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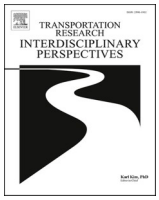

Beyond the plug: unlocking vehicle to grid potentials during climate-induced disasters

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ABSTRACT

Bidirectional charging goes beyond electric vehicle (EV) charging as a vehicles' energy is used to supply consumers, buildings and the electrical grid. This way, EVs can provide flexibility to the grid. The present study considers the special case of bidirectional charging during disaster events. Importantly, EV owners' acceptance for bidirectional charging determines whether it will be successfully employed during future disaster events and if thereby, system resilience can be improved. Through two focus group discussions with homeowners and tenants, all owning an EV, the user perspective is examined and insights into potentials and barriers for bidirectional charging during disaster events are gained. Results show selfish EV-usage motives dominating in anticipation of hypothetical disaster events, even more so for homeowners than tenants. Importantly, the responsibility to provide energy during disaster events was attributed to official actors. Recommendations on how information campaigns for bidirectional charging during disaster events should be designed to enhance acceptance are discussed.

1. Introduction

Humankind is faced with serious challenges: the climate crisis, fatal geopolitical conflicts as well as threats to democratic structures, and this is only to name a few. These challenges are human made and will impact future generations increasingly. Next to finding solutions to solve as well as mitigate these challenges, additional strategies that enhance coping mechanism and foster resilience in society are growing in importance. This particularly holds for the climate crisis where next to political decisions on the way forward, the behaviour of society as a whole is decisive for the successful implementation of climate protection measures but where also, the whole of society is impacted.

In this context, as one specific example, electric vehicles (EVs) have long been discussed as the means to reduce transport emissions (Requia et al., 2018; Ribberink & Entchev, 2013), particularly so as the transport sector continuously fails to reach its emission reduction targets (European Environment Agency, 2025). Here, the growth of EVs is considered as an important opportunity, but, the rapid increase in EV numbers simultaneously poses significant challenges, e.g. for the power grid (Gnanavendan et al., 2024). One promising solution to address both opportunities and challenges is bidirectional charging which allows EVs to draw but also supply electricity to the grid. On the one hand, bidirectional charging could integrate more renewable energy sources to the energy mix, enhance grid stability, and even provide economic benefits to EV owners (Habib et al., 2018). In this context, EVs also provide an opportunity to heighten the share of renewable energy being stored as in times of high renewable energy production (e.g. because of strong winds), parked vehicles may serve as a storage for the surplus of produced energy. Despite these advantages of bidirectional charging as an opportunity for both a climate friendly mobility and energy transition, on the other hand, widespread adoption of bidirectional charging depends on overcoming multiple hurdles, especially the hurdle of user acceptance, and the development of business models acceptable to parties involved. Following, a literature regarding user acceptance is provided, especially regarding the acceptance of emerging technologies in the context of vehicle-to-grid (V2G). Presenting the literature underlines the necessity to further inquire into the specific case of bidirectional charging during disaster events.

Acceptance of bidirectional charging

While EV adoption is increasing and, e.g. policy-related

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interventions can drive EV acceptance (Taamneh & Makahleh, 2025), the adoption of EVs still faces barriers. Particular barriers are technological, financial, and infrastructural ones (Pamidimukkala et al., 2023). In this context, conventional EV charging goes together with high infrastructure costs, low flexibility and underutilisation; with a number of innovative charging solutions being proposed to address these challenges (e.g., Khan et al., 2025; Zaino et al., 2025). Based on a thematic analysis of tweets relating to EV charging, novel charging technologies are shown to excite interest and hope (Ashby et al., 2025). Bidirectional charging, enabling the energy flow from vehicle to grid next to only charging, can be understood as one of these novel technologies. However, in a literature review, Sovacool et al. (2018) showed that in most studies regarding vehicle to grid (V2G), which is a sub-form of bidirectional charging, technical rather than social acceptance aspects were the focus of inquiry. They underline the need for exploratory urban resilience research as well as the influence of externalities to achieve an environmentally sustainable and socially accepted transition. Importantly, when considering sustainable transitions, one also has to consider the increasing numbers of extreme climate events and inquire into the role of an EV for grid stability and societal technology acceptance. Here, in a recent review, Torkey et al. (2024) examine research on electrification in the transport sector as well as disruptive events. Again, the review mostly presents technical aspects regarding optimal charging. As the authors describe, most research about EVs, charging infrastructure and disruptive events has not been conducted in conjunction, even though the fields are interdependent. Human factors as well as different types of disruptive events have been especially understudied and the authors state that information dissemination is currently only inefficiently done.

