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# Electric vehicles and their charging – in or out? User acceptance of bidirectional charging in Germany

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**Abstract**

An electric vehicles' (EV) battery capacity can be used to store energy and redistribute it to the grid while connected to it. This is particularly interesting in times of high grid load. The so-called concept of bidirectional charging is relatively new and has not been introduced widely. In the present study, it is examined from the perspective of EV users. Their acceptance determines whether bidirectional charging will be succesfully introduced and adopted in the future, particularly when charging at home. Through two focus group discussions with EV owners, one with home owners and one with tenants, we find evidence on potentials and barriers from a user perspective that are important to consider when introducing bidirectional charging. Given the design of our focus group discussions, we compare results for home owners and tenants qualitatively. Financial aspects are discussed as both an incentive for use but also as a barrier if one had to invest in new technology. The groups differed with regard to how strongly they wished for governmental support in these issues with tenants requesting incentives for bidirectional charging more strongly. Additionally, acceptance of bidirectional charging was related to its compatibility with daily life, participants had greater concerns of employing bidirectional charging when wishing to use their EV spontaneously. One key aspect for all participants was determining a minimum energy percentage that ought to remain in their vehicle. We find indications that home owners have a more holistic view of their vehicle within the context of their own home energy system. As most home owners also had a private photovoltaic (PV-) system, they played a more active role in their own energy system. Thus, home owners perceived greater personal advantages of bidirectional charging compared to tenants and might even be seen as early adopters. Tenants naturally focussed more on their vehicle and worried about personal disadvantages, e.g. them or their vehicle being impacted by bidirectional charging.


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*Keywords:* bidirectional charging; user acceptance; smart grid; focus group discussions

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## 1. Introduction

For the transport sector especially, new environment-friendly technologies are of the utmost importance. In 2021, 148 million tons of CO2-equivalent had been emitted in the transport sector in Germany alone (Bundesministerium für Wirtschaft und Klimaschutz and Umweltbundesamt, 2022). In order to reduce emissions within private transportation, from 2035 onwards, only emission-free vehicles are to be registered in the EU (European Commission, 2022). Thus, EVs are continuing their rise. At the same time, new ideas of how to improve the use of EVs and energy consumption are advancing. One interesting concept is that of bidirectional charging within the framework of vehicle to grid (V2G). With bidirectional charging, the power flow can go both directions, namely from grid to vehicle ("in") as is the case with vehicle charging, and vice versa from vehicle to grid ("out"). If designed appropriately, bidirectional charging can contribute significantly to making the energy system more flexible and thus help increase the share of renewable electricity. Acceptance of a such new technology by its users is crucial to then be used and adopted, which has been described in a number of models and theories (Taherdoost, 2018). The assessment of the user's attitude is of particular importance for technologies with direct user interaction to understand their intention to use said technology (Ajzen, 1991; Madden et al., 1992). For example, one could argue that for users to accept and consequently adopt a technology, this technology ought to be perceived as useful and easy to use (Davis, 1985; Venkatesh and Davis, 2000). The success of a technology depends on its suitability for everyday use and the acceptance of potential users. Therefore, it is essential to evaluate acceptance factors as well as drivers and barriers for bidirectional charging from the users' perspective. Some studies have already started examining factors influencing user acceptance in this context and are summarised in the following. Our work contributes to closing this research gap by using a qualitative approach. We designed, conducted and analysed focus group discussions with potential users of the technology (i.e., EV-users). Doing this, we explored their usage intentions as well as remaining challenges of bidirectional charging in passenger transport.

### *1.1. Literature review*

As bidirectional charging has not been introduced, at the moment, studies analysing general concepts of vehicle to grid or smart charging dominate. It is important to bear in mind that these studies do not necessarily examine or understand bidirectional charging as we do. However, both the quantative and qualitative results regarding related concepts give orientation which variables could influence potential users of bidirectional charging. Generally, it is important to point out that in earlier studies, user preferences of V2G concepts have been somewhat neglected as shown in a literature review by Sovacool et al. (2018). They found that in the reviewed studies, a clear focus was placed on technical aspects. Less than three percent of the reviewed papers related to aspects of social acceptance. Furthermore, only a small proportion included an assessment of environmental aspects.

