Small Electric Vehicles—Benefits and Drawbacks for Sustainable Urban Development

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Abstract Small electric vehicles (SEVs) have the potential to contribute to climate protection, efficient land use, and mitigation of air pollution in cities. Even though, they show many benefits that could enhance urban quality of life, they are not yet widely used. In this paper, benefits as well as drawbacks for these vehicles are discussed by combining literature research and outcomes of a mixed-method approach with expert interviews and an online survey. Resulting from these arguments, a vision for SEVs in urban areas is drawn showing them integrated in a mix of various transport modes. Environmental benefits are derived, for example, from their lower weight and low maximum speed making them a more energy-efficient transport option than heavier cars. Additionally, the small vehicle size lowers land use for SEVs and, e.g., allows for less parking areas needed. However, they also hold constraints that need to be dealt with in different ways. On the one hand, the lower safety compared to passenger cars is an issue that is further worsened by current traffic regulations. On the other hand, costs in terms of purchase prices seem to be an issue for SEVs.

Keywords Small electric vehicles · Vehicle concepts · Sustainable transport

1 Introduction

Cities are growing worldwide due to an increasing population, and simultaneously, motorization intensifies. Challenges such as local environmental pollution, a lack of space, and saturation of existing infrastructure are thereby becoming more pressing. The urgency to act and the need for new forms of mobility sets the tone not only for politics, urban, and transport planning but also leads some companies to offer new solutions. One contribution to climate protection and to cope with local challenges

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is the deployment of small and lightweight electric vehicles when replacing heavier cars and being applied together with other ecological transport modes like public transport.

This paper discusses benefits and drawbacks that could result through a more widespread usage of SEVs in cities. Adding to a literature-based research is results from qualitative and quantitative methods in a mixed-method approach. Analyses include expert interviews and an online survey. The results show that these vehicles bring many advantages within urban areas. In addition to other aspects, especially lower land use due to the small vehicle size offers potential by conversion of traffic areas and increased air quality. If SEVs would replace vehicles with internal combustion engines (ICE), significantly fewer air pollutants could be emitted. Due to their lower weight and maximum speed, they are even more energy-efficient than most normal battery electric vehicles (BEV).

Nevertheless, the survey showed that there are many hurdles to be overcome. These drawbacks affect the development of the vehicle technology and transport planning within the cities. These include, for example, safety aspects, e.g., as the vehicles are very light which is often connected to lower passenger safety and crash tests are not required by EU law for type approval of this vehicle category. An example for drawbacks regarding city planning is that most cities are not designed for these vehicles and therefore do not offer advantages in use, such as privileged use of lanes or parking spaces. In a global comparison in some world regions, there is a large market for SEVs such as the Asian countries China, Japan, or India [1]. Europe and the United States, however, only show small sales numbers [2, 3].

In the following, the term SEV will first be narrowed down and explained. Then, advantages and limitations of the vehicles are presented using literature research supported by the results of a qualitative and quantitative survey. For the last section, a future vision of how urban mobility could look like is drawn including all types of mobility.

SEV definition. SEVs in this chapter are referred to three- and four-wheeled L class vehicles according to EU Regulation No. 168/2013. They also include electric vehicles of categories M1 or N1 which do not exceed 3.5 m, a maximum drive power of 55 kW, and an unladen weight of up to 1200 kg.

2 Mixed-Method-Approach

Adding to desk-based research, collecting data and existing literature on benefits and drawbacks of SEVs a mixed-method-approach consisting of quantitative and qualitative empirical social research was carried out. For the qualitative approach, semi-structured expert interviews were conducted. This way, it was possible to derive exclusive knowledge from professionals with different backgrounds by giving insights to practical application, experiences, and research. The evaluation approach is based on a concept of Meuser and Nagel [4] and follows the approach of qualitative content analysis. In a repetitive process, successive categories are formed. The content of the interviews is encoded by paraphrasing individual text passages with the same content. They are classified thematically with categories which are congruent with the key questions. Further, sub-codes comprise partial aspects. Then, statements can be compared and conceptualized. Ultimately, a theory is created by inductively generalizing statements on the basis of individual findings [5]. While the interviews were being conducted, at the same time, the target groups filled out a standardized online survey. Combining these methods in a concurrent triangulation similarities, divergences and additional information could be derived and thus ensure higher validity of information. For both methods the same research questions were applied following a parallel design QUAL + QUAN [6]. The survey took place from March to October 2018 on three main topics:

- Knowledge about SEVs within municipalities and the urban population
- Target groups and usage concepts
- Obstacles and chances for SEVs.

