

Portable battery concept for light electric vehicles

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Summary

If the number of electric vehicles (EV) increases in the near future, the situation of parking lots combined with public charging stations will steadily become more difficult in urban and suburban areas. Not all EV drivers have the opportunity to charge their EV privately e.g. by using a Homecharger. This Problem can be solved, if light electric vehicles (LEVs) operate with portable batteries, in order to enable a battery charging as flexible as possible. Therefore the LEV should offer the option to recharge on-board by wire as well as external charging, for example at the apartment or office, due to the battery portability. Compared to usual EVs, the battery capacity and thus the size and weight of LEV batteries are smaller and lighter, which facilitates a portable battery concept. For the development of a portable battery concept, a lot of factors have to be considered for a user-friendly fitting and removing of the batteries such as weight, size, shape, but also installation space, height, and position. Furthermore, a lot of requirements like health protection, ergonomics and technical design have to be taken into account. Within this project, all these factors were researched and moreover a portable battery concept was developed. Additionally three different prototypes of battery packs were engineered and built with additive manufacturing.

Keywords: battery, light vehicles, energy storage,

1. Introduction

If car registrations increase continually like in the last years, our cities will experience an overload of cars in the near future. In that context, we will also suffer a shortage of parking lots and battery recharging opportunities for Electric Vehicles in urban and suburban areas. The nowadays defective and mostly fragmentary charging network will be another problem for EV-Users, as the current network is not sufficient for increasing numbers of EVs. [1] These are two additional challenges which prevent a fast and successful growth of e-mobility as preferred by governments and OEMs. Furthermore the public acceptance of e-mobility unfortunately is also quite low. [2] If the public charging network keeps growing as slowly in the near future as it does at the moment and if sales of EVs increase at the same time, providing enough public charging points will become a difficult challenge. [3] The main problem in urban areas will be scant parking space combined with a lack of charging points. In the field of light-electric-vehicles (LEV), a portable battery system can help to reduce the need of parking lots with charging opportunities. The batteries can be recharged while they are installed (internally) or individually outside of the vehicle (externally), for example in the

apartment or office. The portable part of this concept is already well-known and established at pedelec or e-scooter concepts even though in smaller dimension related to smaller capacities. For example Coup e-scooter sharing in Berlin uses portable Batteries to keep up their System. [6] In a very big scale, there are Omnibus-System with battery swapping and also Tesla investigated the idea for battery swapping at their electric vehicles. [4] [5] But, compared to pedelecs, LEVs are faster, heavier and have a lot of additional electricity consumers on board. Accordingly the required battery capacity of LEVs is higher which leads to the fact, that dimensions, weight and handling become essentially more important. Nevertheless the battery capacity and all consequential specifications of LEVs are much smaller than in full-size EVs and therefore appropriated to relieve or avoid the stationary charging network. The technology of battery swapping and portable batteries is not really new, but the big question is, how big and heavy should a portable battery be, for a daily utilization. In context of development work, the Fraunhofer Institute of Industrial Engineering IAO and the Institute for Human Factors developed a portable battery concept for light electric vehicles and built several versions of portable battery pack prototypes.

2. Requirements

The recharge process in this battery concept includes charging by wire (internally) and also by taking the batteries out of the vehicle for externally charging. At the charging-by-wire process, there are no differences to the existing ones in conventional battery electric vehicles (BEV). The big difference in this portable battery concept is, the battery packs can also get recharged while being removed from the vehicle. This allows to recharge the battery outside of the vehicle without any dependence to stationary charging points. This offers a full variability in case of charging. Like in technic developments the first step is the definition of all necessary requirements. They are separated in technical and ergonomic requirements.

2.1 Technical Requirements

For this work, the technical requirements come from a currently ongoing project. In this project the Fraunhofer IAO is developing a light electric vehicle, called in this paper as LEV1, in cooperation with four more project partners. The vehicle is a single-seater with limited luggage space or optional with a tip-up seat. The maximum speed is 60 km/h and it offers an electric range of 60 km. The maximum vehicle weight should meet 140 kg including the batteries. To save weight, the battery recharger is not integrated into the vehicle, which is important to recharge the portable batteries externally. Table 1 shows the most important target values for the development of the portable battery concept.