Will and Schuller (2016) surveyed participants with regard to smart charging, i.e. controlling the charging process of an EV especially with regard to its charging times. They found that most participants wished for an option to detail a minimum range as well as the possibility to override the smart charging process. Additionally, participants wanted a planned range as well as a planned time for departure. Consequently, users wanted to have their vehicle ready to drive, i.e., retaining sufficient energy for their mobility needs. In a reflective structural-equation model of acceptance, the authors find that grid stability, the integration of renewable energy sources, and flexible mobility influence the acceptance of smart charging.

Sovacool et al. (2020) examined V2G qualitatively in asking about actors and stakeholders and what they perceive to be relevant challenges, benefits, policy mechanisms and business models. Using expert interviews and focus groups as well as a literature review, the authors identified twelve stakeholder types and corresponding business markets that have to be considered. Markets for V2G differ in their content and structure, for example, the authors describe how V2G business models can differ between urban and rural areas. Additionally, they discuss different car ownership models as well as travel and charging patterns. They provide insight into governance as V2G challenges the conventional automotive use and current business model, as with V2G one would need a transformation of the transport and especially the energy sector. Their expert interviews provide deep insight from relevant actors of the energy sector, however, in their foucs group discussion, none of the participants owned an EV.

Huang et al. (2021) employed a different method and conducted a stated choice experiment regarding participants willingness to participate in V2G. They found that generally, Dutch EV drivers did not wish to participate in V2G contracts, they were most concerned about battery degradation. Interestingly, they found that the user preference for V2G would be heightened with fast charging. This went together with participants wish for a minimum driving range as well as their dislike of long plug-in times.

Van Heuveln et al. (2021) conducted 20 semi-structured interviews with EV- and PHEV-drivers concerning acceptance of V2G, with aspects of the theory of planned behaviour in mind (Ajzen, 1991). They found financial aspects or compensation, reliability and control of the V2G system as well as transparent communication to be main drivers of acceptance. However, in line with the results by Huang et al. (2021), they also found that range anxiety is still an important barrier as well as the fear of battery degradation.

In another study regarding V2G (Ghotge et al., 2022), employing the theory of planned behaviour (Ajzen, 1991), 17 participants experienced bidirectional charging in a solar carport system in the Netherlands and were then interviewed in semi-structured interviews. High acceptance from the users went along with full and clear communication on the influence of V2G on an EVs battery. There was also demand for financial compensation regarding the impact on the vehicle battery. Furthermore, real-time insights on battery state-of-charge were mentioned for user acceptance as well as the design of a user-friendly interface. Range anxiety, impact on the vehicle battery and uncertainty about the battery's state of charge were again mentioned as barriers. This goes hand in hand with the increased need to plan charging as well as trips, which could limit the users' freedom or independence to use one's vehicle.

Hubert et al. (2019) also combined different theoretical aspects when looking at smart home usage. They not only focus on acceptance but rather adoption in a holistic way and include research regarding the technology acceptance model (Davis, 1985; Venkatesh and Davis, 2000), the innovation diffusion model (Rogers, 2010), as well as perceived risk. Using structural equation modelling, they find significant effects of perceived usefulness of smart home systems and their compatibility with daily life. Additionally, the model was enhanced by including perceived risk. They argue that the perceived risk can be a critical barrier for technology acceptance and adoption.

These results show some of the recent work on vehicle to grid and smart charging concepts in Europe. We now focus explicitly on EV-owners perception of bidirectional charging in Germany and its overlap to our participants' energy system. To compare different involvement in one's energy system, we conducted two focus groups, one only with home owners and one with tenants. Following the method section, we then present the results, focussing especially on potentials of as well as barriers for bidirectional charging from a user perspective. Finally, we discuss these results and what ought to happen to implement bidirectional charging successfully.

