Rapid-Charging For EVs – A Chance To Increase Acceptance For E-mobility?

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Summary

Still, limited battery capacities and required charging times are one of the biggest challenges for the broader acceptance of e-mobility. The question is, whether a rapid-charging infrastructure – today that means charging 80 % of SOC in about 15 min - can help to increase the acceptance for electric mobility. In order to estimate a potential for a higher acceptance of e-mobility we have to further understand if, and to what extend significantly reduced charging time is actually required from a user’s perspective. Two central use cases for rapid-charging are discussed in this contribution: rapid-charging as a) backup option and b) opportunity for extending the range for a trip. The research project SLAM places the cornerstone for building up and completing a comprehensive rapid-charging grid in Germany to support the build-up of charging infrastructure. As part of the project SLAM, it is planned to install up to 600 CCS (combined charging system) rapid-charging stations in Germany. In order to gain access to real user needs and opinions the project examines potential use cases for rapid-charging from a user’s perspective under real life conditions. Furthermore, a method to quantify the potential usage of rapid-charging technology is being developed.

This contribution aims at providing a better understanding of (potential) use cases for rapid-charging. A novel approach for a method is presented that may help to examine the impact of user aspects on route planning, rapid-charging infrastructure and the adequate usage of e-mobility.

1 Introduction

The use of electric vehicles (EV) is a political topic concerning the German government for several years. Until 2020, the aim of the German government is to bring up to one million vehicles on the roads of the republic. Right now, this goal seems to be a challenge since today just 1 of 1000 vehicles is an EV [4]. Obviously, there seem to be many reasons for not deciding for an EV. Although several studies also identified high costs and low battery capacities of an EV as reasons for deciding against these vehicles (e.g. [1], [8], [9], [10]), this paper focuses on the following topics as possible reasons for the reduced demand of EVs (see also [1], [3] and [14]):
- Less range of electric engines in comparison to combustion engines
- Limited options of charging infrastructure
- Current charging technology.

Combining these three reasons, it will be focused on possible use case scenarios of EVs in general and tried to develop a concept for decreasing the current anticipated disadvantages of electrical mobility and increasing the substitution potential for EVs by especially focusing on rapid-charging technology. Figure 1 gives an overview of our approach which will be discussed in the following chapters. In detail, the current use of EVs will first be examined. Afterwards, it will be focused on a possible increase of the usage rate by adding up rapid-charging technology (as a new and less time consuming charging technology) into the analysis. This charging technology will be explained later. Also, it is assumed that travel purposes and charging scenarios, combined to charging use cases play an important role for the calculation of the usage rate, so these topics are discussed later as well. Furthermore, important parameters and improvements in charging infrastructure for electrical mobility have to be taken into account to calculate a maximal substitution potential for BEVs in the future. The sum of these factors might show the possible maximal substitution potential of BEV usage in comparison to combustion engines, as proposed by the given model.
Fig. 1: Present concept of research for examining the maximal substitution potential of BEVs by focusing on rapid-charging technology (own representation). For explanation see text.

To evaluate this concept for a quantifiable maximal BEV usage rate, current statistics on travel purposes that are relevant for users of private vehicles have to be taken into account (chapter 3). Furthermore these travel purposes have to be examined in dependence of current charging technology (chapter 4). In the given concept the focus of research will be on rapid-charging technology and its impact on possible use cases in combination with the given travel purposes (chapter 5). Finally a project that has the aim of optimal positioning of this technology in Germany from user’s perspective will be introduced (chapter 6).

The next step will be the examination of the BEV usage rate in Germany to get a base rate of current EV usage as starting point for further calculations in accordance to the concept.
2 Use of BEVs in Germany

In 2010, the percentage of EV usage in Germany has been about 0.1% of all private vehicles which means just 1 of 1000 vehicles was powered by an electrical engine [4]. Already in 2009, the Federal Government of Germany developed the aim to register up to 1 million EVs until 2020 [11].

First the different types of vehicles that are referred to as EVs have to be emphasized and differentiated from non-EVs. Table 1 shows the different types of vehicles and their categorization as EV or non-EV.

