantage over active modes: first, when the user is making a large purchase that would be difficult to carry without a vehicle; and second, when the user wants the freedom to go to a store of their choice that isn't the closest alternative to where they live. The benefits of chain routes and the ability to lock the vehicle are consistent with the points made in Vivienne's example. The statements about parking are also consistent with the analysis of all three personas' examples.

First-/ Last Mile:

In contrast to the other two use cases examined, the experts were not very positive about the suitability of LEVs for the first/last mile use case.

Five of the experts were in agreement that there are many other alternatives in urban areas that people can use for this need. They mentioned e-scooters, bicycles, and even walking for short distances as examples. The mentioned advantages of these alternatives over LEVs were that they can be taken on public transport and don't need dedicated parking spaces. Their wide availability for sharing was also mentioned as an advantage. On the other hand, the experts saw the disadvantages of LEVs as being in traffic and having to find a parking space.

While they were not seen as viable in urban areas, the experts saw LEVs as suitable for this use case in suburban areas, where travel distances are longer and public transit connections are not optimal. Experts 3 and 5 mentioned that under these conditions, LEVs also provide a time advantage in addition to their usual benefits. Experts 1 and 5 also added that the benefits of LEVs will increase with the installation of mobility hubs, park-and-ride facilities, and more practical parking solutions.

Once again, the experts' statements here are largely consistent with the arguments in Chapter 4.4. However, because the examples were more specific, the final conclusions about which options fit the given examples show discrepancies from the general statements of the experts here. In both Max's and Anne's examples, the micromobiles appeared to be implausible solutions, while the experts' statements considered the micromobiles to be more suitable for first/last mile connections in urban areas. However, the main reasons for the inappropriateness of the micromobiles in these examples were the things that the personas had to carry. Since these things to carry do not apply to the generality of these trips, this discrepancy in responses does not show a discrepancy between the experts' opinions and the results of this study. Rather, it shows that while the general arguments put the other alternatives in a more advantageous position over LEVs in the first/last mile use case, specific needs such as carrying a large item like luggage can still make LEVs the most appropriate alternative in these examples. Vivienne's example aligns well with the experts' statements.

5 Discussion and outlook

The results of the analysis show that LEVs meet user needs in a similar way to conventional passenger cars in most of the use cases studied. This is particularly true in urban areas. In rural areas, the differences between LEVs and these vehicles start to become more significant in favor of conventional cars. On the other side, the results show that LEVs have more pronounced advantages over micromobiles and public transport, and can meet user needs in some cases where these other alternatives are insufficient.

Weather protection, the ability to carry goods, and shorter travel times over longer distances are all advantages of LEVs over micromobiles that have a direct impact on the practicality and suitability of the vehicle for a given trip. Weather protection carries a high importance because it is relevant for all types of trips and also affects the comfort of the user outside of the trip, since it influences the choice of clothing of the user. The examples studied show that for trip distances around 10 km, trips with micromobiles take more than twice as long as those with LEVs (about 20 minutes versus more than 40 minutes). This can be a significant factor in users' choice of vehicle, and becomes even more important for regular trips such as commutes. Providing a space to carry goods without affecting the driver becomes very important for daily shopping trips and other occasions where the user needs to carry something medium size such as a piece of luggage, or multiple items.

In addition to these points, there are other factors that don't necessarily rule out micromobiles as a viable option, but do put them at a disadvantage. Safety is one of them, especially on routes where the bicycle infrastructure isn't sufficient. On regular routes, comfort differences can also play a role.

Public transport is very often at a significant time disadvantage compared to individual mobility options, as can be seen in the vast majority of the examples analyzed. These examples also show that schedule dependency, not starting and ending at the user's real destinations, transfers and comfort are some of the other points where public transport cannot always offer an ideal solution for users.

All of these points show that there are various occasions where micromobiles and public transport are insufficient and users may lean towards using a passenger car instead. The LEVs show a good potential to offer an alternative to these users. Through this aspect, the availability of LEVs can reduce the number of trips made with conventional cars and also allow some users to replace their passenger cars with LEVs.

On the other hand, when micromobiles can meet the user's needs, they have important advantages, such as being more convenient at the beginning and end of the trip (especially when parking) and giving the user more freedom. They also produce zero or almost zero emissions and cost much less (both to purchase and to use). Therefore, it should be considered unlikely that LEVs will cause a large modal split shift from active modes of transportation to LEVs.

In terms of advantages over conventional passenger cars, however, LEVs don't currently offer many distinctive or significant advantages from the users' perspective other than parking. Their agility in traffic and easier maneuverability in confined spaces are only an advantage in specific situations. The differences in emissions are considerable, but this is not a directly observable advantage during use, and the user needs to be informed and environmentally sensitive in order for this topic to gain importance as a selection criterion. Energy costs are another advantage, but unless it is a regular trip such as commuting, the total amount of cost difference is not too high to be significant enough. Furthermore, this point allows users to have an advantage only if these vehicles replace a car and are not purchased as an additional vehicle. The importance of the benefits in terms of parking is also situational. In countries like Germany, where the cities have a good infrastructure for cars and the density is not too high, the parking problem is usually not as critical as in metropoles. Also, supermarkets and workplaces (locations relevant for the two use cases with high potential for LEVs) usually provide parking, so the occasions when this benefit becomes important are limited.