## 2. Method

Moderated exchanges between selected participants (i.e., focus group discussions) are particularly suitable for exploring new topics. The structured focus group discussions employed in the current study followed a guideline that focussed, among others, on EV-owners' idea of use as well as requirements for bidirectional charging, potentials and barriers of bidirectional charging in everyday life and various user groups for bidirectional charging. As bidirectional charging is a relatively new concept, these aspects are of a rather exploratory nature. However, as a theoretical basis, we also included the perceived ease of use and perceived usefulness of bidirectional charging, which are key components of the technology acceptance model (Davis, 1985; Venkatesh and Davis, 2000).

In a first screening (i.e., a questionnaire sent to participants in advance to the focus group discussion), socio-demographic, and vehicle-related as well as household-related aspects were queried. Groups were differentiated based on whether participants owned their home (i.e., home owners' group) or rented it (i.e., tenants' group). This differentiation assumed that home owners would be more strongly involved with their domestic energy system and might thus perceive bidirectional charging differently than tenants. The home owners group discussion consisted of six participants, the tenants' discussion of eight participants. However, in both groups, one participant was rather quiet. All of the participants in the first group owned their home, i.e. the home owners' group, with only one of them living in a private flat and all other living in a private house. Four of the six owned a photovoltaic system (PV-system) already, the other two planned the installation. Furthermore, all of them had a private parking space and a wallbox, i.e., private charging opportunity. In the tenants' group, most people rented a flat, only one rented a house. All of the tenants had a private parking space but only half of them owned a private charging point (i.e., wallbox). None of them

had a PV-system for use. In general, male participants dominated. We aimed to recruit people of different age groups but especially in the tenants' group, younger participants dominated. See Table 1 for more information.

Table 1. Selected characteristics of the participants

| Participant | Age | Gender | Location | Number of vehicles in the household | EVs | Additional information |
|---|---|---|---|---|---|---|
| Own | | | | | | |
| 1 | 38 | Male | Rural area | Two | One | Work expertise regarding charging infrastructure |
| 2 | 25 | Male | Urban area | Three and more | One | |
| 3 | 24 | Male | Rural area | Two | One | |
| 4 | 55 | Male | Rural area | Two | Two | |
| 5 | 66 | Male | Urban area | One | One | Public charging was mentioned multiple times |
| 6 | 30 | Female | Rural area | Two | One | Did not speak much |
| Rent | | | | | | |
| 1 | 27 | Male | Urban area | One | One | |
| 2 | 55 | Male | Rural area | One | One | |
| 3 | 26 | Male | Urban area | One | One | Work expertise regarding vehicle production |
| 4 | 80 | Female | Rural area | One | One | Talked about electromobility in general as well as environmental aspects |
| 5 | 24 | Female | Rural area | Two | Two | |
| 6 | 27 | Female | Urban area | Two | One | Did not speak much |
| 7 | 31 | Male | Urban area | One | One | |
| 8 | 23 | Male | Urban area | Two | Two | |

The two focus group discussions with EV-owners were conducted in April 2023. We conducted the focus group discussions remotely using an online platform. Both focus groups were moderated using the same guideline and lasted between 105 and 120 minutes. The discussions were recorded, transcribed and then analysed using the software MAXQDA (Verbi Software, 2021). We followed a rather inductive approach of analysis (Mayring, 2014). Nevertheless, we used structured discussions and had some theoretical assumptions on acceptance in mind and thus employed a hybrid form of analysis as proposed by Kuckartz (2014).

## 3. Results

In general, participants in both groups were open to the discussion of bidirectional charging and showed interest in the topic. However, the discussion between home owners was more technical and more strongly related to their domestic energy system, for example, it became obvious that they were interested in and had very deep technical knowledge about their vehicle and energy consumption. The discussion between tenants was less technical, this could already be seen when introducing themselves. Home owners mentioned their vehicles battery capacity, its range and how they used it while tenants mentioned their vehicle model but also where they lived and what job they worked. Furthermore, in the tenants' group, participants sometimes discussed their experience with electromobility rather than

that they provided new insights to bidirectional charging. It was stated in both groups that bidirectional charging would be especially useful in combination with a PV-system. In both groups, financial aspects were discussed to a great extent which underlines their importance from a users' perspective.