<table>
<thead>
<tr>
<th>Definition</th>
<th>Type of vehicle</th>
<th>Usage of power grid</th>
<th>EV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BEV</strong></td>
<td>Electric vehicle</td>
<td>100 %</td>
<td>Yes</td>
</tr>
<tr>
<td>Battery electric vehicle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>REEV / EREV</strong></td>
<td>Electric vehicle with range extension</td>
<td>Partially, depending on battery range and usage</td>
<td>Yes</td>
</tr>
<tr>
<td>Range extended electric vehicle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PHEV</strong></td>
<td>Hybrid electric vehicle with plug-in for grid connection</td>
<td>Partially, depending on battery range and usage</td>
<td>Yes</td>
</tr>
<tr>
<td>Plug-in-Hybrid Electric Vehicle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MHEV / FHEV</strong></td>
<td>Hybrid electric vehicle without plug-in for grid connection</td>
<td>No grid connection</td>
<td>No</td>
</tr>
<tr>
<td>Mild / Full Hybrid Electric Vehicle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>FCEV</strong></td>
<td>Electric vehicle with fuel cell</td>
<td>No grid connection</td>
<td>no</td>
</tr>
<tr>
<td>Fuel Cell Hybrid Electric Vehicle</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tab. 1: Classification of electrical vehicles (EV, own representation, according to [1], p. 10).

For developing a coherent concept, the present paper focuses on BEVs, but not on REEVs/EREVs or PHEVs because of their extended range, enabled by a combustion engine in addition to the electrical engine. Furthermore the different charging behavior makes it difficult to mix up the use cases of PHEVs with those of BEVs. In a nutshell, to examine a valid substitution potential of combustion engines, just with electric engines, to the present paper focuses on the technology without additional range extenders.
One important question in this context is if and to what extent a vehicle with a regular combustion engine could be substituted by an EV and especially a BEV. Currently, the general increase of BEVs is expected to be about 2% of all German vehicles until 2020 [6]. To examine a valid substitution potential, specific prerequisites have to be turned out that affect the usage of a vehicle in general like specific distances the vehicle is moved per day as well as given parking opportunities with a private or public charging station at home. For instance, Engelen [3] states that for now, EVs are not made for one-vehicle households because they are still characterized by low ranges and the necessity of recharging points close-by. These characteristics label EVs to be primarily a “second vehicle”, in the household. This is the most momentous reason why substitution potentials are just calculated for households with at least two vehicles [3]. According to the calculation of Engelen [3], an EV is able to substitute a vehicle with combustion engine when:

- The vehicle usually moves a distance not more than 50 km a day
- The vehicle moves a distance more than 50 km a day for not more than 3 days per month
- The household has a private parking space or garage for the vehicle.

These prerequisites in combination with the data of the MiD 2008 [7] result in a minimal substitution potential of 29.9% and maximal substitution potential of about 43.5% [3] (see also Figure 1).

Taking into account parameters of the substitutable vehicle-household as well as technological and infrastructural requirements, current problems in the given charging infrastructure and the current (limited) range of BEVs have to be further examined. As mentioned above, limited battery capacities are a major problem for BEV users as they limit the possible moving distance of their vehicle. Although the estimated range of BEV’s is often up to 120 km, in vivo, these ranges vary a lot, depending on the use of additional loads like radio or air condition. The consequence is that current research deals with an effective range of about 80 km [1]. Due to both, the users’ range anxiety and the psychological barrier in terms of the perceived “no point of return”, however the user is forced to charge the battery of the vehicle already after a travelled distance of 40 km. Otherwise it would be impossible to get back home. This fact inevitably leads to two major problems: First, the limitation of the use of the BEV to a minimal set of use cases because, under the premise that no charging infrastructure is available close-by, the distances should not be more than about 40 km. Second, if the BEV should be able to manage a distance more than 40 km, the user is forced to recharge the battery either on the way or at the destination.

In contrast to rapid charging technologies, regular charging infrastructure demands charging times between six and eight hours [12]. This very long charging time in combination with an insufficient density of charging stations in Germany forms one primary reason for users to not decide for a BEV [3].
In order to shed light on further relevant facets connected to the issue of ‘chances to increase acceptance for e-mobility’ the following chapter will focus on travel purposes as important data for developing BEV use cases will be analyzed.

### 3 Travel purposes with a private EV

For the purpose of quantifying the usage rate of BEVs, especially in dependence of rapid-charging technology (see next chapter), it is necessary to identify travel purposes that occur daily or at least one day per week and affect both, BEV users as well as combustion engine users. First it has to be noted that in this chapter, all EV users are taken into account because current literature focuses on EV users in general and does not distinguish between different kinds of EVs. However, to be able to compare the current literature with future findings of the presented concept, it is necessary to disregard the focus on BEVs for this evaluation.