These show that if a user shift from conventional passenger cars to LEVs is desired, the LEVs must provide further significant user benefits over conventional passenger cars. These could be time advantages, cost advantages, or the ability to enter areas where conventional vehicles are not allowed; and can be achieved through a mix of push-pull measures. Some recommendations for achieving these are given below:

- **Citywide streetlight charging points:** One potential application for LEVs not addressed in this study is free-floating carsharing. Short, one-way trips in urban areas are well suited to LEVs, and the efficiency, lower cost, and ease of finding a parking space of LEVs can make them attractive to both carsharing providers and users. However, the issue of charging poses a problem for the implementation of LEVs in free-floating carsharing, because the need to find a place to charge the vehicle at the end of a trip conflicts with the main appeal of free-floating carsharing, which is the ability to leave the vehicle at any desired location. A clear way to eliminate this would be to create a system where users can find a place to charge the vehicle near their destination, wherever that destination would be (in the given operational area). This could be a reality if every street had a charging opportunity for LEVs. While installing charging stations on every street in a city is a costly task, there is one piece of street furniture that can be found on almost every street in cities that is also connected to the electrical grid and can enable a lower-cost solution: Street lights. The idea of using street lights to install new charging stations without digging up the streets is not new, and has already been implemented in several countries [91, 92]. According to reports, the cost of these charging stations is already 30 to 50% lower than conventional charging stations [93, 94]. As mentioned in this study in Chapter 3.3.2, one advantage of LEVs over conventional BEVs is the plausible charging times using household outlets and low-power charging. If these streetlight charging stations can be designed with LEVs in mind, even cheaper charging stations may be possible and can be implemented throughout a city at relatively low cost. One or two low-power street-light charging stations with a dedicated LEV parking space on each street can give LEVs a unique advantage over conventional passenger cars. This solution would support not only three- and four-wheeled LEVs, but also two-wheeled LEVs and micromobiles, as these vehicles would also be able to use this infrastructure. Enabling one or more free-floating LEV car-sharing services in a city can bring visibility to this category of vehicles and further encourage their widespread adoption.

- **Restricted streets and areas in the cities:** Specific areas in city centers, as well as selected small streets that don't carry the majority of traffic, can be restricted to conventional passenger cars (except for residents' vehicles) while being open to LEVs. Restricting conventional cars on these streets while allowing LEVs would mean that LEVs would have shortcuts compared to conventional cars, which are forced to take longer routes through arterials. Such restrictions can also allow these streets to reallocate some of the road space to more social uses, as in the example of Barcelona's "superblocks" [95]. The city of Ljubljana, where the city center has been closed to traffic with an exception for small electric buses since 2008, is a good example of the success potential of such an application and how such measures can have a positive impact on the cities [96].
- **Introducing subsidies for LEVs:** As mentioned earlier in this study, LEVs are currently at a disadvantage compared to BEVs in Germany because their price gap is narrowed by subsidies for BEVs that LEVs do not receive. Introducing subsidies for LEVs until these vehicles reach a similar level of momentum and market share can help make this category of vehicles a more attractive option for customers and help this sector grow. However, this is a complex issue that needs to be studied in more detail, as unbalanced subsidies may also bring the price of LEVs too close to that of active mobility modes and encourage an undesirable modal shift. It may also encourage some people to buy these vehicles who didn't want to buy an additional car, increasing the total number of vehicles and negating the space-saving benefits. This increase in the total number of vehicles can also negate their use-phase emissions benefits over conventional vehicle travel through their additional CO_2 emissions during production.
- **Including the LEVs in CO_2 regulations:** Another way to improve the cost advantage of LEVs may be to include them in CO_2 fleet emission regulations and allow LEV manufacturers to participate in CO_2 pools. Under EU Regulation 2019/631, new passenger cars and light commercial vehicles are subject to CO_2 emission performance requirements and their manufacturers have fleet-wide targets in the EU [97, 98]. To meet these fleet targets, manufacturers are allowed to form pools where their fleet emissions are considered as a single entity. In this way, manufacturers with higher

than permitted fleet CO_2 emissions can team up with manufacturers with lower fleet CO_2 emissions in exchange for commercial benefits and achieve a lower fleet average. Currently, L-class vehicles are not included in these regulations. However, as this study shows, LEVs have the potential to play the same role as conventional passenger cars in certain use cases. And since these vehicles have the potential to be used in the same way as cars and to replace car trips, they can also be included in these CO_2 regulations. This idea, mentioned by Expert 3 during the expert interviews, may allow LEV manufacturers to offset some of their development costs through this alternative revenue and indirectly lower the sales prices of these vehicles. The inclusion of LEVs in the CO_2 pools may also motivate major OEMs to develop their own LEV models, thus increasing the variety of choices on the market for users. Not being included in these regulations currently removes a financial advantage of having an electric powertrain for the LEVs and puts them at a disadvantage to the conventional BEVs.

