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Smart Charging in Germany: Acceptance and Tariff Design

Marvin Helferich[1*], Josephine Tröger[1], Annegret Stephan[1**]
[1] Fraunhofer Institute for Systems and Innovation Research ISI, Breslauer Straße 48, 76139 Karlsruhe, Germany
* marvin.helferich@isi.fraunhofer.de
**presenting author

Executive Summary

Electrification is one of the key means to decarbonize the transportation sector, but the growing number of electric vehicles (EVs) in the market contributes to the risk of bringing existing electricity grids to their limits. Smart and bidirectional charging offer a solution to alleviate grid load and increase the use of renewable electricity. We conducted 12 expert interviews with smart charging stakeholders in Germany and a consumer study with 689 German EV users to identify opportunities, risks, barriers, and feasibility, as well as user preferences related to smart charging tariff designs. We found a generally positive view among the stakeholders, and identified barriers that need to be overcome before a large-scale deployment of smart charging. Consumers are generally willing to accept smart charging, with financial compensation for offering flexibility being the most important design attribute. We discuss implications in light of the reformulation of pertinent regulations in Germany.

Keywords: consumers, demand, smart charging, user behavior, V2G (vehicle to grid)

1 Introduction

Electrification is one of the key means to decarbonize transportation, and hence contribute to the climate targets set in the Paris Agreement [1]. Many countries have set targets for electric vehicle (EV) deployment [2]. Germany wants to reach a stock of 15 million EVs by 2030 (including battery electric and fuel cell vehicles) [3], whereof at the beginning of 2023 more than one million battery electric vehicles (BEVs) have been deployed [4]. Thus, the number of EVs is expected to increase substantially during the next decade—in Germany and beyond.

While a high number of BEVs can stress existing grids, especially in case of uncontrolled, fast and cumulative charging, BEVs can also serve as flexibility source in case of smart charging [5] and may help to include high shares of intermittent renewable power production. For example, delaying charging processes or reducing charging capacity can prevent peak loads especially at distribution grid level. Moreover, bidirectional charging could even enhance this flexibility and provide electricity to customers (vehicle-to-customer, V2C) or to the grid (vehicle-to-grid, V2G). In addition to technical advances, smart charging can represent potential revenue sources for customers or investors while reducing or preventing grid investments [6, 7].

Demand side management, in particular smart charging, is expected to be an important lever for reaching net zero greenhouse gas (GHG) emissions and coping with both the increasing intermittent power production and the increasing electricity consumption due to the electrification of sectors such as heat and transportation [2, 8, 9]. While the amounts of future flexibility supply and demand are uncertain because of the complex interplay of technologies (and their developments and deployments), grid levels, and behavioral issues [10], flexibility needs are expected to grow to maintain electricity security—e.g., up until fourfold in 2050 in the announced pledges scenario by the IEA [1].

In addition to technical barriers, regulatory and social barriers still hamper the deployment of smart charging, which need to and can actually be removed. Industry has started to develop technologies, specifically relevant control and monitoring technologies. In 2021 more than 55 billion USD were spent on digital infrastructure in transmission and distribution grids, nearly 50% of those went into smart meters and public charging infrastructure [11]. In addition, governments all over the world have recognized the potential of smart charging / demand side flexibility and started to remove regulatory barriers [8]. In Germany, the Federal Network Agency currently drafts paragraph 14a of the German Energy Industry Act, regulating the integration of controllable consumer, i.e., user, devices and network connections [12], which hence would allow for smart charging processes. In addition to technical and regulatory efforts, tapping into the full potential of charging flexibility requires EV users' consent [13], i.e., acceptance, and incentives that steer user behavior into the desired direction [10, 13, 14].

However, especially regulatory and social barriers such as lack of acceptance or fears with regard to partial control of charging processes [15, 16] are context-specific and might, in addition, change over time. Hence, boosting smart charging does not only depend on (typically global) technical developments but on current local regulatory and social conditions. Moreover, smart charging involves a variety of actors from different fields of expertise and practice, such as utilities, grid operators, charging infrastructure providers, and automotive OEMs. While BEV users can be incentivized to participate in smart charging e.g., with specific tariffs [10, 13, 14, 17], concerns and barriers from all related fields have to be considered for successfully implementing smart charging.