For the purpose of the optimal positioning of charging infrastructure with respect to the range of BEVs, it is necessary to identify travel purposes that occur daily or at least one day per week. The MiD report [7] summarized the user’s daily travel purposes to the following seven categories:

1. Work: trips going to / coming from work place
2. Official business: business related trips, not driving from home to work or otherwise
3. Education: education-related trips like driving to university etc.
4. Shopping: trips with purpose of purchase like driving to stores, grocery shopping etc.
5. Private errands: trips to run an errand like seeing a doctor, for banking matters etc.; not shopping
6. Recreation: trips for recreation like holiday trips, going to sport events etc.
7. Bring / pick-up: trips for bring somebody to a place or pick somebody up, like pick-up a child from school etc.
Fig. 2: Use of an EV in percent, depending on travel purpose ([5], own representation). Only values of at least 5% are indicated. For explanation see text.

As depicted in Figure 2, 63% of daily private uses of electric vehicles are because of work/education. 20% use their EV at least one day per week for official business and 82% at least one day per week for shopping. Three out of four persons use the EV at least one day per week for recreation or to run an errand, other than shopping. Every second use of an EV for at least one day per week was for bringing/picking-up other persons. In total, 22% of the asked persons could use the EV for all private purposes. However, deficits in using an EV for private purposes occurred a lot, especially in case users wanted to go on vacation (56%) or use the EV for holiday/short trips (51%, Fig. 3). To meet family and friends, 27% could not use their EV for this purpose, 22% had to use a regular vehicle or another kind of transport system. Hence, according to the user, especially these travel purposes are currently not possible with an EV. As a consequence from this statement, users are nearly forced to own at least one regular combustion engine vehicle; EVs seem to be an “add-on”. As a consequence, just households that are able to buy at least to vehicles belong to the potential EV consumer group - for now.
The next chapter will introduce a charging technology that the concept will focus on as a possibility to increase the usage rate of BEVs. The assumption is that this charging technology has the potential to decrease current deficits especially concerning the problems of range anxiety and range on daily routes.

4 Rapid-charging technology for BEVs

Rapid-charging is a charging technology for a BEV that recharges the battery up to 80% of the maximum capacity in about 15 min. [12]. Although the definition of rapid-charging starts with 21 kW in the following rapid-charging means a BEV with a battery of a minimum of 43 kW. The advantage of this technology is that the BEV can be recharged within a much shorter period of time than in contrast to the regular six to eight hours (see also chapter 2). The disadvantage of the current technology is the battery’s fall into "stop" mode to minimize the danger of a battery overheating after reaching 80% of maximum capacity. As a consequence, in order to reach a battery level of about 100%, the charging procedure has to be re-induced with the consequence that the charging durance of the final 20% approximately equals the time span for recharging with regular charging technologies. Hence, from a technical perspective rapid-charging is restricted to charging about 80% of the battery, whilst steadily charging the battery up to 100% would severely reduce the endurance of the battery.

Currently, there are about 3,737 public charging stations registered in Germany [15]. About 5.1% of these charging stations are rapid-charging stations. They allow for
charging “80% of an electric car’s battery in less than an hour” [15] and are operated by different companies at locations with very diverse infrastructure and environmental parameters. For instance, the time span of one hour as definition of rapid-charging on www.chargemap.com [15] exemplifies the omnipresent uncertainty in defining the technology ‘rapid-charging’ precisely.

5 A method for quantification of BEV use

So far, past studies did not develop a full concept of user’s expectations on possible use cases of BEVs, depending on their travel purposes and focusing on the time benefit of rapid-charging technology presented in the last chapters. Therefore the aim of the following concept is to identify use cases as a combination of travel purposes and rapid-charging scenarios. These use cases can finally be used to quantify the current lack of BEV usage and allow for an assumption of the general usage increase by adding up rapid-charging technology into the use case modeling.

First, the impact of reduced charging time on the user’s acceptance of electrical mobility has to be examined. The present paper focuses on two central points of view for the impact of rapid-charging:

- Seeing rapid-charging as a backup option
- Seeing rapid-charging as an opportunity for extending the range of a trip

The present paper states the premise that the first point of view will result in a reduction of a latent psychological barrier by reducing range anxiety through additional charging possibilities. This can be seen as an approach primarily tailored for metropolitan and urban areas aiming for an increased acceptance of BEVs by equivalently minimizing range problems (one of the major issues of electrical mobility; see also chapter 1).