A few selected studies have already looked at human acceptance dimensions regarding V2G concepts. Fear of battery degradation as well as range anxiety are typical barriers for the implementation of V2G in both qualitative (Fahrner et al., 2023; Hu et al., 2025; Huang et al., 2021) and quantitative studies (Will & Schuller, 2016). Acceptance studies often include some reference to either the theory of planned behaviour (TPB, Ajzen, 1991) or the technology acceptance model (TAM, Davis & Venkatesh, 1996; Venkatesh et al., 2012). For example, Van Heuveln et al. (2021) considered the TPB when conceptualising their semi-structured interviews. In their study, added fears that participants had to battery degradation and range anxiety were financial disadvantages and lack of transparent communication. Also employing the TPB, (Ghotge et al., 2022) conducted a field experiment, with participants actually experiencing bidirectional charging in the Netherlands. Again, communication was key as acceptance was promoted by explaining and displaying the impact of bidirectional charging on an EV and its battery comprehensively. Here, users also wished to be kept in the loop regarding state-of-charge and asked for an efficient app interface presenting relevant information to them. Additionally, as participants experienced the technology, their knowledge increased likewise. Finally, regarding V2G acceptance with the TAM in mind, Hubert et al. (2019) also found that the perceived usefulness of smart charging was impacted by how compatible it was with daily life. Most importantly, their structural equation model (SEM) was enhanced as they included the perceived risk marking it as a relevant aspect to consider for the acceptance and adoption of emerging technologies. The same was supported in a recent quantitative study (Chen & Lai, 2024) using the extended Unified Theory of Acceptance and Use of Technology (UTAUT2, Venkatesh et al., 2012) where the authors show through a SEM that perceived risks of V2G negatively influence usage intention. With the importance of risk perceptions and different charging styles already identified during regular charging scenarios (Hajhashemi et al., 2024), EV charging preferences during disaster events are particularly important to understand in order to derive insights into grid resilience.

Acceptance in the context of disaster events

Studies have started to include disruptive or disaster events when analysing the impact of V2G concepts, even though evidence is still scarce. Most studies take a modelling approach, focusing for example on the resilience of the electricity-gas system during winter storms (Liu et al., 2023), the interdependence of the EV charging infrastructure and the power grid (Wang et al., 2024), the best location for energy resilience hubs (Rodriguez-Roman et al., 2024) or the different EV battery capacities (in an agent-based model) analysing their potential to provide support during earthquakes (Churchill, 2023). Further, results show that during power outages, EV or even electric buses can serve as buffer that is more environmentally-friendly than backup diesel generators (Liu et al., 2025a; Liu et al., 2025b).

While sometimes stating that users' confidence in emerging technologies may be impacted (Wang et al., 2024), this is not taken into focus in the modelling studies. Here, one review (Loni & Asadi, 2024) places partial focus on social vulnerability within the context of EVs and power outages. The authors argue that not only technical aspects should be analysed but that resilience is especially impacted by societal dimensions. In this context, they particularly focus on socioeconomic elements, which is of great importance to underline the disparities that still exist given different user characteristics such as social capital or political powers that (or rather the lack thereof) may be a vulnerability. Importantly, when it comes to EVs and bidirectional charging, households differ in their technical and financial possibilities to connect to other buildings or the grid. Here, home owners have more flexibility compared for example with tenants who have less decisional freedom and face more bureaucratic barriers. Such acceptance barriers on the individual level remain highly understudied, particularly regarding whether people would provide their EVs to the grid during disastrous events. Here, it is of particular importance how EV owners would like to be addressed during a disaster event in order to heighten their willingness for bidirectional charging during disaster events. The current research particularly aims to address these two questions employing two structured focus group discussions in Germany. Thereby, the research merges technology-centred approaches with sustainable, socially relevant mobility solutions, bridging engineering-focused infrastructure improvements to human-centric behavioural analyses.

2. Methods

Qualitative formats like focus group discussions help better explore emerging topics. Smart utilisations of charging, particularly during disaster events, still are highly novel to analyse from a user perspective. Further, by including users in the process of designing information and communication channels regarding a technology in line with their needs should foster greater acceptance and adoption of a technology (Chammas et al., 2015).