Table 1: Vehicle characteristics and target values of the LEV1

Power	electric
Seats	1 plus luggage space (or extendible to a tip-up seat)
Under carriage	inclinable
Power	4.5 kW
Maximum Speed	60 km/h
Electric range	60 km
Weight	140 kg (incl. battery)
Height	about 1500 mm
Width	<1000 mm

These specifications are in a direct dependence to the battery pack requirements and therefore to the volume and weight. For the electric range of 60 km the vehicle needs a capacity of 2.5 to 3 kWh if lithium-ion-batteries will be used. One big battery would be too big and heavy. To reach this capacity, two or three battery packs are needed. For manageable batteries, they should be split in three battery packs with 1 kWh and therefore 8 kg to 9 kg each or two battery packs with 1.5 kWh and 10 kg to 11 kg each. Due to the weight and size of the battery cells, there is no smaller and lighter composition possible. Also the regulation and monitoring electronics, electromagnetic relays, the cabling, mounts, the pins and a battery management

system is included. An active cooling or water cooling is not designated. The battery pack type characteristic is shown in Table 2.

Table 2: Battery pack type characteristics

Battery pack	Type 1	Type 2
Capacity	1 kWh (three battery packs)	1,5 kWh (two battery packs)
Volume	7,5 l	10 l
Weight	8-9 kg	10-11 kg
Range (electric)	20 km	30 km

Not only the weight and size of the battery packs are important, also the installation position in the vehicle is fundamental for a user-friendly installation and removal. The LEV1 has four different potential installation points which are given by the constructing engineers. These are in the front of the vehicle, in a height of about 700 mm (Position 1), under the driving seat (Position 2), behind the luggage space or tip-up seat (Position 3) or in the rear end of the car in a height of about 1000 mm. (Position 4). Figure 1 shows the different possible installation positions in order to the vehicle design. In the figure, there are shown two battery packs as an example. All installation positions are different and have been evaluated according to their characteristics. These are accessibility, balance point, passive cooling and safety in case of a crash.

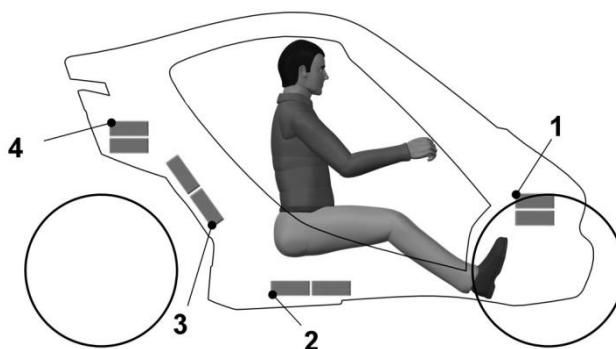


Figure 1: Possible position for the battery packs in the LEV

Position 1 has clear advantages in accessibility and a good working height for the removing and installation process. The position in the front of the vehicle has good possibilities for a passive cooling by the airstream. In case of an accident, the position 1 is unfavourable to safe the batteries with passive provisions. Relating to the balance point and driving dynamics, position 2 is absolute appropriated. The accessibility is worse, because the driver seat has to move to get access to the battery packs. The passive cooling in position 2 is possible, but not that easy to realize like in position 1. The accident safety is way better than in all other positions. The underfloor might be the best position to carry batteries in case of safety requirements. The accessibility at position 3 is analogical to position 2. Behind the luggage space or tip-up seat, it isn't very comfortable to remove or install the battery packs. The small size of the vehicle and entrance mouth demands a body twist to remove the batteries for external charging. Additional, the passive cooling properties aren't very good. The accident Safety is bad in case of a rear end collision. The same problem shows position 4 at the rear end of the vehicle. The height at that position could be too high for smaller persons to install or remove the battery packs. According to this height, the balance point is too high and therefore very bad for the driving performance. The passive cooling possibilities in the rear are also worse. Additionally there could be a conflict between luggage space and space for the battery packs. The User should not decide whether he wants to take luggage/person or battery packs with him. This evaluation shows that the installation position 2 is the fittest, followed by position 1. Table 3 shows an overview for the technical evaluation of the installation positions.