The survey collects assessments of international experts from municipalities, research institutes, consultants, associations, and manufacturers. In total, 32 telephone interviews were held, and the online questionnaire had a sample of 90 with respondents from Asia, USA, and Europe. For both methods, results are not representative due to the limited number of experts.

3 Definition of Small Electric Vehicles

Literature contains a vast array of descriptions, definitions, and categorizations of SEVs and differs regionally. Some of the designations are listed in Table 1 with respective regulations. The categories often include not only type approval for vehicles with electric drive but also vehicles with ICE. In Japan, for example, the term new Mobility vehicles is used which includes Kei cars that have been in use since the 1950s. In this publication, the term SEV is applied as a superordinate term.

European regulation. There are various country-specific categories which in turn have different designations and regulations for type approval. For the vehicles in the scope of this paper, the European regulatory framework for L-category vehicles (L2e, L5e, L6e, and L7e) is defined in Regulation No. 168/2013. Micro- and subcompact electric vehicles with four wheels could in certain cases also be part of category M1, passenger cars, that are laid out in 2007/46/EC. M1 is defined as a light category of motorized vehicles. Some technical parameters of cars in this segment are limited, e.g., number of passenger seats must not exceed 8, but have no further requirements regarding, e.g., mass, maximum speed (minimum speed is 25 km/h), or measurements. Even though there are differences between the M1 category and L7e such as the maximum mass, required crash tests, and width, some vehicles that fulfill requirements of both categories can be registered as either M1 or L7e [8, 11, 12].

Table 1 Alternative terms for SEVs in different countries and limitation of parameters [1, 7–10]

Country	Term	Max. speed (km/h)	Max. mass (kg)	Max. power (kW)	Max. dimensions L × W × H (m)
USA	Low-speed-vehicle (LSV)	40	1360	–	–
	Medium-speed-vehicle (MSV)	56	2268	–	–
	Also: Neighborhood electric vehicle (NEV)				
China	Low-speed electric vehicle (LSEV)	Legislative proposal for vehicles with speed limits <100 km/h in discussion			
Japan	New mobility vehicle	–	–	8	3.4 × 1.48 × 2
	Mini vehicle (Kei car)	–	–	47	3.4 × 1.48 × 2
South Korea	Low-speed electric vehicle (LSEV)	60	1361	–	–
Europe*	L-category vehicle	Various**	Various**	Various**	Various**

* small M1 vehicles are not further specified in this table
** limitation of parameters depending on subcategory

Most of the L-subcategories have the same permitted maximum dimensions: width $\leq$ 2 m, height $\leq$ 2.5 m, and a length that varies between 3.7 and 4 m. The maximum speed varies between 45 km/h, 90 km/h, or no maximum speed. The L2e vehicles are defined by three-wheeled mopeds and represent the lightest class in terms of weight limit ($\leq$ 270 kg). Category L5e includes three-wheeled tricycles, which can weigh up to 1000 kg without batteries. L6e describes light on-road quadricycles with four wheels and a maximum unladen weight of 425 kg. The maximum power permitted varies between 4 and 15 kW, although 15 kW only relates to class L7e. An exception is L5e with no power or speed limitations.