Materials

Using structured and guided discussions yields the advantage that user's subjective associations are assessed while it is ensured that they stay focused on the topic of interest. In the current study, a semi-structured approach was chosen. A guideline was developed but the focus group moderator was flexible as to when questions should be administered and where to dive into more detail. The guideline topics built on previous research regarding bidirectional charging (Fahrner et al., 2023), but were adapted to the specific case of a moderate to extreme disaster events including extreme winds and flooding. These examples were chosen as they were most likely to occur in the study region of Germany and therefore of assumed relevance for the participants. Participants were presented with a visualisation of the disaster as well as information regarding key infrastructural impairments.

Further, to understand user requirements for communication

channels, an approach based on user-centred design was employed. As the technology of bidirectional charging is in its initial stages, we aimed to gather user needs for future developments of relevant bidirectional charging applications during disaster events. Therefore, participants were presented with an example regarding a potential mobile app that could be used during a disaster event and were asked to evaluate the concept. A mock-up visual presentation of the app (see Fig. 1) was chosen to get more detailed responses from participants.

Procedure

The overarching structure of the focus groups was as follows: introduction of participants, informational presentation regarding bidirectional charging, stance of the participants regarding bidirectional charging, presentation of disaster scenario. We further included perceived ease of use and perceived usefulness of bidirectional charging in our guideline, both of which are part of the TAM and its extensions (Davis & Venkatesh, 1996; Venkatesh et al., 2012). Three topics from the guideline are key for comparing between focus groups as well as between participants within one focus group:

(1) General associations with and interest in bidirectional charging,
(2) Influence of disaster events and their severity, and.
(3) Role of relevant actors as well as design of information channels.

Participants

With regard to the participants of the discussions, we focus on a specific sociodemographic aspect by analysing differences of homeowners versus tenants regarding bidirectional charging. One discussion was conducted with EV owners living in their own home and one with EV owners renting their home (both N = 7). Participants were recruited and incentivised for participation by a company specialised in participant recruitment. In both groups, male participants dominated (see Table 1), in numbers as well as their speaking duration. Homeowners were highly motorised, meaning most participants had more than one vehicle in their household. Most homeowners stated that they had good knowledge of the concept of bidirectional charging before the discussions which can reflect interest. Generally, in the homeowners' group, participants underlined their early adopter status regarding electromobility and displayed their perception of themselves as experts. On the contrary, in the tenant's group, a more mixed knowledge base was perceivable. Additionally, tenants had fewer vehicles and were more diverse regarding age groups.

Analysis

Both discussions lasted around 120 min and were conducted online. The focus groups were recorded, then transcribed and analysed using the qualitative data analysis software MAXQDA (VERBI Software, 2021). Using a guideline and having theoretical assumptions about acceptance based on TAM and its extensions in mind, while inductively deriving relevant aspects from the discussions, we consequently employed a hybrid form of analysis as suggested by (Kuckartz, 2014). Thereby, statements of participants have either been coded with predefined categories or, if mentioned repeatedly or by multiple