Table 3: Evaluation of the possible battery pack positions

Features	Accessibility	Balance point	Passive cooling	Safety (crash)
Position 1	●●●	●●	●●●	●
Position 2	●●	●●●	●●	●●●
Position 3	●●	●●	●	●●
Position 4	●●	●	●	●

2.2 Ergonomic Requirements

The portable battery pack concept presupposes that the packs have to be carried from the vehicle to a recharging place. This can be for example the apartment or office. In this case the ergonomic requirements are very important to avoid injuries and particularly long-term damages of the user's bodies.

The weight and size for carrying battery packs are limited by the maximum portable weight for the human body. This helps to protect the user and avoid injuries. This maximum weight is determined by the *DIN 33411 physical strength of humans*. [7] This norm comprises the maximum human physical strength based on representative examinations. The removal of a battery pack is corresponding to a horizontal grab in a height of 400 mm. Figure 2 shows the scheme of the one-handed force portability.

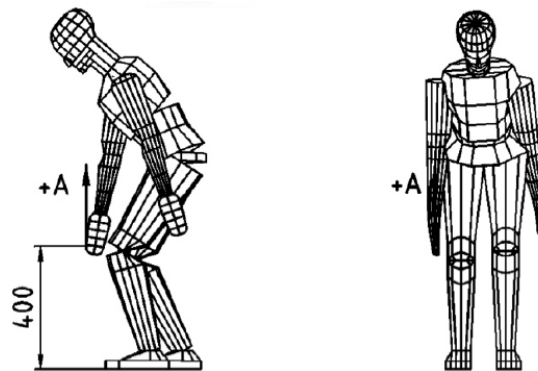


Figure 2: One-handed force portability, height 400 mm (Source: Norm DIN 33411-5, P. 10)

In consideration of the fifth force-percentile (that means 95 % of all women), the maximum weight for women is 28 kg and for men 57 kg. This value is the top boundary of the execution and does not include possible health risks. The approximate value for a safe using without damage for a longer time under load should not overstep 15 % of the maximum weight. For average women the top boundary is 5 kg and for men 7.5 kg. [8] Both types of battery packs, which were described in Chapter 2.1 with 8 kg to 11 kg are heavier. In this case, more analyses are necessary.

For carrying weights, there exist more parameter than maximum weight and long-term load. The worksheet for risk assessment published by the federal Institute of work protection and occupational medicine helps to identify more requirements. [9] The scenario of load-handling at the workplace is transferable to the removal and installation process of battery packs. The worksheet includes several weightings in the following fields: Time, load, posture and execution. The first step is the time-weighting. In this case, the operation is 'bearing' because the battery packs usually must be carried more than 5 meters. The total journey per day is determined between 300 m and 1000 m. Resulting in these parameters, the time-weighting has the characteristic weight number of 2.

The second step is the identification of the load-weighting characteristic number that is affected by the effective load. This is for male from 10 kg to <20 kg and results in the characteristic number of 2. For women the effective load is from 10 kg to <15 kg and brings the characteristic number of 4. In that case, the higher number for women is used for load-weighting.

The third step is the identification of the posture-weighting. There are four different categories which consider the body posture and load position. In our case the category with a light forward lean or twist of the body and the load near to the body fits best for portable batteries. The characteristic weight number is 2.

The last step is determining the risks of load-handling. Because of the restricted accessibility, depending on the installation position, the characteristic weight number for execution is 1. All characteristic weight

numbers make a score, which is shown in a table at the worksheet. That table contains statements about the risk for the human body which exists by removing or installing the portable battery packs.

$$total_{cwn} = (load_{cwn} + posture_{cwn} + execution_{cwn}) * time_{cwn} \quad (1)$$

cwn: characteristic weight number

Equation 1 shows, how the total characteristic weight number is calculated. The $total_{cwn}$ has a value of 14 and yields to the risk level 2. That means, there is an increased body stress, which can overstress less-resilient persons. This result shows, the battery packs should not be heavier than 15 kg and the installation position is responsible for the stress level of the human body in case of their movements by removing or installing the battery packs.