- **Parking fees in city centers:** In city centers and other high-density areas, LEVs may be exempt from parking fees while conventional passenger cars are charged. Thus, LEVs can have an apparent cost advantage per trip over cars, while encouraging a shift from cars to LEVs in areas where this shift is most needed. Similar applications to encourage BEVs are already in place in many cities, such as Stuttgart, Germany. This can be taken further by introducing reduced fees for LEVs in parking garages and similar facilities, where dedicated parking spaces can also be introduced.

It is also recommended that the maximum design speed for L2e and L6e vehicles be increased from 45 km/h to 50 km/h to allow these vehicles to keep up with other vehicles in urban traffic.

Due to the size of the study, the cost aspect in terms of total cost of ownership, as well as the acquisition types and second-hand vehicles are not covered in detail in this work. However, they play an important role in the choice of mobility options for users. A detailed examination of these topics can complement the findings of this study and provide a more comprehensive understanding of the user's perspective on the choice of mobility options.

An examination of the given use cases with real-world tests can validate the results of the analysis in this study and provide a more in-depth understanding of the trip details with the different vehicle types. This can be especially important to detail the subjective points such as driving characteristics and comfort, which could only be analyzed in a limited scope in this study. User interviews and surveys, coupled with real-life tests with these vehicles focusing on specific use cases, as in this study, can also provide more insight into this topic and possibly also show the perspective of further user groups. Further analysis of the remaining use cases not covered in this study is recommended to broaden the understanding of the subject and provide a more complete picture. Future work on the given recommendations is encouraged to quantify the potential benefits of these measures and to support local governments and policymakers in translating these into practice.

6 References

[1] ACEM. "ACEM statistical release: Motorcycles registrations in the European Union grew by 8% in 2019." https://www.acem.eu/images/publiq/2019/ACEM_statistical_release_Jan-Dec_019.pdf (accessed Jan. 7, 2022).

[2] eurostat. "Passenger cars in the EU." https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Passenger_cars_in_the_EU#Overview:_car_numbers_grow_with_a_rapid_increase_in_electric_but_a_low_share_of_overall_alternative_fuels (accessed Nov. 17, 2022).

[3] European Commission. "Developments and Forecasts on Continuing Urbanisation: Foresight." https://knowledge4policy.ec.europa.eu/foresight/topic/continuing-urbanisation/developments-and-forecasts-on-continuing-urbanisation_en (accessed Nov. 24, 2021).

[4] T. Reed, "Global Traffic Scorecard," INRIX Research, 2020.

[5] C. Buyssee and J. Miller. "Transport could burn up the EU's entire carbon budget | International Council on Clean Transportation." https://theicct.org/blog/staff/eu-carbon-budget-apr2021 (accessed Nov. 25, 2021).

[6] European Commission. "A European Green Deal: Striving to be the first climate-neutral continent." https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en (accessed Jun. 20, 2022).

[7] Deutscher Bundestag. "Nur 1,46 Personen pro Pkw unterwegs: Verkehr und digitale Infrastruktur/ Antwort - 22.03.2018 (hib 182/2018)." https://www.bundestag.de/webarchiv/presse/hib/2018_03/548536-548536 (accessed Jun. 20, 2022).

[8] United Nations Development Programme. "Sustainable Development Goals." https://www.undp.org/sustainable-development-goals (accessed Jul. 4, 2023).

[9] European Union, *Regulation (EU) No 168/2013 of the European Parliament and of the Council of 15 January 2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles*, 2013. Accessed: Dec. 9, 2021. [Online]. Available:

https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013R0168&from=DE

[10] M. Brost *et al.,* "Elektrische Klein- und Leichtfahrzeuge: Chancen und Potenziale für Baden-Württemberg," e-mobil BW GmbH, Oct. 2019. Accessed: Nov. 16, 2021. [Online]. Available: https://www.e-mobilbw.de/fileadmin/media/e-mobilbw/Publikationen/Studien/LEV_e-mobil_BW_Leichtfahrzeug_Studie.pdf

[11] European Union, *Directive 2006/126/EC of the European Parliament and of the Council of 20 December 2006 on driving licences (Recast)*, 2006. Accessed: Jun. 20, 2022. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32006L0126&from=DE

[12] H. J. Dennig, A. Burri, and P. Ganz, "BICAR—Urban Light Electric Vehicle," in *Small Electric Vehicles: An International View on Light Three- and Four-Wheelers*, A. Ewert, S. Schmid, M. Brost, H. Davies, and L. Vinckx, Eds., Cham: Springer International Publishing, 2021, pp. 157–166.