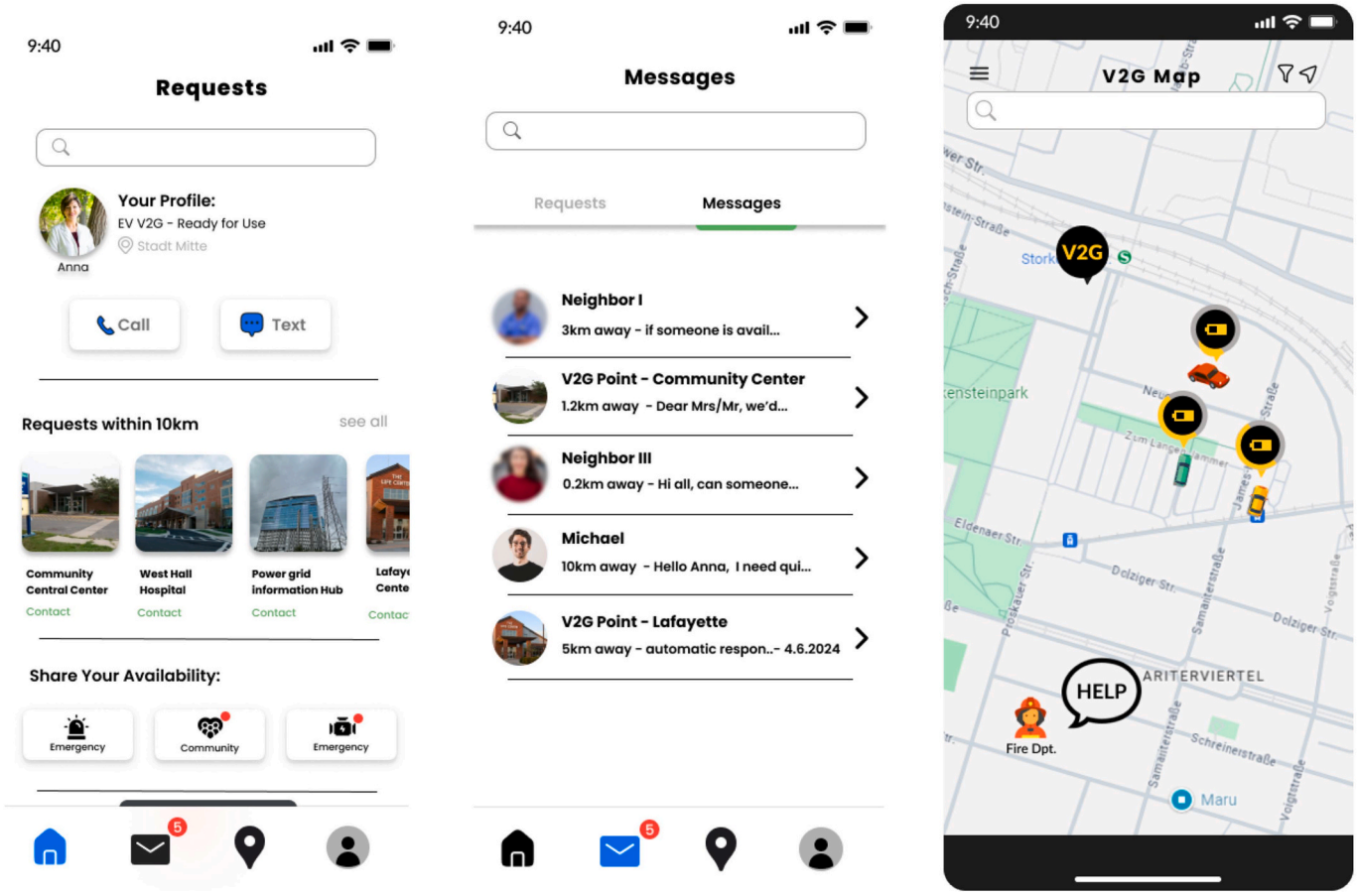

Fig. 1. Mock-up presented to the participants regarding a potential app for sharing their EV during disaster event. One can see enquiries for support (left), chats (middle) and a map (right) visualisation. Note: The original content was in German. Prototype interface adapted from "Medical Emergency App UI / Go Go Ride" by Aldo Sanchez / Marta, licensed under CC BY 4.0. Changes were made by the authors.

Table 1
Characteristics of the participants.

Nr	Age	Gender	Location	Subj. V2G knowledge	Vehicles in household	EVs	Additional information
Tenants							
1	30	Male	Urban area	High	One	One	
2	47	Male	Urban area	High	One	One	Lived in flat but stated that he owns flat
3	24	Male	Urban area	Relatively low	One	One	
4	61	Male	Rural area	High	Two	Two	Lived in flat but stated that he owns flat
5	25	Female	Urban area	Low	One	One	
6	57	Female	Urban area	Relatively high	Three and more	One	Only spoke when prompted by moderator
7	61	Male	Urban area	Relatively high	Two	One	
Homeowners							
1	46	Male	Rural area	High	Three and more	Two	
2	24	Male	Urban area	Medium	Three and more	Two	
3	55	Male	Rural area	High	Three and more	One	Works in energy sector
4	59	Male	Urban area	High	Three and more	Three and more	
5	46	Male	Urban area	High	Two	One	
6	61	Female	Rural area	Relatively high	One	One	Did not speak much
7	66	Male	Rural area	Medium	One	One	Stated that he is disabled and has specific mobility needs

Note: Subjective knowledge was indicated answering the following: "Please indicate to what extent you agree with the following statement: I am familiar with the concept of bidirectional charging." on a five-point Likert scale ranging from disagree completely to agree completely.

participants, novel categories are inductively derived.

3. Results

Evaluation of bidirectional charging

In general, during both discussions, drivers and barriers of electromobility were debated, however not always with regard to disastrous events. In both groups, concerns regarding battery degradation with bidirectional charging were voiced. Results show a certain willingness to share energy through bidirectional charging but only when basic personal needs are met. In the case of disaster events, mostly selfish motives for vehicle use were voiced, even more so for homeowners than tenants.