4 Benefits and Obstacles Derived from SEVs

The survey included perception on advantages and disadvantages of the application of more SEVs within urban traffic. The most important aspect mentioned in the interviews is the reduction of land usage especially in regards to stationary traffic. Another major advantage mentioned in the interviews and in the online survey is seen in the vehicles' light weight and the corresponding low energy consumption. An important prospect in particular for municipalities is the improvement of air quality. Air pollution in cities is a concern worsened by population growth and motorization rate. Figure 1 shows the quantitative online evaluation and draws decisive advantages to the reduction of land use and air quality. One benefit that stands out while occurring sporadically in the interviews is noise reduction. An

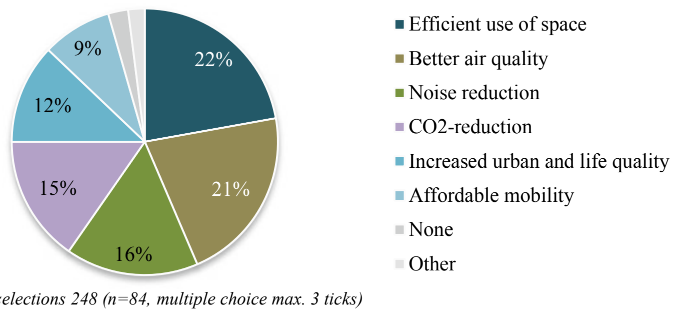

Fig. 1 Prospects for more SEVs in cities

important component in the decision of transport options for consumers is costs. Compared to EVs these vehicles are less expensive and have lower operation costs. The costs are, however, a controversial topic depending on the comparison of SEV purchase prices with different types of vehicles.

In regards to possible concerns in the interviews and the online survey, safety was mentioned as the most sensitive issue. Another stated worry in both methods (Fig. 2) was the possible switch from public transport (PT) and active modes to SEVs. Even though, this is a mentioned concern in the existing literature, there is no evidence on the potential of people switching from PT or active modes to SEVs. According to the interviewed experts, the aim of transport planning has to be on reducing the overall number of vehicles and not simply increasing it by introducing more SEVs. SEVs, however, can play a part in new mobility forms such as sharing systems. For the use, a lack of adapted infrastructure needs to be taken under consideration as currently there are no benefits for SEVs.

When talking about a sustainable mobility offer, the three pillars of social, ecological, and economic sustainability should always be considered. Although not all of them are explicitly mentioned in this paper, they often implicitly find their effect. For example, saving space for private parking would mean that the cost of parking, which is often passed on to residents, regardless of whether they own a car or not, could decrease.

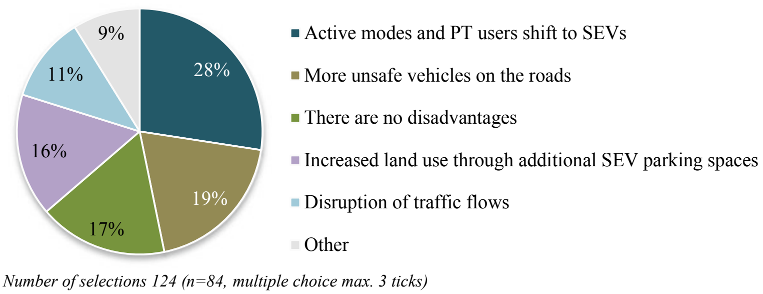

Fig. 2 Obstacles if more SEVs would operate in urban areas

4.1 Potential for Environmental Benefits

The switch from ICE vehicles to electrically propelled vehicles itself holds many benefits especially in urban areas. SEVs and BEV have a positive effect on global climate and air quality. Charging of batteries using electricity generated on renewable energies increases the positive effects and does not simply shift the CO_2 tax geographically from the city to energy production plants based on fossil fuels [13]. However, low energy consumption is still important to mitigate negative impact from renewable energy generation and due to limited available energy amount.