[13] roo. "About us." https://go-roo.com/about-us/ (accessed Mar. 8, 2022).

[14] roo. "Product." https://go-roo.com/product/ (accessed Jun. 27, 2022).

[15] Toyota Europe Newsroom. "Toyota i-ROAD the agility of a motorcycle, the comfort of a car." https://newsroom.toyota.eu/2019-toyota-i-road-the-agility-of-a-motorcycle-the-comfort-of-a-car/ (accessed Jun. 17, 2022).

[16] B. Halvorson. "Toyota i-Road Electric City Car: Here's How It Leans." https://www.greencarreports.com/news/1095168_toyota-i-road-electric-city-car-heres-how-it-leans (accessed Jun. 17, 2022).

[17] Toyota Global. "Toyota iRoad." (accessed May. 8, 2022).

[18] Toyota Motor Europe. "Toyota i-ROAD Concept: Putting some lean into driving in the city." https://www.toyota-europe.com/world-of-toyota/concept-cars/i-road (accessed Apr. 20, 2022).

[19] Toyota Deutschland. "i-ROAD Teil des Verkehrsprojekts Ha:mo in Toyota City und Grenoble." https://www.toyota.de/entdecke-toyota/innovation-nachhaltigkeit/i-road (accessed Apr. 20, 2022).

[20] TWIKE. "TWIKE 5." https://twike.com/twike5/ (accessed May. 18, 2022).

[21] Renault Deutschland. "Renault Twizy." https://www.renault.de/elektromodelle/twizy.html (accessed Jan. 21, 2022).

[22] ADAC. "Autokatalog: Renault Twizy 45 Life (inkl. Batterie) (L6e-BP) (ab 08/15): Technische Daten." https://www.adac.de/rund-ums-fahrzeug/autokatalog/marken-modelle/renault/twizy/1generation/250123/#technische-daten (accessed Jun. 28, 2022).

[23] C. Rosamond. "Renault Twizy (2012-2021) boot space & seating." https://www.drivingelectric.com/renault/twizy/practicality (accessed May. 20, 2022).

[24] Micro. "Microlino." https://microlino-car.com/en/microlino (accessed Aug. 8, 2022).

[25] welches-e-auto.com. "Micro Microlino 2.0 (10.5 kWh)." https://welches-e-auto.com/e-auto/micro-microlino-10/?ref=det (accessed Aug. 25, 2022).

[26] Micro. "Our Journey." https://microlino-car.com/en/our-journey (accessed Aug. 8, 2022).

[27] A. Ewert, M. Brost, C. Eisenmann, and S. Stieler, "Small and Light Electric Vehicles: An Analysis of Feasible Transport Impacts and Opportunities for Improved Urban Land Use," *Sustainability*, vol. 12, 19: 8098, 2020, doi: 10.3390/su12198098.

[28] M. Santucci, M. Pieve, and M. Pierini, "Electric L-category Vehicles for Smart Urban Mobility," *Transportation Research Procedia*, vol. 14, pp. 3651–3660, 2016. doi: 10.1016/j.trpro.2016.05.433. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2352146516304409

[29] A. Ewert, M. Brost, and S. Schmid, "Small Electric Vehicles—Benefits and Drawbacks for Sustainable Urban Development," in *Small Electric Vehicles: An International View on Light Three- and Four-Wheelers*, A. Ewert, S. Schmid, M. Brost, H. Davies, and L. Vinckx, Eds., Cham: Springer International Publishing, 2021, pp. 3–15. Accessed: Jun.

27, 2022. [Online]. Available: https://link.springer.com/content/pdf/10.1007/978-3-030-65843-4_1.pdf

[30] T. Gorges, C. Weißmann, and S. Bothor, “Small Electric Vehicles (SEV)—Impacts of an Increasing SEV Fleet on the Electric Load and Grid,” in *Small Electric Vehicles: An International View on Light Three- and Four-Wheelers*, A. Ewert, S. Schmid, M. Brost, H. Davies, and L. Vinckx, Eds., Cham: Springer International Publishing, 2021, pp. 115–125. [Online]. Available: https://link.springer.com/chapter/10.1007/978-3-030-65843-4_9

[31] ADAC. “Autokatalog: Micro Microlino (6 kWh) Urban (ab 12/22): Technische Daten.” https://www.adac.de/rund-ums-fahrzeug/autokatalog/marken-modelle/micro/microlino/1generation/321562/#technische-daten (accessed Jun. 28, 2022).

[32] ADAC. “Autokatalog: smart fortwo coupé EQ (ab 01/20): Technische Daten.” https://www.adac.de/rund-ums-fahrzeug/autokatalog/marken-modelle/smart/fortwo/453-facelift/308857/#technische-daten (accessed Jun. 28, 2022).