### *3.1. Idea of use as well as requirements for bidirectional charging*

The home owners all agreed that bidirectional charging would not change their vehicle use. One person stated that they wouldn't change their life for bidirectional charging but rather regarded it as a nice-to-have. Another person stated that one would look after their battery but that this was something EV-drivers would generally do. However, one of them stated that potentially, their behaviour at home would be altered when using bidirectional charging, e.g. using the washing machine when the car was employed for bidirectional charging. This way, energy that had formerly been taken from the grid could be taken from the car. Additionally, some people stated that they would leave their vehicle plugged in more.

In the tenants' group, two people were very firm in that their vehicle use should not change, for example stating that bidirectional charging not impacting their daily life was a precondition for use. For two others, not much would change as their vehicles were always charging when at home. One participant who could only charge publicly perceived bidirectional charging as a form of automatic and controlled charging which would ease their EV-charging. Furthermore, another person stated they would plug in their EV daily instead of twice a week, especially when charging cheap at work. Another person stated that, potentially, use times would change depending on whether the energy from the vehicle was needed at a given time for the grid. Two participants not only stated they would leave the vehicle plugged in more but would actively plug it in at home when formerly they wouldn't have.

One key aspect, in which both groups agreed, was the necessity to retain a minimum battery level. This means, they wanted to predetermine a state-of-charge percentage which must necessarily be retained in the vehicle. In the tenants' group, one participant also expanded this to a maximum level above which the vehicle should not be charged to preserve their battery.

### *3.2. Potentials for and barriers of bidirectional charging*

Interestingly, when asking about potentials and barriers of bidirectional charging, home owners started only discussing barriers even though they generally seemed to evaluate bidirectional charging as something positive. This could be in line with an initial statement of one participant saying that bidirectional charging was important but that it came too late and still had many obstacles.

In general, home owners evaluated bidirectional charging as interesting and practical as one would not need an additional energy storage. All of them who dwelt on this topic owned a PV-system and also mentioned that it would thus be a financial benefit as they could save the investment cost of a static home storage when using their vehicles battery. In the group of tenants, this topic was less obvious as only one participant mentioned it.

Another potential of bidirectional charging mentioned in both groups also related to financial aspects. Participants stated that some form of monetary compensation for the use of their battery was necessary when thinking of implementing bidirectional charging. In the group of home owners, the topic was again related to their PV-system. They asked for a reasonable or market-driven pay of the fed-in energy as they criticised today's compensation of energy from a PV-system. In the tenants' group, this was mentioned in less depth. For example, one participant only stated that their car would make money for them whereas another one stated that car user, seller and producer would fix the cost with each other, potentially along with governmental subsidies. Generally, financial aspects were also evaluated as barriers to bidirectional charging as either a new wallbox, cable or vehicle would be necessary. The group of tenants had more to say to these issues and mentioned the necessity of governmental support or subsidies. The tenants also discussed whether there would be a sufficient selection of cars capable of bidirectional charging.

Participants in the two groups also differed with regard to their preferred current. One home owner believed an alternating current (AC) to be more interesting to compensate for the daily, little energy demand in the evening for example. However, another home owner thought AC to have disadvantages as one would be bound to a certain electrical power, especially if one focused on electrically driven systems (e.g., one's vehicle, heat pump, etc.). Thus, they preferred direct current (DC), also to account for peak load in one's home. In the group of tenants, it was stated

by a participant that they could not imagine bidirectional charging with fast charging and thus, in their opinion, not with DC. Here, another tenant explained the aspect that it could be easier to get energy from the car with DC.

One technical barrier mentioned in both groups was the fear of battery degradation with bidirectional charging. One aspect mentioned only in the group of home owners were energy losses during charging which would become greater with bidirectional charging as there would be more charging processes. The issue of responsibility arose, as one participant asked who would bear those losses.