Contradicting climate change mitigation efforts, a trend toward larger and heavier cars can be seen since the introduction of the first serial production EVs, as the technology is advancing in terms of, e.g., higher ranges. As a negative effect, this in turn requires larger and heavier batteries using more critical raw materials for the production of the batteries and making the cars inefficient in operation. Comparing an M1 electric car, the BMW i3, with an L7e category vehicle, the Renault Twizy, the BMW i3 has a significantly higher power consumption with 13.1 kWh/100 km (measured according to VO (EU) 715/2007 [14]) than the Twizy with 8.4 kWh/100 km [15] (ADAC-Autotest). Though the consumption statements are not directly comparable due to different test cycles and should therefore not be used to quantify relative energy savings, they show the energy inefficiency of heavy vehicles bearing in mind average occupancy rates of below two persons per vehicle [16]. The inefficiency can further be illustrated by comparing the range per kWh. In this way, an SEV with one kWh can go considerably further than an electric car. Figure 3 shows the relation between the Twizy with maximum speed of 45 and 80 km/h, a Smart for two and a Mercedes-Benz B-Class EV. Adding to this, the relation between transport task and vehicle weight is highly inefficient for passenger cars based on average occupation rate. The transport task passenger transport in Germany in average means a carrying capacity of 115 kg, calculated from the average occupation rate 1.5 [16] and the average weight of an adult person 77 kg [17]. While the weight of the Twizy exceeds this transport weight 4.3 times, the B-Class exceeds the average transport task by almost 14 times.

4.2 Potentials for Land Use

Increasing population in cities intensifies the situation of scarce space and raises the question of equitable contribution of land. The current land used for transport infrastructure accounts for a large part of the total area. For example, in German large cities, transport infrastructure takes up 12% in average of the total area and even a quarter of land used for transport infrastructure compared to human settlement areas [18]. Considering the average rate of occupation, private cars are the most intense mode of mobility occupying valuable space in cities [13].

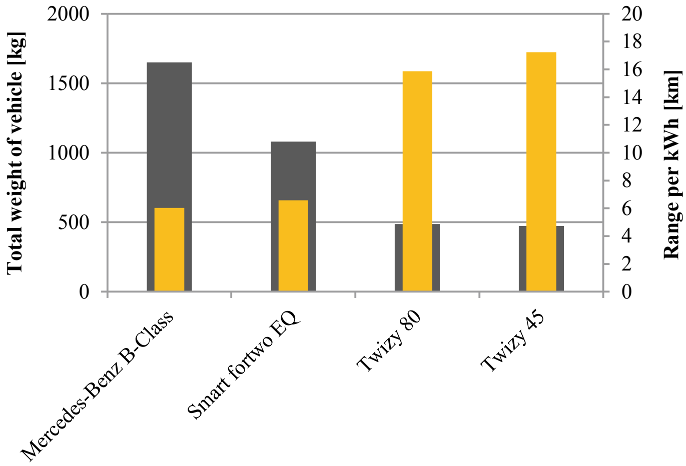

Fig. 3 Vehicle weight depending on the range in kWh, range values based on different driving cycles, for passenger cars: NEDC combined

Smaller sized vehicles take up less space on the road and require smaller parking spaces. An average parking space size of 5 m in length and approximately 2.5 m in width could be used by, e.g., three Renault Twizys or Toyota i-Roads.

Comparing space needed by SEVs, smaller M1 models, and large M1 cars, differences become apparent in parking position and in case of operation with speeds of 30 km/h (see Fig. 4). Taking into account stopping and reaction distance, the Renault Twizy needs about 20 m^2 less space than the Mercedes B-Class car in situations with 30 km/h speed. Differences in space requirement for driving are therefore minor compared to parking space potentials. Furthermore, the Mercedes B-Class enables the transport of up to five persons, resulting in a low space per person, However, with regard to average occupancy rates of 1.5 [16], this is a rather theoretical potential, used in a low percentage of trips. Even more, the figure shows the high potential for savings in land use for SEVs in parked position.

Although efforts are being made in some cities to introduce stricter regulations, e.g., in connection with the construction of new buildings, the cost of parking is mostly carried by residents. Less and smaller parking lots could decrease the overall costs for residents as well as for municipalities. Furthermore, under current circumstances SEVs spend less energy idling as they account for shorter parking search traffic than cars, because they fit in many different sized and shaped parking lots and usually can park crossways [7].

With regard to the actual potential for rededicating land used by cars, it is important to identify which user groups can switch to SEVs according to their travel behavior and how high the potential is. In the chapter “Fields of applications and transport-related potentials of small electric vehicles in Germany,” a technical feasible substitution potential is calculated using data from a national household survey (MiD).