[33] Volkswagen Deutschland. “Der vollelektrische ID.3.” https://www.volkswagen.de/de/modelle/id3.html#MOFA (accessed Jan. 21, 2022).

[34] F. Del Pero, M. Delogu, and M. Pierini, “Life Cycle Assessment in the automotive sector: a comparative case study of Internal Combustion Engine (ICE) and electric car,” *Procedia Structural Integrity*, vol. 12, pp. 521–537, 2018, doi: 10.1016/j.prostr.2018.11.066.

[35] ADAC. “Autokatalog: VW Golf 1.0 TSI (03/20 - 08/21): Technische Daten.” https://www.adac.de/rund-ums-fahrzeug/autokatalog/marken-modelle/vw/golf/viii/311459/#technische-daten (accessed Jun. 28, 2022).

[36] ADAC. “Autokatalog: VW Golf 2.0 TDI SCR Style DSG EcoTest Gesamtergebnis.” https://www.adac.de/rund-ums-fahrzeug/tests/ecotest/details/4379/vw-golf-20-tdi-scr-style-dsg/ (accessed Jun. 28, 2022).

[37] P. Icha, T. Lauf, and G. Kuhs, “Entwicklung der spezifischen Treibhausgas-Emissionen des deutschen Strommix in den Jahren 1990 - 2021,” Umwelt Bundesamt, Rep. 15/2022, 2022. Accessed: Apr. 7, 2022. [Online]. Available: https://

www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2022-04-13_cc_15-2022_strommix_2022_fin_bf.pdf

[38] M. Kriescher, S. Scheibe, and T. Maag, "Development of the Safe Light Regional Vehicle (SLRV): A Lightweight Vehicle Concept with a Fuel Cell Drivetrain," in *Small Electric Vehicles: An International View on Light Three- and Four-Wheelers*, A. Ewert, S. Schmid, M. Brost, H. Davies, and L. Vinckx, Eds., Cham: Springer International Publishing, 2021, pp. 179–189.

[39] Y. Li, S. Zuo, L. Lei, X. Yang, and X. Wu, "Analysis of impact factors of tire wear," *Journal of Vibration and Control*, vol. 18, no. 6, pp. 833–840, 2012, doi: 10.1177/1077546311411756.

[40] C. Wang, H. Huang, X. Chen, and J. Liu, "The influence of the contact features on the tyre wear in steady-state conditions," *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, vol. 231, no. 10, pp. 1326–1339, 2017, doi: 10.1177/0954407016671462.

[41] U. Sandberg, L. Goubert, and P. Mioduszewski, Eds., *Are vehicles driven in electric mode so quiet that they need acoustic warning signals?*, 2010.

[42] D. Ibarra, R. Ramírez-Mendoza, and E. López, "Noise emission from alternative fuel vehicles: Study case," *Applied Acoustics*, vol. 118, pp. 58–65, 2017, doi: 10.1016/j.apacoust.2016.11.010.

[43] G. v. Blockland and B. Peeters, Eds., *Modeling the noise emission of road vehicles and results of recent experiments*, 2009.

[44] U. Sandberg and J. A. Ejsmont, *Tyre/Road Noise Reference Book,* 1st ed. Kisa Sweden: Informex, 2002.

[45] ADAC. "Autokatalog: Aktuelle News und Autodatenbank." https://www.adac.de/rund-ums-fahrzeug/autokatalog/ (accessed Jun. 29, 2022).

[46] L. Evans, "Driver injury and fatality risk in two-car crashes versus mass ratio inferred using Newtonian mechanics," *Accident Analysis & Prevention*, vol. 26, no. 5, pp. 609–616, 1994, doi: 10.1016/0001-4575(94)90022-1.

[47] W. Bauer, S. Wagner, F. Edel, S. Stegmüller, and E. Nagl, "Mikromobilität: Nutzerbedarfe und Marktpotenziale im Personenverkehr," Fraunhofer Institut für Arbeitswirtschaft und Organisation (IAO), Stuttgart, 2017. Accessed: Nov. 11, 2022. [Online]. Available: https://publica.fraunhofer.de/handle/publica/299020

[48] A. Ewert, M. Brost, and S. Schmid, Eds., *Fostering small electric vehicles on a municipal level*, 2019.

[49] A. Antonakopoulou, A. Rigos, E. Portouli, and A. Amditis, "Explaining the Public Acceptance of Electrified L-Category Vehicles Towards Sustainable Urban Mobility Planning," in *Advances in Human Aspects of Transportation*, Cham, N. Stanton, Ed., 2021, pp. 288–297.