Tenants' evaluation

In the tenants' group, concerns regarding battery degradation were very pronounced, five out of seven participants mentioned this topic, independent of a disastrous event. Participants were worried their own needs wouldn't be sufficiently satisfied with bidirectional charging, e.g. asking how it could be implemented "*in a sensible way so that my battery capacity is still sufficient to meet my personal needs afterwards*". Tenants argued that bidirectional charging would only become interesting if one lived in an own home, preferably with a photovoltaic system. Additionally, as three tenants did not have a wall-box, they did not consider bidirectional charging as interesting for them. They further mentioned that there still were common and general barriers with charging infrastructure, and based on this, concerns about the feasibility of bidirectional charging were raised. Still, a greater number of photovoltaic systems was discussed as a solution in order to produce more available energy.

Homeowners' evaluation

In the homeowners' group, battery degradation was discussed by four participants as well, however, two of them argued that this topic was no longer of relevance, if only for very small vehicles. Regarding bidirectional charging, homeowners also mentioned that photovoltaic systems were beneficial with electromobility in general, however, with regard to their interest in bidirectional charging, they focussed more strongly on concrete regulatory aspects like financial and political decisions. All of the homeowners strongly disfavoured bidirectional charging if they were needed to provide their own resources in the form of their vehicle and its battery capacity for grid stability without having personal and attractive (financial) benefits. Only two made exclusions during disaster events stating that in such a case, individual (financial) benefits would be irrelevant, and later on, other discussants hesitantly agreed. These hesitations also seemed to be founded in distrust regarding current regulations, with one participant stating: *"I simply don't believe that our government will be able to find applicable solutions without ending up in a bureaucratic nightmare or something similar*". Further, two participants explicitly stated that political regulations in order to find a suitable implementation of bidirectional charging, e.g. regarding grid fees, were lacking.

Influence of disaster events and their severity

Across both groups, during disaster events, the first idea was to employ bidirectional charging for one's most important own personal needs. Needs that were mentioned were cooking and storing food (e.g. keeping the freezer on) as well as working from home. Leisure activities (like watching TV) were declared to be less important and could be refrained from. In both groups, it was requested that a control option for EV discharging only up to a certain level during disaster events should be left with the vehicle owner to ensure some degree of individual control.

Tenants perspective during disaster events

One of the tenants argued that given the technical specification of bidirectional charging, during disaster events, the utilisation for one's own consumption would be more realistic and feasible. Four others agreed as they mentioned insecurities how bidirectional charging should work given the current public energy grid which was not yet perceived as intelligent enough for bidirectional charging during disastrous events. Importantly, the discussion in the tenants group shifted as one participant related the experience of a power shortage of several days in Berlin Treptow. He related that the doctrine of everyone thinking of themselves first quickly was "*driving them into a corner*". Hospitals no longer had an emergency power supply and he mentioned it became really scary with everyone afterwards agreeing that one should learn from this. But indeed, he mentioned, no concrete measures were taken. The other participants were taken by surprise and stated they were strongly persuaded that the critical infrastructure would be secured via emergency power which is why they took the liberty to be "*so egotistical*". For two participants it seemed unimaginable that this was not regulated and considered by official authorities. As a result of the discussion, the question remained as to what extent it was the responsibility of the individual, private person, to iron out any omissions (by grid providers or the government) through the provision of private infrastructure. Even though dissatisfaction with official actors became visible and

participants questioned: "*is it the responsibility of the individual, the private person, to smooth over any shortcomings by making their private infrastructure available*", tenants were generally open to do as much as they could if a disaster event should occur and they had the power to provide the energy stored in their vehicles via bidirectional charging. In this context, tenants discussed helping others, here, hospitals and homes for the elderly were especially prioritised.

Homeowners perspective during disaster events

Owners differed when compared to tenants in their differentiation of a disaster event as one stated that given a "*lighter*" disastrous event, bidirectional charging would be more important as more room for action would be possible. Another participant agreed that if the disaster was more extreme, other problems would dominate and bidirectional charging would be relegated to the background. Generally, becoming independent from the grid given a combination of one's EV and photovoltaic system as well as using their vehicle as a private storage was the key interest for five of the homeowners. A sixth homeowner agreed but conceded that one would not have the freedom of decision but that the network operators might control energy usage in the event of a disaster whenever the vehicle was connected. One participant answered that in such a case, he would simply disconnect his vehicle. The last homeowner also agreed that bidirectional charging would give him personally a secure feeling for disaster events. Evidently, even though differentiating between levels of disaster event, independent of the severity, priority was given to the autonomous use of bidirectional charging, with two participants stating that everything else was not their task. One participant summed it up as follows: "*Generally, my shirt is closer to me than my neighbour's trousers*". Another participant made the concession that it depended on whether one personally was affected by stating: *"If I am not affected and can help, then I am happy to do so for a limited period of time, but if I am affected myself, then I become selfish*".