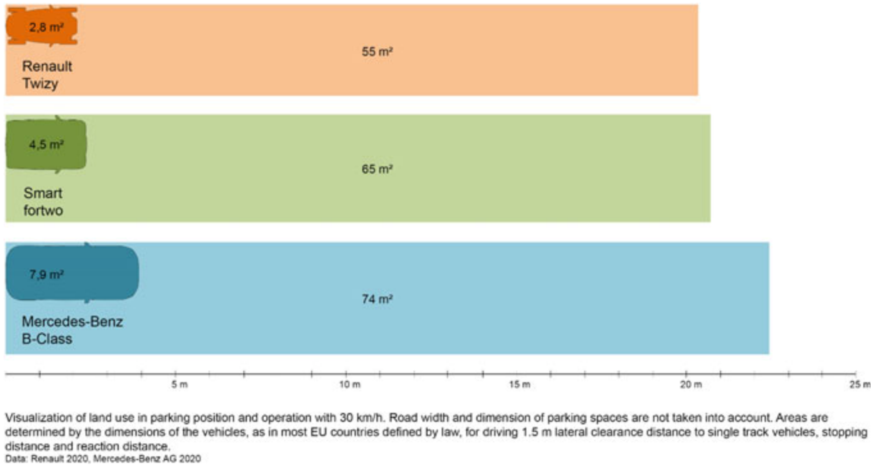

Fig. 4 Land use of different vehicle models

4.3 Safety as a Large Drawback

Although the reduced size and weight bring many benefits for the user, municipalities, and the environment, they have a higher safety risk to occupants, especially in the event of a collision with larger vehicles. This is reflected by the results of the quantitative survey, where concern about more unsafe vehicles on the road is the second leading obstacle for SEVs in the opinion of the participants. In this case, occupants of the vehicle with the lowest mass sustain the highest damage [7]. Besides disadvantages for lightweight vehicles due to physical laws that determine accident dynamics of collisions with unequal opponents, safety features of both lightweight and heavy vehicles influence the extent of lesions in case of a collision.

On the one hand, SEVs are not equipped with extensive safety equipment due to the necessity of lightweight design and cost. In many countries and also according to EU regulations, crash tests for SEVs are not required by law. Therefore, the vehicles are equipped with minimal safety features [19]. Besides the lack of mandatory crash tests, there are safety requirements that are laid down in EU Regulation No. 168/2013 and the delegated EU Regulation No. 3/2014.

On the other hand, safety structures of heavy cars are not optimized for collisions with very lightweight vehicles and usually relatively rigid. Deformation of structures that would reduce impact forces by transforming kinetic energy into deformation energy is therefore limited. This cannot be compensated by structures of SEVs and thus leads to high deceleration of occupants in the lightweight vehicle, causing more severe injuries. High speeds of passenger cars add to the risks in case of an accident.

Extended safety features like airbags as standard equipment, improvement of vehicle structures and active safety features like emergency brake assistants could enhance safety of SEVs. Even more than technological measures, regulation could improve the situation for SEV occupants. When both SEVs and fast, heavy cars are mixed in high speed traffic, the safety risk is higher. The reduction of the maximum speed allowed, e.g., in inner-urban areas or city highways, would improve the situation. This would not only protect SEV occupants, but also vulnerable road users like mopeds, bicycles, or pedestrians. Scientific investigations show a direct link between reduction in average speed and decrease in accident numbers and crash severity, e.g., [20–23]. The extent of safety increase varies depending on initial speed and further parameters like infrastructure characteristics. For urban roads, speeding is one key factor in traffic accidents with impacts on both frequency of crashes and severity of injuries [24].

Safety issues of transport modes like bicycles and mopeds are more severe compared to SEVs; however, in contrast to SEVs, they are sold and used in large volumes. It is common consent that safety could be increased by optimized traffic regulation and infrastructural measures rather than with enhanced safety structures of these kinds of vehicles. This is similar for SEVs, even though the safety potential of vehicle technology is considerably higher and should therefore be further developed additional to regulative and infrastructural measures.