[50] M. Nicholas and S. Wappelhorst, "Regional charging infrastructure requirements in Germany through 2030," ICCT, 2020. Accessed: Jan. 7, 2022. [Online]. Available: https://theicct.org/wp-content/uploads/2021/06/germany-charging-infrastructure-20201021.pdf

[51] Bundesamt für Wirtschaft und Ausfuhrkontrolle. "Förderung Elektrofahrzeuge." https://www.bafa.de/DE/Energie/Energieeffizienz/Elektromobilitaet/Neuen_Antrag_stellen/neuen_antrag_stellen.html (accessed Feb. 23, 2022).

[52] M. Ouboter, *Herausforderungen und potentielle Einsatzfelder von leichten elektrischen Fahrzeugen (LEVs)*.

[53] Y. Li, A. Winder, and H. Chen, "Mobility demand, vehicle usage and a priori public perceptions towards EL-Vs in the ELVITEN demonstration cities," May. 2018. Accessed: Dec. 16, 2021. [Online]. Available: https://www.elviten-project.eu/wp-content/uploads/2018/12/ELVITEN-study_Mobility-demand-vehicle-usage-and-a-priori-public-perceptions-towards-EL-Vs.pdf

[54] A. Winder, A. Maj, K. Torp, E. Portouli, and Y. Li, Eds., *Perceptions of using electric light vehicles in cities: Survey results from six cities in the ELVITEN project*, 2018.

[55] L. Echternacht, J. v. Gaibler, K. Stadler, J. Behrend, and J. Meurer, "Methoden im Living Lab: Unterstützung der Nutzerintegration in offenen Innovationsprozessen (Entwurf Methodenhandbuch): Arbeitspapier im Arbeitspaket 2 (AS 2.2) des INNOLAB

Projekts," Wuppertal Institut für Klima, Umwelt, Energie GmbH, Wuppertal, 2016. [Online]. Available: https://epub.wupperinst.org/files/6521/6521_innolab_ap2-2.pdf

[56] K. Yüksel, "Typisierung infrastruktureller Knotenpunkte (Hubs)," Masterarbeit, Institut für Fahrzeugtechnik, Karlsruher Institut für Technologie (KIT), Karlsruhe, Germany, 2020. [Online]. Available: https://publikationen.bibliothek.kit.edu/1000150080

[57] S. Blomkvist, "Persona - an overview," (Extract from the paper The User as a personality. Using Personas as a tool for design. Position paper for the course workshop "Theoretical perspectives in Human-Computer Interaction" at IPLab, KTH, September 3, 2002), 2002. [Online]. Available: https://www.it.uu.se/edu/course/homepage/hcidist/vt05/Persona-overview.pdf

[58] E. Brangier and C. Bornet, "Persona: A Method to Produce Representations Focused on Consumers' Needs," in *Human factors and ergonomics in consumer product design: Methods and techniques* (Ergonomics design and management: theory and applications), W. Karwowski, M. Soares, and N. Stanton, Eds., Boca Raton: CRC Press (Taylor & Francis Group), 2011, pp. 37–62.

[59] Bundesministerium für Verkehr und digitale Infrastruktur. "RegioStaR Regionalstatistische Raumtypologie des BMVI." https://www.bmvi.de/SharedDocs/DE/Anlage/G/regiostar-raumtypologie.pdf?__blob=publicationFile (accessed Dec. 12, 2020).

[60] C. Nobis and T. Kuhnimhof, *Mobilität in Deutschland – MiD Ergebnisbericht: Studie von infas, DLR, IVT und infas 360 im Auftrag des Bundesministers für Verkehr und digitale Infrastruktur (FE-Nr. 70.904/15)*. Bonn, Berlin, 2018. [Online]. Available: www.mobilitaet-in-deutschland.de

[61] unsplash.com. "Wes Hicks." https://unsplash.com/de/fotos/4-EeTnaC1S4 (accessed Jun. 29, 2023).

[62] unsplash.com. "Christina @ wocintechchat.com." https://unsplash.com/de/fotos/5v2Q5b4onY8 (accessed Jun. 29, 2023).

[63] unsplash.com. "Woman using her macbook pro inside white room." https://unsplash.com/de/fotos/VKJt1EZHlWs (accessed Jun. 29, 2023).

[64] Amazon Deutschland. “Amazon.de Best Sellers: The most popular items in Electric Scooters.” https://www.amazon.de/-/en/gp/bestsellers/sports/3955199031 (accessed Jun. 14, 2022).

[65] Kraftfahrt-Bundesamt. “Monatliche Neuzulassungen 2022.” https://www.kba.de/DE/Statistik/Fahrzeuge/Neuzulassungen/MonatlicheNeuzulassungen/monatl_neuzulassungen_node.html?yearFilter=2022&monthFilter=05_Mai (accessed Jun. 15, 2022).

[66] European Union. “Worldwide harmonised Light-duty vehicles Test Procedure (WLTP) and Real Driving Emissions (RDE).” https://eur-lex.europa.eu/EN/legal-content/summary/worldwide-harmonised-light-duty-vehicles-test-procedure-wltp-and-real-driving-emissions-rde.html (accessed Aug. 25, 2022).