Role of relevant actors and design of information channels

The final question focused on the role relevant actors play and how participants wished information to be conveyed to them. In both groups, the discussion turned to if there was a way to centralise the coordination during disaster events, e.g. through a register of EVs. In the tenant's group, trusted actors for the coordination tasks were emergency management ("Katastrophenschutz") as well as the Federal Agency for Technical Relief ("Technisches Hilfswerk"). Trust was also placed in the Red Cross, firefighters as well as other emergency service workers. With regard to how bidirectional charging should be requested from participants as well as how information should be communicated to them, participants generally favoured an app solution.

Tenants perception of actors and information

As mentioned, tenants had the conception that the critical infrastructure would be controlled and secured during a disaster event by some official actor. That this did not appear to be so led to high dissatisfaction among the participants. An additional influence that tenants discussed regarding their propensity to provide bidirectional charging during a disastrous event was whether the disaster was unforeseeable or whether it was due to mismanagement or lack of maintenance by other actors. Three tenants underlined explicitly that it would be important to foster greater acceptance and awareness within the population by preventive (informational) campaigns prior to a disastrous event.

Regarding how to convey information, in the tenant's group, comparisons were made to other app services like the first aid's app ("Ersthelferapp") or the "Nina" app warning in the case of extreme weather events. A comparison was drawn to organ donation by participants as they discussed whether or not one should automatically be registered for a bidirectional charging service during disaster events to heighten accessibility. In general, also to keep barriers low, tenants wished to have bidirectional charging integrated in existing apps but to also retain the option to choose direct messaging for all that are not constantly connected to the internet. Additionally, some concerns were also raised with regard to data protection. With regard to the design of the app, tenants agreed with the proposed mock-up but suggested to include more visualisation (e.g. indicate level of disaster by green, yellow or red symbol). Additionally, one participant stated that a social norm comparison could be beneficial to motivate more people through the app, e.g. by showing how many others have already participated. This was rejected by another participant as in their opinion, this might also lead to effects similar to social loafing. The other participants however mostly took the stance that it was more important to make visible in the app that they had helped, also for their personal motivation.

Homeowners perception of actors and information

Within the owner's group, emergency management, the Federal Agency for Technical Relief and firefighters were mentioned as trusted actors for the coordination tasks as well. At the same time, one's own role during a disastrous event was also discussed as one participant described to think that during a disaster event, emergency laws would be applied and they wouldn't have much freedom of choice. However, he also explained to consider himself and his EV to be essential during the disastrous event. Another participant took up that notion and discussed whether they could perform system-relevant tasks during a disaster with their EVs, in a sense that they would be a "*travelling battery tank and supply energy to the crisis area*". At the same time, distrust regarding official actors also became visible in the owner's group, for example, they stated that they wouldn't provide energy if they didn't know who would be the receiver. Generally, voiced unhappiness with political actors mostly related to the overall use case of bidirectional charging and financial regulations but not so much to disaster events.

Regarding the conveyance of information, owners discussed relatively similar topics to tenants, data protection was a worry. If an app was implemented, it should be run by emergency services or firefighters. Again, participants wished an integration into existing services like the first aid's app to have a centralised solution. The comparison was again drawn to organ donation when it came to barriers for use with one participant stating: "*I think additional apps that you then download (…) are problematic. It's like the organ donor card. Everyone wants to get an organ if necessary, but hardly anyone registers*". However, owners were generally less inclined towards an app than tenants as one participant mentioned German bureaucracy as well as digitalisation as hindrances and stated that during a disaster event, personal communication would be best. Another participant stated that potentially, depending on different affinity for technology, different solutions should be offered.

4. Discussion

In the current study, we investigated the potential of bidirectional charging from a user perspective during an hypothetical disaster event. Through bidirectional charging, flexibility can be provided to the grid which could be especially important during disaster events. However, bidirectional charging is a technology that is only emerging, for a successful design and diffusion of the technology, user acceptance and willingness to adopt the technology have to be analysed. This user-centric focus is imperative to achieve a better understanding of how bidirectional charging should be employed and thereby derive indicators of whether grid resiliency will be enhanced. To this end, two focus group discussions, one with tenants and one with homeowners were conducted online in Germany. The distinction between tenants and homeowners is not a German-specific one, so results can be transferred and compared to other countries. Generally, the current results underline general hesitations regarding bidirectional charging and particularly during disaster events, especially for homeowners. A diffusion of responsibility became visible with most participants focusing strongly on personal rather than grid-friendly benefits. Thus, recommendations

on how to communicate about bidirectional charging in order to heighten the willingness to provide it to the grid during disaster events are discussed.