At the end there is a conflict between electric vehicle range and the battery pack weight. This analyse indicates, that the battery packs should not be heavier than 15 kg each. Less weight is better for the human health and avoids long-term damages. We expect the procedure of recharging batteries in this concept is repeating 4 times per day maximum. So there is no constant load for the human body and no following health risks by using a maximum weight of 15 kg per battery pack.

3. Questioning supported by a demonstrator

Not only the technical and ergonomic requirements are important for this battery concept, also the user's view is fundamental. Maybe the people don't accept the weight of 15 kg, which is the result of chapter 2. In that case, a portable battery concept has a minor chance of success. To analyse the user's opinion, a questioning was carried out which contained the ideal weight and installing positions. To bring the test-persons the concept closer, the questioning was gripped with a demonstrator for an interactive survey.

3.1 The demonstrator

According to the real measures of the vehicle, a demonstrator was constructed to illustrate a real situation for the procedure of removing and installing the battery packs. Also the doorway is nearly the same, like at the LEV1. In the demonstrator, there are platforms to simulate the installing position 1-4 in the correct height. Figure 3 shows a sketch of the demonstrator including the height of installations points.

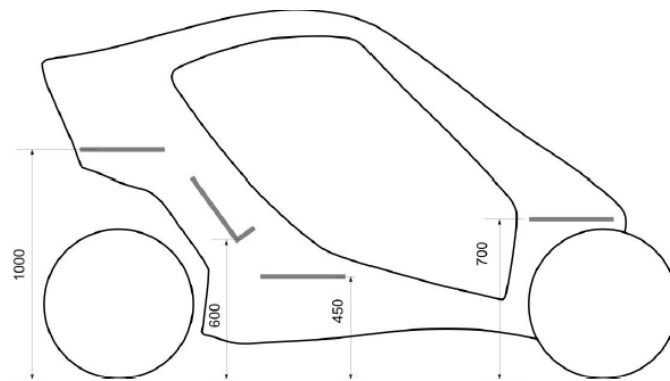


Figure 3: Sketch of the installation positions at the demonstrator (dimensions in mm)

For the weight simulation of the battery packs, battery dummies were made with standard jerry cans, filled up with cement. In order to a public research project, the demonstrator should be built as cheap and simple as possible. Three types of battery dummies were made with a weight of 8 kg, 10 kg and 12 kg according to the technical and economical results. The test-persons didn't know the weight of the different dummies during the questioning. The demonstrator helped the test-persons also to get a feeling about the dimensions of the developing vehicle. Figure 4 illustrates the vehicle demonstrator and battery dummies.



Figure 4: Vehicle demonstrator and battery dummies

3.2 The Questioning

The realization of the questioning effected by means of a standardized questionnaire. The demonstrator supported to get an interactive experiment to evaluate the battery weight and installation positions. The test-persons were chosen as consistent as possible in gender and age. Altogether, 52 persons were interviewed. 30.8 % of these were women and 69.2 % men. The age ranged from 20 to 70 years, with a median of 34 years. For a better overview, the age range was clustered in people with 29 years and younger, like trainees, Students or entrants, people between 30 to 49 years for persons with family and solid employment and also in people with 50 years and older, like pensioner and persons in the last period of their working life. The balance between these categories in the questionnaire was quite good. 34.6 % were under 29 years, 38.5 % between 30 and 49 years and 26.9 % were 50 years and older. Figure 5 shows the gender and age distribution.