[67] Decathlon Deutschland. “Fahrradkorb 100 13 Liter für Gepäckträger.” https://www.decathlon.de/p/fahrradkorb-100-13-liter-fur-gepacktrager/_/R-p-171294?mc=8396335&gclid=CjwKCAjwu5yYBhAjEiwAKXk_eIr328pqRpk-0PRYpxke6NHmqEiMLbWt0wFm1qLs-JolLmUc20Hy_BoC8l0QAvD_BwE (accessed Aug. 25, 2022).

[68] Mi Deutschland. “Mi Electric Scooter 1S.” https://www.mi.com/de/mi-electric-scooter-1S/specs/ (accessed Aug. 4, 2022).

[69] Giant Bicycles Deutschland. “Tourer GTS (2021).” https://www.giant-bicycles.com/de/tourer-gts (accessed Aug. 4, 2022).

[70] Giant Bicycles Deutschland. “Entour E+ 0 [LDS/CORE/500WH] (2022).” https://www.giant-bicycles.com/de/entour-eplus-0--lds-core-500wh--2022 (accessed Aug. 4, 2022).

[71] TWIKE Blog. “Mehr Effizienz – weniger Verbrauch.” http://blog.twike.com/mehr-effizienz-weniger-verbrauch/ (accessed Jun. 17, 2022).

[72] TWIKE Blog. “TWIKE 5 hat große Klappe … und auch was dahinter.” https://blog.twike.com/twike-5-hat-grose-klappe-und-auch-was-dahinter/ (accessed Aug. 5, 2022).

[73] Renault Group Newsroom. “All there is to know about Renault Twizy.” https://www.renaultgroup.com/en/news-on-air/news/all-there-is-to-know-about-renault-twizy/ (accessed Jun. 27, 2022).

[74] Micro. “FAQ: Does the Microlino have a heating/air conditioning system?” https://microlino-car.com/en/support/faq/hat-der-microlino-eine-heizung-klimaanlage (accessed Jun. 17, 2022).

[75] Smart Deutschland. “smart fortwo: Technische Daten.” https://www.smart.mercedes-benz.com/de/de/modelle/fortwo-coupe/technische-daten (accessed Aug. 4, 2022).

[76] ADAC. “Autokatalog: smart fortwo coupé 1.0 (05/18 - 06/19): Technische Daten.” https://www.adac.de/rund-ums-fahrzeug/autokatalog/marken-modelle/smart/fortwo/453/293306/#technische-daten (accessed Jun. 28, 2022).

[77] Smart Deutschland. “Technische Daten.” https://www.smart.mercedes-benz.com/de/de/modelle/technische-daten-eq (accessed Jun. 17, 2022).

[78] Volkswagen Newsroom. “The technical data of the new Golf.” https://www.volkswagen-newsroom.com/en/the-new-golf-international-vehicle-presentation-5609/the-technical-data-of-the-new-golf-5626 (accessed Jun. 17, 2022).

[79] ADAC. “Autokatalog: VW ID.3 Pure Performance (01/21 - 05/21): Technische Daten.” https://www.adac.de/rund-ums-fahrzeug/autokatalog/marken-modelle/vw/id3/1generation/319026/#technische-daten (accessed Nov. 11, 2022).

[80] Volkswagen Deutschland. “Konfigurator - Der neue ID.3.” https://www.volkswagen.de/de/konfigurator.html/__app/der-neue-id-3/id-3-pro-sg/der-id-3-pure.app?---=%7B%22filter-service%22%3A%22%2F%3FengineType%3DElektro%22%2C%22configuration-step-navigation-service%22%3A%22%2F%3FconfigStep%3D%257B%2522context%2522%253A%252230270-33212-Pro%2522%252C%2522configurationStep%2522%253A%2522exterior%2522%257D%22%7D&buildabilityStatus-app=buildable&category-app=private&carlineId-app=30270&salesGroupId-app=33212&trimName-app=Pro&modelId-app=E113MJ&

modelVersion-app=0&modelYear-app=2023&exteriorId-app=F14+C2A1&interiorId-app=F56+++++XX&options-app=GYCRYCR (accessed Jun. 17, 2022).

[81] K. Schleinitz, L. Franke-Bartholdt, T. Petzoldt, S. Schwanitz, T. Gehlert, and M. Kühn, "Pedelec Naturalistic Cycling Study," Gesamtverband der Deutschen Versicherungswirtschaft e. V., Rep. 27, Aug. 2014. Accessed: Oct. 31, 2022. [Online]. Available: https://www.udv.de/resource/blob/79742/8cde8674da1bc5f8543052606804ac08/27-pedelec-naturalistic-cycling-study-data.pdf

[82] B. Föttinger, "E-Scooter - Fahrrad oder Kraftfahrzeug?," Diplomarbeit, Johannes Kepler Universität Linz, 2021. [Online]. Available: https://epub.jku.at/obvulihs/download/pdf/6110725?originalFilename=true

[83] ADAC. "Spritpreis-Entwicklung: Benzin- und Dieselpreise seit 1950." https://www.adac.de/verkehr/tanken-kraftstoff-antrieb/deutschland/kraftstoffpreisentwicklung/ (accessed Nov. 16, 2022).