Evaluation of bidirectional charging – public vs. private use

In line with prior research, fears of battery degradation were voiced (Van Heuveln et al., 2021), particularly in the tenants' group. Battery degradation is predicted to increase with bidirectional charging, for example, a simulation study (Timilsina et al., 2024) finds that over a year, with an EV not employing V2G a capacity loss of 2.2% would result whereas with V2G, a capacity loss of 3.8% over a year (keeping the other specifications constant) is predicted. Calls for financial compensation of bidirectional charging are thus understandable. Here, again the importance of fiscal encouragements, e.g. from policy or relevant actors are decisive. For tenants particularly, their vehicle is an important asset whereas homeowners have the vehicle integrated in their home energy system and could derive additional benefit from bidirectional charging apart from financial compensation. Homeowners can generally be considered early adopters of bidirectional charging (Fahrner et al. 2023; however, the current results indicate that they would not focus on grid solutions. While tenants also perceived the scenario of using the EV in one's own home as the easiest option for bidirectional charging, their greater willingness to provide their vehicle to the grid could potentially be attributed to their lower immersion in the topic and home energy system. They had less to gain from keeping their vehicle to themselves as they were not responsible for their energy system, contrary to most of the homeowners.

Additionally, as has been the case in our pre-study (Fahrner et al., 2023), tenants directly mentioned that bidirectional charging would be more interesting if one had an own home, preferably with a PV-system and private charging infrastructure. One could thus argue that for bidirectional charging, the coupling and individual responsibility for one's energy system are a facilitating factor. That individual use patterns of bidirectional charging would then result was accepted as doubts of feasibility were voiced given a lack of intelligence in the current energy grid. These structural barriers in the grid need to be disarmed first, as need aspects of bureaucracy and privacy concerns. Relevant policy measures that countries could adopt to promote V2X technologies are to transfer EU regulations into national laws, e.g. encourage greater penetration of smart meters and adequate parking options (Kühnbach et al., 2024) or, taxation and regulation strategies (Kester et al., 2018). If, however, grid solutions are in focus, and given financial compensation, tenants might be best to address to achieve public bidirectional charging. Interestingly, with tenants and a larger number of public photovoltaic systems, more energy from renewable sources could be included in the grid, thereby making public bidirectional charging more interesting and feasible as a use case for them. These results for tenants and homeowners are in line with early results of Wall (1995) showing that if environmental issues are either linked to individual concerns or a beneficial societal arrangement, behavioural change can be achieved.

Influence of disaster event – personal needs and benefits

With regard to bidirectional charging during disaster events, results show selfish motives to dominate, even more so for homeowners than tenants. For tenants, supporting the grid during disaster events in the form of bidirectional charging was only accepted if the disaster was not due to human mismanagement, showing that in that case, they attributed the responsibility to the originator. Importantly however, the direct experience with a disaster event of one participant in this group further influenced their willingness to provide bidirectional charging during a disaster event as it became evident that support would actually be needed. At the same time, it became evident that tenants had initially thought that a fall-back on officials and their role during disaster events could be assumed. That this was not the case led to great dissatisfaction and a discussion regarding the allocation of responsibility. While gaining personal benefits was the initial outlook on bidirectional charging in the tenants' group, through the shared experience they shifted their role perception during disaster events.

At the same time, owners prioritised the usage of their EVs for their own purposes rather than public resilience. This could go together with the general dissatisfaction they voiced regarding political regulations and the feeling that not enough was done for them. Furthermore, this could explain some extent of why they strongly opposed sharing energy capacities for social purposes. Generally, across both groups, dissatisfaction with official actors became evident. For owners, personal reasons might have also played a role, for example, one of the owners stated that he was disabled thus had different needs in the case of a disaster event. Results by Hubert et al. (2019) showed that smart charging technologies are accepted in the context of their suitability with daily life and that individual conditions have to be considered. A clear analysis of use cases of bidirectional charging would be important. Additionally, it is worth noting that many of the homeowners were highly motorised with three or more vehicles in their household. One could thus argue that they were generally interested in vehicles and new technologies which could also explain their participation in the focus groups, but especially that they were used to having a vehicle for themselves. This could further limit their motivation to provide their vehicle and its battery capacity to the grid.