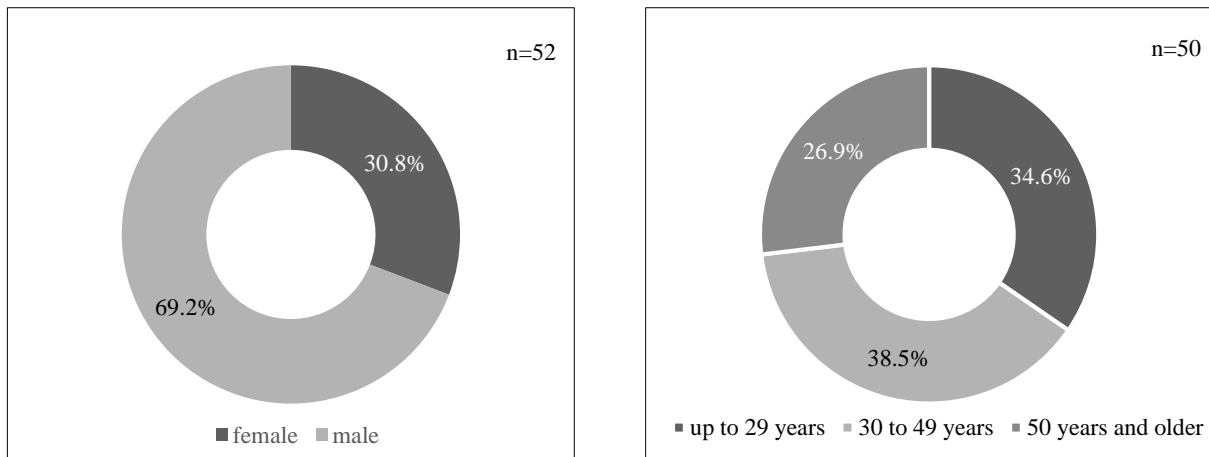


Figure 5: Gender distribution (left) and age distribution (right)

One of the main target at this work, is the identification of the ideal weight for portable batteries. Therefore, the test-persons should hold all types of the battery dummies and think about, which of them they can imagine to carry to the second floor, for example to the apartment or workplace. For the men, there is no clear trend between 8 kg, 10 kg and 12 kg. 12 male test-persons chose the heaviest pack which is not significant higher than for the other weights. Some of these saying, that the weight could easily be higher. The transportation will be no problem. In contrast to that, no one of the female test-persons choose the heaviest battery pack with 12 kg. The most of them prefer the lightest weight of 8 kg, which is acceptable for them to hold. Some of the test-persons said, that they accustomed to hold heavy weights at their work. The result is, that the maximum weight of a portable battery pack has to be 10 kg. Figure 6 illustrates that outcome. By offering a

higher weight for the battery packs, some people possibly can't change the packs or there is an uncomfortable procedure for them. This results in a no acceptance, which is bad for this concept. At the beginning of the questioning, all test-persons should rank the dummies according to their weight. No one had problems to rank them precisely. That result shows, the use of portable battery packs is very sensitive and a light weight reduction could result in a great effect.