In both groups equally, participants asked how bidirectional charging could be implemented when charging at work or publicly. Both groups acknowledged that for public bidirectional charging, sufficient charging points needed to be established so that public bidirectional charging would not take away the space for necessary (regular) public charging. The use case of charging at work was discussed with regard to the legal questions pertaining to it. In the group of home owners, other legal barriers were related to space constraints of where to place solar panels or registration of higher current wallboxes (above 22kW). This was not mentioned by tenants. Even the installment of a wallbox proved difficult for one tenant in their apartment building. This can be related to the aspect of self-sufficiency with bidirectional charging. For the group of owners, this was a potential of bidirectional charging, whereas in the group of people who rent, it was mentioned conditionally only, as being interesting for people who own rather than people living in an apartment building who do not have similar freedom.

### *3.3. User characteristics*

Differences between home owners and tenants were explicitly mentioned. Amongst home owners, one person mentioned that the discussion had been relatively privileged as all of the participants owned their own home and could for example decide whether they wanted to install a PV-system or not. They explained that in the city, there were bigger apartment buildings and more people renting, thus them not being the owner and not able to make such decisions themselves. They stated that even though as a tenant one could ask for a wallbox, the technical preconditions were not always met and compared to being a private home owner, the interest for installment was lower. When looking at one participant in the tenants' group, we could clearly see that they wanted a wallbox and potentially even a PV-system but that other people in their apartment building weren't willing to cooperate on the pay for it and that there were questions regarding fair billing. In the tenants' group, it was generally mentioned that bidirectional charging could be more interesting when owning a home and PV-system.

Furthermore, participants expected differences between urban and rural areas, for example with regard to a minimum range capacity that should remain with bidirectional charging. They attributed that to the fewer charging options in rural areas. However, at the same time, it was mentioned that in rural areas, people owning their houses would be more prevalent and thus the interest in the topic might be greater. This was supported by another participant believing the private parking space in rural areas and thus the chance to install a wallbox to be greater.

## 4. Discussion and Conclusion

We have investigated the potential of bidirectional charging from a user perspective employing focus group discussions. Bidirectional charging is a new technology with which most people do not have direct experience. However, to understand the potentials and barriers of integrating EVs to one's daily life and energy system and thus to also help increase grid efficiency, we need the perspective from potential users. Our results show the different potential of bidirectional charging for home owners and tenants. While home owners had a combined view on their vehicle and home energy system, tenants focused strongly on their vehicle. For example, battery degradation was in stronger focus with tenants as they feared personal disadvantages when allowing bidirectional charging. Interestingly, even bidirectional charging being a relatively new technology could be seen as a disadvantage from the tenants' point of view as the vehicle market was not yet that advanced and did not provide sufficient selection. Some tenants feared that their personal preferences regarding their vehicle could not be met given the market selection of vehicles capable of bidirectional charging. Another example is the discussion of which current to use with bidirectional charging in both group discussions. While one owner wanted to maximise the power available and thus imagined bidirectional charging to happen with DC, in the tenants focus group discussion, one stated that DC would not be sensible as they reiterated their use case of fast charging with DC. While the owner wanted to optimise their energy system, the tenant

focussed on what they already knew regarding regular charging. Interesingly, the study of Huang et al. (2021) showed that employing DC could be a strategy to make users more comfortable with V2G or bidirectional charging given their range anxiety. One further, important aspect to keep in mind is the technical interest of a person as well as their scope for decision making. The home owners in the current study had a deep understanding of their vehicle and private energy system. They saw the advantages that bidirectional charging could have for themselves, especially in combination with a private PV-system. If bidirectional charging could be implemented, they would have other advantages next to potential financial benefits, such as being self-sufficient and independent. However, in this context and as participants stated that they would not need another static energy storage, it became evident, that home owners wanted to later use the stored energy themselves rather than freely providing it to the grid. For tenants, bidirectional charging had fewer advantages as they had less freedom to decide in their home energy system. They weren't driven to implement bidirectional charging merely for the aim of grid stability or to increase the share of renewable energy but needed some form of compensation or support. When employing bidirectional charging, tenants could at best charge cheaper than they normally would, even though the participants already anticipated legal barriers when charging at work and then using the energy at home. It is noteworthy that in the tenants' group, they repeatedly mentioned the potential need for governmental subsidies. This shows that they were less active in seeking out bidirectional charging compared to home owners but needed some form of incentive for use. This seems natural as home owners have greater responsibility and freedom within their energy system whereas tenants are dependent on their landlord. The integration of their vehicles to the energy system seemed harder to imagine for tenants as they had less to gain personally. For tenants, they rather wanted to ensure that their private vehicle and interests regarding it were protected when allowing its use for the public energy sector.