The second point of view could extend the possible substitutable use cases of regular vehicles with a BEV since users might actually cover longer distances with the BEV. This includes distances they would not have covered without additional charging opportunity. This scenario is especially true for routes over longer distances (e.g. axes).

As mentioned above, the present concept concentrates on the second point of view. Due to this the question arises, which parameters have to be adjusted to increase the radius of mobility due to prevalent recharge options? First, it has to be examined what usage rate can currently be substituted by BEVs, regarding any kind of rapid-charging technology. Second the add-up of rapid-charging technology, optimal charging infrastructure and charging use cases are in focus of research. Finally, it is assumed that there will still be a gap in BEV usage rate compared to combustion engines which cannot be deleted by any rapid-charging technology and its connected parameters of the concept (called “delta” in our concept; see Figure 1). Therefore it
has to be examined if there are other parameters that could decrease this delta and finally maximize the substitution potential of combustion engines.

As already pointed out, it is assumed that the potential increase of BEV usage might depend on specific charging use cases, especially rapid-charging scenarios with an alternate positioning of charging infrastructure. For that, six possible scenarios, depending on the route and distance of the BEV, are being postulated (see also [2]):

**Scenario 1** - direct way (short distance), rapid-charging point at destination: This use case is defined by driving directly from start to destination with exceeding the half of the maximum range making a rapid-charging of the BEV necessary to get back. A rapid-charging point is available at the destination.

**Scenario 2** – direct way (short distance), rapid-charging point on the way: This use case is defined by directly driving from start to destination with exceeding the half of the maximum range making a rapid-charging of the BEV necessary to get back. A rapid-charging point is available on the way.

**Scenario 3** – direct way (short distance), rapid-charging point on the way and at destination available: This use case is defined by driving directly from start to destination with exceeding the half of the maximum range which makes a rapid-charging of the BEV necessary to get back. Contrary to the first and second use case, several rapid-charging points are available: one on the way and an additional one at the destination.

**Scenario 4** – direct way (long distance), rapid-charging point on the way and at the destination necessary: This use case is defined by driving a longer distance, directly from start to destination with exceeding the half of the maximum range several times which makes a repeatedly rapid-charging of the BEV necessary to a) get back and b) reach the destination. Several rapid-charging points are necessary: on the way and additionally at the destination.

**Scenario 5** – route chain with several destinations, rapid-charging at several destinations points available: This use case is defined by driving a long distance within an area that exceeds the half of the maximum range of the BEV which makes a rapid-charging necessary to get back or to reach the destination. Rapid-charging points are available at several destinations of the route chain.

**Scenario 6** – route chain with several destinations, rapid-charging at destinations not available: This use case is defined by driving a long distance within an area that does not exceed the half of the maximum range of the BEV which would not make a rapid-charging necessary to get back. Contrary to the fifth use case, rapid-charging is not available at the destinations of the route chain.

To find possible use cases of BEVs for our concept, these six scenarios are being combined with the travel purposes of the MiD 2008 [7] (see chapter 5). The priorities consist of four categories, depending on their user relevance (as indicator for
personal importance of the travel purpose) and their frequency of occurrence. The four priorities are defined as follows (see also table 2 and [2]):

**Priority 1**: These use cases occur frequently in the user’s everyday life. They also have a high relevance and acceptance from the user’s perspective what gives them a high potential as an important rapid-charging use case to be focused on.

**Priority 2**: These use cases occur frequently in the user’s everyday life, but have a low relevance in the user’s perspective; or the use cases occur infrequently, but have a high relevance in the user’s perspective. They are highly accepted from the user and have a high potential as an important rapid-charging use case to be focused on.

**Priority 3**: These use cases occur infrequently in the user’s everyday life and have a low relevance and acceptance from the user’s perspective what gives them a low potential as an important rapid-charging use case.