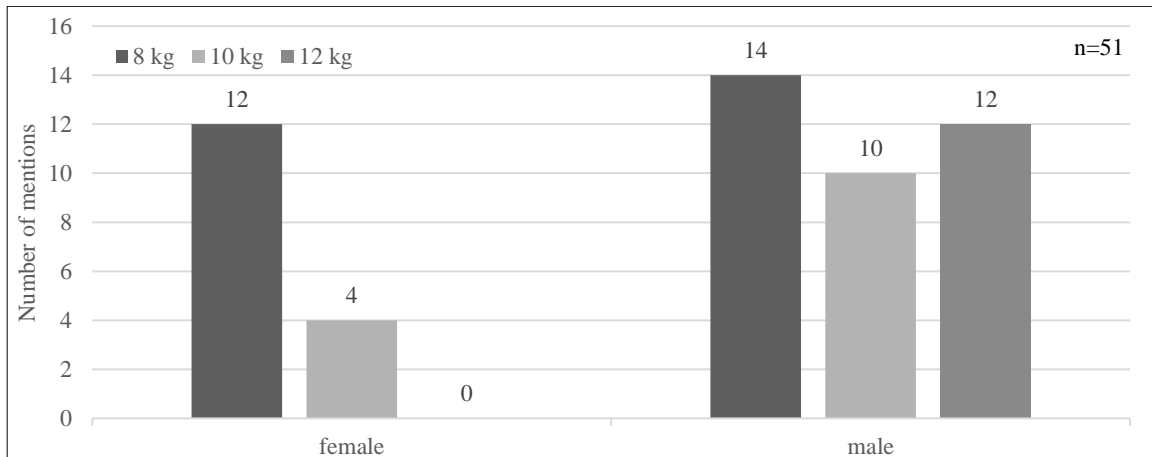


Figure 6: Tested weights in different weight categories

The second main target of this work, is to identify the user-optimized and technical expedient installation position for the portable battery packs inside the vehicle. The test-persons took the preferred battery dummy and carried out the removal and installation process at all possible installation positions. They had to rate the positions from good to bad within five steps. The absolutely preferred installation position is number 1 at the front of the vehicle. It is rated as 'good' from the most of the people. If test-persons rated this position as 'bad', they said, by parking forwards, the access is restricted. An interesting result is given by position 4, which differs to position 1 only in the height. The result is wide gritted with no clear trend. So the working height is a very important factor. In the literature the height for heavy lifting is between 800 and 900 mm. [10] Position 1 fits that range under consideration of the handle bar, positioned at a higher level. The test-persons said often, that a bending into the vehicle and twisting the torso to remove or install the battery packs, is not very comfortable. This is the reason why position 2 and 3 polled badly. To twist the torso is for the most people very uncomfortable. This result is confirmed by the statements of treatment recommendations for ergonomic and occupational medicine. If the battery packs are installed inside the vehicle, they should be accessible without twisting the upper part of the human body. Furthermore, the packs should not be in a too low position, to avoid an unfavourable lifting. Figure 7 shows the results of the evaluation according to the installation positions.

The biggest problem for the acceptance of the mobility change into the era of the electric vehicles, is the electric range and recharging possibility in context with the recharging time. This concept tries to degrade these problems for light electric vehicles. In that case, the test-persons were asked, which electric range they expect from one of the battery packs described in chapter 2.1. The Result includes a range of 10 km to 200 km. But the most people have a good feeling, how much electric range they can get with one battery pack which weighs 8 kg to 11 kg. The expectations are in a reasonable field. If a battery pack with an electric range of 20 km to 30 km will be produced, 44.2 % of the test-persons expectations will be fulfilled. These results are displayed at Figure 8.