In line with Will and Schuller (2016), we also found that users wished for a minimum range to allow for flexible mobility and ensure that they are able to use their EV as before. In this, owners and tenants agreed alike. This is also in line with Ghotge et al. (2022) where users feared not being able to reach their destination (i.e. range anxiety) as well as a restriction on their freedom when using their vehicle within the framework of V2G. Range anxiety seems one of the main barriers, both found in the literature (Gothge et al., 2022; Van Heuveln et al., 2021) but also in our current study. Thus, in order for bidirectional charging becoming useful and easy to use, the use of the EV should not be altered too much, for example allowing to use it spontaneously. EV-owners in both focus groups even stated that they could not imagine to change their vehicle use. This is line with results by Hubert et al. (2019) who found compatibility with daily life to be one significant aspect when looking at smart home systems.

It is also necessary to note the important role that financial aspects played in both discussions. This is again in line with results by Ghotge et al. (2022) who found that participants wanted to be reimbursed for potential impacts on their vehicle battery. For tenants especially, financial aspects seemed the main discussion topic. One tenant acknowledged that grid stability was of course important but that this was not really what drove their decisions but that rather, some form of personal incentive had to be given. One could argue that owners did not focus as strongly on this aspect as they need not have grid stability but their own energy storage and consumption in mind and profit this way.

Additionally, users also differentiated between urban and rural areas, as already mentioned in Sovacool et al. (2020). Though participants expected fewer public charging options in rural areas, they also saw the potential of bidirectional charging in rural areas given a greater number of owners and less space constraints. One owner of an urban home was first very vocal in that public charging should also be open to bidirectional charging, stating that it should be easy to use everywhere. The others agreed conditionally, however did not want to take public charging space just for the stabilisation of the grid. For tenants, charging at work seemed particularly interesting. However, most use cases other than private charging had more barriers to keep in mind, e.g. legal ones. It therefore seems that in terms of ease of use, home owners with a PV-system are most likely to adopt bidirectional charging.

Finally, there are some limitations to keep in mind. First, EV users were invited for the focus group discussions; thus, it can be assumed that the participants were more progressive and open to new technologies than the average German citizen. In this context, the same limitations apply as is usually the case with research concerning EV-users: our sample was male-dominated, not only in number but also in how strongly they participated. Furthermore, most of the participants, especially in the owners' group, had a high socio-economic status. Interestingly however, it did not seem that the environmental aspect of bidirectional charging or electromobility in general was of high priority for most of our participants. This is contrary to results by Will and Schuller (2016) who found the integration of renewable energy to the grid to be one significant factor for the acceptance of smart charging. This is one important limitation to keep in mind. Generally speaking, the opinions transported in these focus groups are of a rather small subgroup of the

German population. We only included EV users and did not compare them to non-EV users. However, it was important to assess specifically the two groups of owners and tenants as we can now assume that home owners who have a PV-system as well as an EV might be early adopters of bidirectional charging. Comparing them to EV users who rent shows what ought to happen and which legal questions to address in order for bidirectional charging to become more widely accepted. Furthermore, we saw that EV users were predominantly keen to use bidirectional charging for their own benefit or in a smart home sense, e.g., with owners, it often seemed as if they wanted to later use the stored energy themselves, thus not really helping grid stability. For future studies, this should be kept in mind and one should also focus on how potential users can be motivated to use bidirectional charging, next to financial incentives. Our focus group discussions provide a good basis for such future research and help better understand user requirements as well as barriers for bidirectional charging.

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