Information channels

Finally, communication and information dissemination has been identified as key for user acceptance (Ghotge et al., 2022). As mentioned, to elicit more detailed user needs, we used images of a mock-up application in the focus group sessions (Fig. 1). Prior research suggests that when visual stimuli feel more realistic to participants, their responses tend to be more detailed and reflective of actual needs (Hughes & Huby, 2004). Our approach, in line with user-centred design, focused on a suitable app design and helped identify needs that participants potentially wouldn't have voiced if they were not presented with such a visual example. The design was perceived positively but participants asked that it should be embedded in existing apps to keep accessibility low. Interestingly, in both groups the discussion focused on similar topics regarding communication means. The comparison with discussions regarding a default organ donation underlined that participants wished for an automatic, standard procedure in favour of bidirectional charging. Furthermore, research has shown that social norm is a relevant indicator for trust and can motivate behaviour (TPB, Ajzen, 1991). Remaining trust in official, though not political, institutions was perceivable (e.g. red cross). Potentially, informational campaigns promoted by these organisations might help restore some level of trust in officials. This is especially important as an egotistical use intention will pose significant challenges for communities during disaster events as critical infrastructure (e.g. hospitals) will not be provided with sufficient energy. Therefore, considering different needs and tailoring information to specific users is the best strategy forward. Sociodemographic aspects like age, personal situation and living area but also affinity for technology ought to be considered to address users most efficiently. More research focusing on targeted information communication is needed and could be an interesting way to add to the current results.

Limitations

As is visible from the results, the discussion sometimes focussed on bidirectional charging in general without specific focus on a disastrous event. This could indicate that it was hard for participants to immerse themselves in the provided scenario. Future studies should put particular focus on making the scenario as clear as possible as we could sometimes perceive difficulties of the participants as they appeared

uncertain to the level of disaster in question. One solution would be to iteratively present different levels of disaster. Furthermore, as one can see from Table 1 containing participant information, not all tenants were indeed actual tenants. While this did not seem to impact the discussion, in future studies, the differentiation should be upheld more strongly. Generally, future studies should add to the current findings that are only a first exploration of relevant topics and user aspects. Potentially, there also is a self-selection bias in our sample as men – particularly with many cars, which may indicate greater interest or affinity for vehicles' and their technology – dominated in our sample. But then again, given the early adopter characteristics of EV users, this can be perceived as a general limitation of EV studies. Nevertheless, within the groups, more focus should be laid on heterogeneity, particularly with regard to gender, number of vehicles as well as living area.

Further, to better embed results within the broader bidirectional or V2X context, future research questions should place more focus on energy related aspects. For example, one could focus on the various essential needs participants state during different levels of disasters and make them rank their (subjective) relevance. This way, it could be assessed from a user perspective, e.g. if needs in the home like lighting / heating are ranked as more relevant than IT needs. Importantly, various scenarios could differentiate different user roles, e.g. depending on whether they wish to stay in their home and supply the building or for example, if users state they would drive somewhere (e.g. a hospital) to become an energy provider there. Here, especially financial questions and drivers, e.g. how high incentives to switch roles would need to be, could be inquired into further.

Conclusion

The current study provides valuable insights to understand human attitudes and behavioural intentions in the case of a disastrous event regarding bidirectional charging. The results underline the importance of developing strategies that enable people and potentially (tenants') communities to cope with potential disaster events in both a socially acceptable but also more strategic way. As results showed a more individualistic – or at times selfish – focus, a more strategic policy governance for grid friendly emergency bidirectional charging could help manage future disaster events more effectual. Efficient policy design (e.g., regulation and taxation, smart meter penetration) as well clear communication strategies that are resilient to disastrous external impacts need to be promoted. Explorative studies with psychological theories in mind are particularly suited to address these emerging topics and better understand mechanisms of crises all the while trying to identify solutions that are sustainable and suited for different users. The identified need for (preventative) information campaigns and their adaptability to different users is of the utmost importance to promote resilience. It currently appears that community structures are not yet built or sufficiently accepted. Furthermore, social cohesion is lacking, but here, potentially, accepted officials could explain why a more collectivistic focus could be beneficial, especially during disastrous events.

CRediT authorship contribution statement

Vera Maria Fahrner: Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Conceptualization, Visualization. **Yuri Hwang:** Writing – review & editing, Methodology, Investigation, Visualization. **Julius Pfeifer:** Writing – review & editing, Investigation, Methodology. **Moritz Bergfeld:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The authors do not have permission to share data.

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