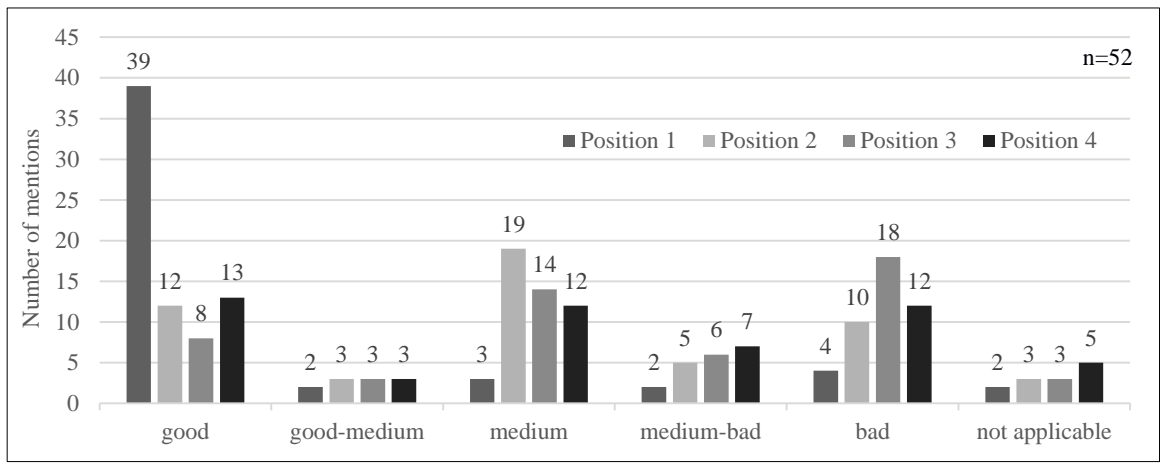


Figure 7: Evaluation of the installation positions in the vehicle

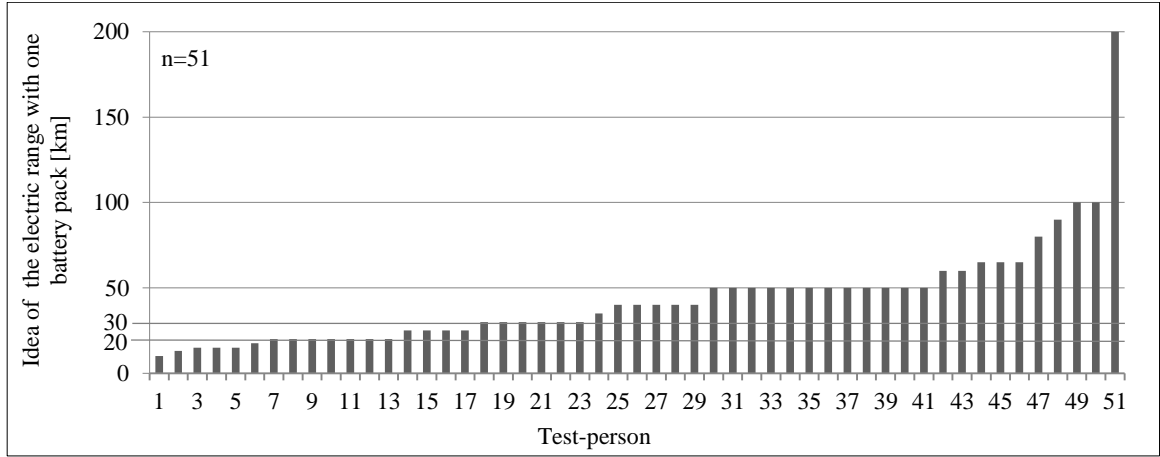


Figure 8: Expectation of electric range with one battery pack

At least, the test-persons were polled in case of their preferred charging concepts, to analyse if a portable concept is competitive with the conventional wired recharging system. 71.2 % say that a portable battery concept is sustainable but only, if wired charging is also available.

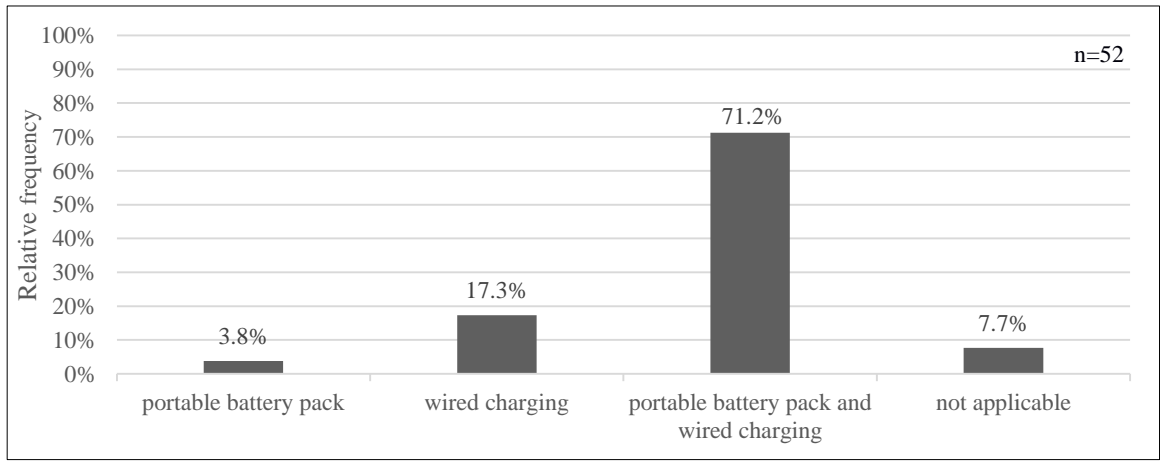


Figure 9: Preferred charging concept

A concept which offers only a portable battery system, should not be implemented. The combination of portable and wired recharging will be the best solution for light electric vehicles. People who have the possibilities to recharge their LEV in a garage at home or at a public recharging network, will not accept to remove the battery pack for each recharging process, if it's not necessary. The result is shown in Figure 9.