Extant work investigating barriers for smart or bidirectional charging deployment has typically applied a global focus [10, 18, 19], while the importance to consider local or national conditions has been highlighted [10, 18]. Moreover, studies addressing user acceptance of smart charging [13] are scarce for the German case. Typically, studies on smart charging in Germany either refer to demonstration projects [20–22] or have been conducted in the early years of EV deployment [23, 24], limiting the transferability of results to the current situation in Germany. Over the past few years, there has been significant acceleration in technology development and deployment as well as the design of regulatory frameworks. According to previous studies, within these developments, financial remuneration or charging costs have been identified as one of the key influencing factors for EV users' charging decision [13, 23], indicating the potential of smartly designed tariffs to stimulate EV users' participation in smart charging. A recent study conducted in Switzerland suggests that the compensation required by electric vehicle users for the increased uncertainty created by smart charging is exceptionally high in cases where the charging location is changed or the battery's state-of-charge is low after half of the charging duration [13]. However, we lack a comprehensive overview of barriers for smart charging in Germany, as well as a good understanding of how tariffs should be designed to make smart charging more appealing to German BEV users in order to stimulate the development and deployment of smart charging in Germany.

This paper aims to address this gap by (1) investigating the potential of and barriers for smart and bidirectional charging in Germany from a holistic perspective that takes into account the viewpoint of various relevant stakeholders. Additionally, this paper (2) analyzes the preferences of German BEV users for tariff design, as well as the (psychologically) relevant factors that may influence these preferences.

2 Methods

We combined two approaches to answer the research questions. First, we conducted 12 semi-structured interviews [25] with experts from most of the actors that are relevant to the field of smart charging between December 13th, 2022 and March 1st, 2023. Interviews were carried out virtually through the use of Microsoft Teams and had a duration ranging from 36 to 60 minutes. We interviewed one lawyer, two representatives from state politics, one representative from federal politics, one researcher, and one representative each from grid operators, consumer advocacy, industrial unions, associations of BEV drivers and technical-scientific associations, electricity providers, and consulting.

The interviews were based on an interview guide, which had been carefully crafted focusing on drivers and barriers for smart and bidirectional charging from the respective actor's perspective. Each interview addressed the interview partners' vision for mobility 2030, their expertise and previous experiences in the field of smart and bidirectional charging, the developments of the recent years, the different design options and their respective feasibility, risks and opportunities, as well as relevant actors and measures to reduce current barriers. Each interview was transcribed verbatim and coded by two coders according to a pre-defined coding scheme. Two of the authors coded six interviews each and then exchanged and double-checked the codes to ensure coding reliability. Disagreements were solved by discussion. After coding, the interviews were analyzed using qualitative content analysis [26, 27] with MaxQDA 2020 Plus.

Second, we conducted a quantitative consumer study. We designed an online questionnaire using the Sawtooth Software Lighthouse Studio version 9.14.2. The questionnaire consisted of 67 mostly closed-ended questions and a choice-based conjoint (CBC) experiment with four random tasks and one fixed task. The survey took on average 13 minutes (median) to complete and was fielded between February 14th, 2023 and March 17th, 2023. The goal was to identify consumer preferences for different configurations of smart charging tariffs and to reveal influencing factors for these preferences.

We recruited 689 German BEV users from the respondent panel of a market research institute, who were financially compensated. We implemented quotas on the respondents' gender, age and income to ensure a sample that is close to demographically representative of the German population. Due to the current population of German EV drivers, our sample included more men of lower age and with higher income than would be representative of the German population. Table 1 displays the socio-demographic characteristics of our sample.

After the participants agreed to the terms of participation and completed the questions that were relevant for the implemented quotas, they were shown an introductory text explaining the basics of smart and bidirectional charging and asked about their familiarity with the topic. This introductory question was followed by several questions regarding their EV. These questions were followed by questions about their charging and driving behavior [28].

Table 1. Socio-demographics.