**Priority 4**: These use cases are not relevant for an EV user at all. The potential as a rapid-charging use case is very low.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Relevance</th>
<th>Priority 1</th>
<th>Priority 2</th>
<th>Priority 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>High</td>
<td>Priority 1</td>
<td>Priority 2</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>Priority 2</td>
<td>Priority 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Very low frequency and relevance: Priority 4</td>
</tr>
</tbody>
</table>

Tab. 2: Use cases’ priority categories, depending on frequency and relevance of the use case

This prioritization is a first draft to categorize and summarize relevant recharging use cases to finally find out the potential EV usage for the future and, as a consequence, to decrease the delta to combustion engine usage in the future. The next step will be the prioritization of charging use cases as combination of travel purpose and recharging scenario and the summary of this prioritization into a schema that shall help to examine relevant use cases for further empirical research. So the concept will be a guideline for quantification of a general (maximal) BEV usage rate as well as a summary of relevant use cases for BEVs, depending on their travel purpose and the given charging infrastructure.
6 Summary of concept

The concept presented in this paper aims at quantifying the maximal usage rate of BEVs as well as the maximal substitution potential of combustion engines. This in turn means to decrease the given “delta” of use between BEVs and combustion engines. The concept first examines the current (theoretical) BEV usage and substitution potential. It then analyses travel purposes of daily private EV usage and combines it with possible recharging scenarios, especially taking into account rapid-charging technology. This combination results in BEV use cases which are then prioritized by their relevance and frequency in daily BEV usage. The presented travel purposes, recharging scenarios and the combination of these two factors into relevant BEV use cases, supported by a prioritization cluster, have to be considered when talking about a general increase of BEV usage. The next step in accordance to this prioritization would be the empirical examination of this prioritization from the user’s perspective. This examination can be done by respecting charging infrastructure positioning in accordance to the assumed recharging scenarios. The next chapter will introduce a research project funded by the German government that picks up the technology of rapid-charging in alliance with user’s daily routes and use cases. The project has the aim to build up a comprehensive and nationwide charging infrastructure in Germany with taking into account the user’s perspective on optimal positioning and is called „SLAM - Schnellladenetz für Achsen und Metropolen“ (rapid charging network for traffic axes and metropolitan areas, [16]).

7 „SLAM” and the importance of the users´ perspective on rapid-charging

The project „SLAM“, consisting of a consortium with partners of research and industry, is to explore conditions for a comprehensive and demand-oriented rapid-charging grid for electric mobility in Germany, supported by the Federal Ministry for Economic Affairs and Energy [16]. Until 2017, it is planned to install up to 600 CCS rapid-charging stations which will be able to charge compatible BEVs up to 80% of their maximum capacity within less than 30 minutes. Leader of the consortium is the BMW AG. Further partners are the Daimler AG, the DG Verlag eG, the EnBW AG, the Porsche AG, the RWTH Aachen University, the Stuttgart University and the Volkswagen AG.

An interdisciplinary research consortium of the RWTH Aachen University, coordinated by the Institute for Automotive Engineering (ika), aims to develop a new concept for determining efficient and sustainable location parameters for CCS rapid-charging stations. Amongst others, one major aim of SLAM is to set up a simulation model, comprised of the following layers: User level, mobility level, power grid level, urban/region planning level (Fig. 4). The architecture and logical conjunction of these layers will help to identify optimal locations for CCS rapid-charging infrastructure across the German republic. In order to validate first results of the simulation model, the ika actually runs empirical field studies to examine the users’ perception and acceptance as well as the perceived additional value of this novel technology.
Additionally, relevant use cases and further user parameters for CCS rapid-charging infrastructure are being identified.

![Model structure of the concept for the SLAM simulation tool with the following levels (from top to bottom): user level, mobility level, power grid level, urban/region planning level (source: SLAM, see also [16])](image.png)

The project is based on the premise that a user oriented and appropriately optimized rapid charging-infrastructure will increase the willingness to use BEVs. However, for implementing an optimized rapid-charging infrastructure it is necessary to understand the user’s mobility purposes and their expectations on rapid-charging infrastructure in the first place.

8 Further research according to concept

Right now, due to the above implications, it can be hypothesized that the positioning of charging infrastructure with respect to the above travel purposes has the potential to increase EV usage. On the other hand the arbitrary installation of more rapid-charging infrastructure might not lead to an increase of EV usage. There might be other parameters in this “delta” that cannot be defined for now. The final step of the concept will be the examination of possible parameters that could solve this delta between the maximal BEV usage rate, taking into account rapid-charging technology, and combustion engines. The challenge for further research is to identify name and impact of these parameters.
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