4. Construction of portable battery packs

To show, how portable batteries can be constructed, three variations are designed. For this construction the following requirements are considered. Like in Table 2 stated, volume and weight are defined. As good as possible, the connections, electric safety and the material are included. The most important requirement is the ergonomic design. For the construction, parts of the typical construction method are used. To get the ideal variants of possible solutions, the morphological box was exercised. Furthermore, the following five requirements are defined: Architecture of the case, orientation of the pack, design of the handle, handle order and the distribution of forces in the prototype. For the handle configuration the formal design is used. There are different design principals, but for the battery packs only the types of an additive, integrative or integral are considered. [11] For an ergonomic correct design, the following parameter are included:

- Hand position
- Type of grip
- Type of coupling
- Form
- Dimensions
- Material and surface

The designed battery pack prototypes were produced with an additive manufacturing process. The weight is simulated with blocks of lead inside the battery pack to analyse the outcome with variable weights. Figure 10 shows the three different types of the portable battery packs.

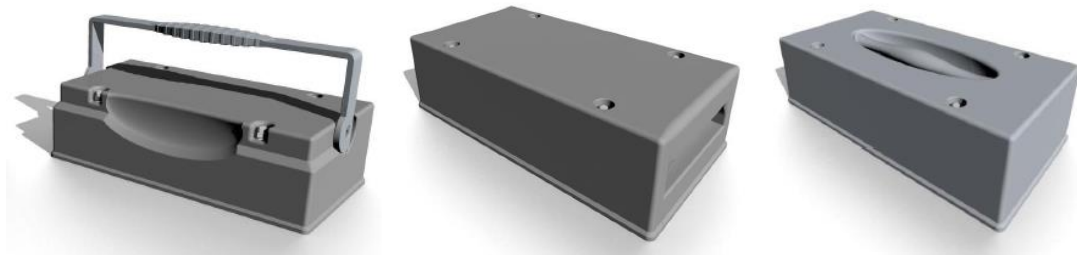


Figure 10: Designed variations of portable battery pack prototypes

5. Conclusion

How heavy and which dimensions should a portable battery pack have and also which installation positions in a light electric vehicle are for the human body able to use without a risks for health. This research questions are contents of this work. The maximum load for 95 % of all women is 28 kg. But this value is for a one-time lift up. For a long term load, the maximum weight is about 15 % of the maximum load, which is 5 kg for women. Both results are not exactly transferable for the portable battery concept, because the procedure of recharging is not a one-time and also no long-term process. The process of this concept stays between these results. The battery pack has also to be carried from the vehicle to the recharging place. So the transportation process has also to be analysed. Therefore four specific characteristic weight numbers had to be defined. By means of an equation, the risk for the human body was identified. The determined maximum weight of a portable battery is 15 kg. To evaluate these results of the maximum weight and the ideal installation positions in the vehicle, a questioning was carried out. This shows, the maximum weight of a

battery for a successful concept pack is 10 kg. The installation position must be good accessible, not too high (<900 mm) and not too low for a user-friendly removal and installation. Also very important is the ergonomically correct installation without any bending or twisting of the human's torso. The electric range between 20 km and 30 km per battery pack, is absolutely in an area of acceptance. The multitude of test-persons assessed a combination of a portable battery and a wired recharging system as the best concept for recharging a light electric vehicle. Finally three different battery pack prototypes were designed and produced under consideration of technically and ergonomically requirements to review the producibility. In summary, the portable battery concept is predesignated for the use in light electric vehicles if the combination with a wired recharging system for the maximum variability is given and the maximum weight is not beating 10 kg per battery pack.

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