Characteristics	Share in sample ($N = 689$)	Share in population
Gender		
Male	62.26%	49%
Female	37.74%	51%
Age	$M = 43.45$, $SD = 13.57$, Min = 18, Max = 84	
18-30	19.16%	18%
31-45	38.75%	24%
46-60	29.90%	25%
> 60	12.19%	33%
Net household income		
< 1500€	4.21%	17.8%
1500€-2600€	14.22%	25.3%
2600€-3600€	25.25%	17.8%
3600€-5000€	30.62%	16.9%
> 5000€	25.69%	22.2%

Then followed the CBC experiment. We chose the CBC method over other choice experiment methods because of its closeness to reality (in the experiment participants were presented with 3 options next to each other, just as they would be in real life), the shorter response time especially compared to the ACBC method (particularly important because we also included other questions in the questionnaire) and the large enough sample size, which rendered other more complex choice experiment methods unnecessary [29–31]. In addition, CBC has been used in similar previous studies [13, 32–34], which makes our study comparable.

As we planned on recruiting 750 participants, we also generated 750 unique CE versions. Each tariff option in the choice experiment consists of attributes and levels. Levels are the specification of the respective attributes for a given tariff option. A rule of thumb is that each level should appear at least 500 times across the entire sample [35]. We thus consulted the literature for attributes that would be theoretically important [e.g., 13] and came up with five attributes and two to four levels each. Together with the prohibitions that will be outlined below, we ensured at least 1,500 appearances per level, which thus satisfied the recommended rule of thumb. Table 2 displays the attributes and corresponding levels. A link to a pdf file explaining the different levels to the participants was available throughout the CBC experiment.

We introduced prohibitions such that charging mode level 1 could not appear with intervention possibility and V2G capability, because these were not realistic options. For random task generation, we opted for the balanced overlap method, which ensures that each level is shown nearly an equal number of times and that each level is shown with each other level nearly an equal number of times [30]. We went for four random tasks because this number satisfies the rule of thumb of keeping standard errors for main effects below 0.05 [35], while keeping the time it would take participants to complete the questionnaire short.

We chose to include three options per choice task to keep it manageable, and to include a so-called 'dual response none' option. Hence, participants first chose their preferred option and were then able to indicate if they would be likely to choose this option in the real world. This way, dual response none is a good option for both participants and researchers. Participants can indicate they would not choose any of the presented options, while researchers can still gather the necessary choice information [36].

The CBC experiment was followed by additional closed-ended questions about participants' living arrangement, their current electricity tariffs, and further person-level factors, such as risk aversion *(M* = 4.49 points on a 7-point scale, *SD* = 1.14, *MD* = 4.40).

We used Hierarchical Bayes (HB) estimation to calculate the importance and part-worth utility values reported in the next section. This method is widely considered the gold standard for the analysis of CBC data as it is the most effective at modeling individual-level heterogeneity in choices [30]

Table 2. Overview of attributes and levels

Attribute	Level 1	Level 2	Level 3	Level 4
Pricing scheme	Constant price	Two pre-defined prices (HT/LT)	Pre-defined price corridor	Pre-defined price corridor plus emergency price
Charging mode	Directly starting, complete charging process with full power	Directly starting, complete charging process with lower but guaranteed minimum power	Shift charging process to uncritical times, with guaranteed SoC at desired time	Directly starting charging of emergency SoC (25-30%), then variable charging time and power with guaranteed SoC at desired time
Savings potential compared to current charging tariff	None	Up to 10%	10-20%	20-30%
Possibility of intervention by user	Yes	No	n/a	n/a
V2G capability	Yes	No	n/a	n/a

3 Results

3.1 Interview study

3.1.1 Opportunities

The interviewees associated many opportunities with smart and bidirectional charging. Most of all, they saw the opportunity to increase grid stability which will be challenged by an increasing amount of EVs. Smart charging thus presents the opportunity to distribute grid loads more evenly and to reduce the pressure on electricity grids. However, the possibility of smart charging might also incentivize the decision not to invest in grid reinforcement projects, although both will be needed. A lawyer explained, "in order to evenly distribute grid and generation capacities, we need intelligence to control charging processes" (interview 1).

Furthermore, the interviewees saw the opportunity for EV users to benefit from smart and especially bidirectional charging, primarily through financial incentives (e.g., reduced network charges) and reimbursements for electricity that is fed into the grid in the case of bidirectional charging. A representative from the consumer advocacy sector said, "the most important driver [for smart charging deployment] are financial benefits, there's no denying it" (interview 6). In addition, bidirectional charging can help EV users to become increasingly energy self-sufficient, an opportunity especially in the light of the currently looming energy crisis.