[84] Bundesministerium für Wirtschaft und Klimaschutz. "Durchschnittlicher Strompreis für einen Haushalt." https://www.bmwk.de/Redaktion/DE/Downloads/I/Infografiken/durchschnittlicher-strompreis-haushalt.pdf?__blob=publicationFile&v=6 (accessed Apr. 7, 2022).

[85] K. August. "„Wie viel CO_2 steckt in einem Liter Benzin?"." https://www.helmholtz.de/newsroom/artikel/wie-viel-co2-steckt-in-einem-liter-benzin/ (accessed Jul. 5, 2022).

[86] Umwelt Bundesamt. "Bilanz 2019: CO_2-Emissionen pro Kilowattstunde Strom sinken weiter: Deutschland verkauft mehr Strom ins Ausland als es importiert." https://www.umweltbundesamt.de/presse/pressemitteilungen/bilanz-2019-co2-emissionen-pro-kilowattstunde-strom (accessed Jan. 25, 2022).

[87] regiomove. "regiomove: Vernetzte Mobilität für die Region Mittlerer Oberrhein." https://www.regiomove.de/ (accessed Oct. 31, 2022).

[88] Allgemeiner Deutscher Fahrrad-Club. "Musikhören beim Radfahren." https://www.adfc.de/artikel/musikhoeren-beim-radfahren (accessed Jul. 25, 2022).

[89] J. Fehrenbacher, "Herausforderungen und potentielle Einsatzfelder von leichten elektrischen Fahrzeugen (LEVs)," Bachelorarbeit, Institut für Fahrzeugsystemtechnik, Karlsruher Institut für Technologie (KIT), Karlsruhe, Germany, 2022.

[90] R. Kaiser, "Konzeptionelle und methodologische Grundlagen qualitativer Experteninterviews," in *Qualitative Experteninterviews*, Springer VS, Wiesbaden, 2014, pp. 21–49. [Online]. Available: https://link.springer.com/chapter/10.1007/978-3-658-02479-6_2#citeas

[91] ubitricity. "Laternen werden Ladesäulen - E-Mobilität für Deutschland." https://www.ubitricity.com/de/ladepunkte-deutschland/ (accessed Jul. 11, 2022).

[92] C. Jeß. "Shell will E-Autos das Laden an Straßenlaternen ermöglichen." https://www.autobild.de/artikel/e-auto-laden-strassenlaterne-shell-ubitricity-enercity-ilamp-eon-100-kw-berlin-20368977.html (accessed Jul. 11, 2022).

[93] Hochschule Koblenz. "E-Auto an der Laterne in Rekordtempo laden: Hochschule Koblenz meldet Patent an." https://www.hs-koblenz.de/hochschule/organisation/pressebereich/aktuelles/detail/_n/e-auto-an-der-laterne-in-rekordtempo-laden-hochschule-koblenz-meldet-patent-fuer-innovativen-ansatz-an (accessed Jul. 11, 2022).

[94] H. Dilk. "So wird die Laterne zur Ladestation fürs E-Auto - Mobility.Talk." https://mobility-talk.com/laterne-als-ladestation-e-auto-an-der-laterne-laden/ (accessed Jul. 11, 2022).

[95] S. Rueda, "Superblocks for the Design of New Cities and Renovation of Existing Ones: Barcelona's Case," in *Integrating Human Health into Urban and Transport Planning: A Framework*, M. Nieuwenhuijsen and H. Khreis, Eds., Cham: Springer International Publishing, 2019, pp. 135–153.

[96] EBRD Green Cities Policy Tool. "Pedestrianisation and car-free zones: Ljubljana, Slovenia." https://www.ebrdgreencities.com/policy-tool/pedestrianisation-and-car-free-zones-ljubljana-slovenia-2/#results-and-lessons-learned (accessed Dec. 28, 2022).

[97] European Commission. "CO_2 emission performance standards for cars and vans." https://climate.ec.europa.eu/eu-action/transport-emissions/road-transport-reducing-

co2-emissions-vehicles/co2-emission-performance-standards-cars-and-vans_en (accessed Apr. 11, 2022).

[98] European Parliament, *Regulation (EU) 2019/631 of the European Parliament and of the Council of 17 April 2019 setting CO_2 emission performance standards for new passenger cars and for new light commercial vehicles, and repealing Regulations (EC) No 443/2009 and (EU) No 510/2011*, 2019. Accessed: Apr. 11, 2022. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:02019R0631-20210111&from=EN#tocId8

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