4.4 Costs of SEVs

The aspect of costs, in particular with regard to the purchase price, was discussed diversely in the qualitative analysis. In a comparison of costs, it is always very important to distinguish between the different types of vehicles. For example, the cost of owning or buying an SEV to offer in a sharing business is very high compared to e-scooters, bicycles, and some second-hand cars. Particularly in comparison with lower-priced cars, the purchase price can have a negative effect on the purchase decision, as SEVs often appear expensive with regard to limited flexibility in the transport of people and goods. However, compared to new cars, especially BEVs, they are relatively less expensive (Fig. 5).

For manufactures, the production costs for small series vehicles are significantly more expensive than mass production. However, in order to offer a vehicle to a broader user group, an attractive price is necessary. Manufacturers are therefore often faced with a dilemma. For example, by setting higher safety standards, they could offer a safer and high-quality product, but would have to set the selling price very high. For large companies developing a model for a small series vehicle in their portfolio often does not make sense as the economic risk is too high to invest in.

In the qualitative analysis, it became clear that the current situation is not favorable for SEVs in many countries, i.e., high speed limits in cities, no advantages in regards to parking or use of lanes, few incentives, few models on the market. In comparison with cars for many people, this leaves SEVs with few rewards to people considering them as relatively expensive.

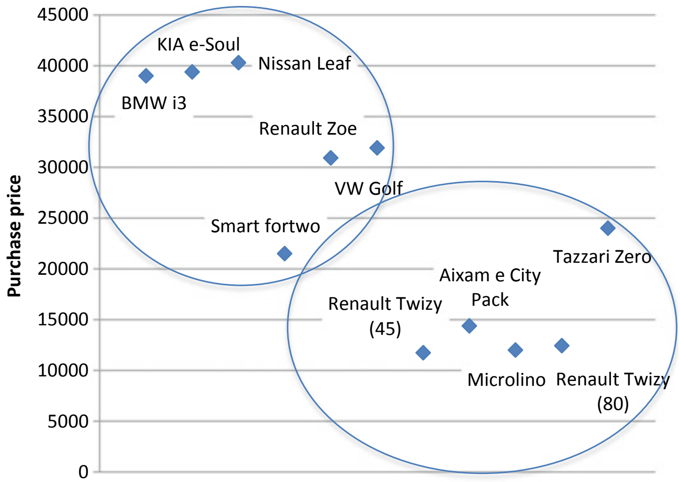

Fig. 5 Purchase prices of the top five new registrations of EV models in Germany 2018 [25], (Smart fortwo includes *EQ fortwo coupe* and *fortwo coupe ed*) and purchase price of common SEV models, Renault Twizy and ZOE purchase price calculated with battery rent for 8 years, estimated purchase price for Microlino

5 Vision of SEVs

Increasing the number of SEVs on the road, certain risks remain in the opinion of many experts. Thus, in the current traffic environment and with their lack of minimum safety requirements, they might pose some safety risks. Furthermore, a change in the mind set of how people move is needed in order to achieve that these vehicles are regarded as an equal vehicle concept for everyday mobility. Otherwise, SEVs tend to be considered at most as an additional vehicle, which makes the vehicle price appear very high. Overall, however, SEVs offer great potential for sustainable change, especially in urban areas. Scaling down weight and size of large and heavy cars has a high impact as they consume less energy and show potential to reduce space used in cities. In order to provide benefits for these vehicles to become more widely used measures including push and pull elements with the objective of replacing passenger cars with SEVs are of high importance.

As an exemplary visualization of the positive potential of SEVs for urban planning, Fig. 6 shows a vision of how urban transport could look like with SEVs. This vision is derived from statements made in the expert interviews as well as from literature research. In light of future urban landscapes especially land distribution could be modeled differently with, e.g., smaller sized parking lots, if SEVs would replace considerable numbers of passenger cars. The car would not be the dominant part which allows people-oriented city planning, creating more attractive

Fig. 6 Vision for SEVs in urban areas

surroundings with higher living standards. The introduction of SEVs into the mobility mix offers a high degree of diversification. The wider the range of mobility solutions available, the better the overall transport system can develop and harmonize with requirements of inhabitants. Therefore, SEVs can be used either as private passenger cars or within sharing schemes.

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