Many interviewees highlighted the importance to consider user acceptance when implementing smart charging. Smart charging should be designed in a way that it satisfies both the users' needs and the grids' requirements. Signing up for smart charging should thus not be made mandatory, but incentivized through financial benefits and the possibilities for grid operators to reduce charging power or otherwise meddle with the charging process should be limited. An employee of a grid operator formulated that, "we continuously test how much control we need to exert so that we have a benefit without restricting the users too much" (interview 4).

Lastly, the opportunity to increase the integration of renewable energies into the electricity grid especially through bidirectional charging played a small yet important role in several interviews. Especially in combination with stationary home storage, the integration of, among others, privately produced PV electricity in the charging process could be improved. According to a state politician, smart and bidirectional charging is all about "the most efficient use of renewable energies" (interview 11).

3.1.2 Risks

As for the risks of smart charging, the interviewees most often referred to risks for the electricity grids through an overcoordination effect, meaning that smart charging might lead to high simultaneities due to an automatically started charging process, typically occurring at the starting time of low-price periods. In this case, the simultaneity factor might be even higher than without smart charging, because a large number of EVs in an area start the charging process at exactly the same time, not five minutes earlier or later. As a representative of an electricity provider put it, "there are risks regarding herding effects, regarding synchronous behavior that we would consequently induce en masse" (interview 10).

Another risk the interviewees anticipated was for EV users to not be able to use their EV as they wished to in case the EV doesn't have the desired state of charge when departing. This risk depends to a large extent on the design of smart charging, particularly whether grid operators are given the opportunity to reduce the charging power for an unlimited amount of time or if that possibility is restricted to two hours a day for example. The consumer advocate said that, "it can stir up fears if driving an EV is related to the question whether I can always charge my car when I want to or whether I will strand sometime because my wall box was regulated by the grid operator" (interview 6).

A third risk was seen in social equity as it pertains to tenants versus home owners. In Germany to date, it is generally easier for home owners to install charging infrastructure than for tenants. Thus, home owners are more likely to benefit from potential financial savings associated with smart or bidirectional charging. This risk is increased for tenants who don't have an associated parking spot and depend on public charging infrastructure, where smart charging is not (yet) an option[1]. A researcher told us that, "the extent to which [smart charging] is fair is a different question. That someone who doesn't have a car but needs electricity wouldn't get a cheaper price would be something to further think about. Potentially it would be interesting to apply the same logic to running the washing machine when there is a lot of wind" (interview 5).

3.1.3 Barriers

In terms of barriers that currently prevent smart charging deployment, interviewees mentioned above all regulatory barriers that need to be overcome. Especially for bidirectional charging, many aspects need to be clarified, such as the definition of an EV battery as storage, avoiding double taxation when charging and discharging, or accounting issues when charging happens at a different place (e.g., at work) than discharging (e.g., at home). A consultant mentioned that, "ISO 15118-1 and -2 are just two standards that come into play here. Standards can be developed more quickly or more slowly. The process is slowed down whenever there are a lot of different interests involved" (interview 12). But also for unidirectional smart charging, regulatory issues have to be fixed. Transparency is needed regarding how EV users will benefit from offering flexibility (e.g., reduced network charges or otherwise attractive charging tariffs), the possibility for grid operators to reduce charging load should be limited to a certain amount of time per day, and more opportunities for tenants to benefit from smart charging should be introduced.

Technical barriers refer, among others, to EVs' capability to charge bidirectionally (to date, only very few car models are V2X-capable). Another big technical (and regulatory) barrier is the lack of (global) standards of how such an interface should look like or which kind of plug should be used. An electricity provider told us that, "for us it continues to be unclear which vehicles will support bidirectional charging under which conditions, with which communication system and to what extent" (interview 10). In addition, the digital infrastructure in Germany is on a level that most likely wouldn't permit real-time communication to the extent necessary for smart charging. This is reinforced by the fact that grid operators are "blind" on the level of distribution networks due to the lack of smart metering systems, so there are few ways of knowing what is happening in the local grids.

The third group of barriers is market-based, especially as electricity providers don't see a business case for smart charging yet. Particularly in the case of bidirectional charging behind the meter, electricity providers could even lose money if EV users bought less electricity in case they increase the consumption of their own PV-generated electricity. An electricity provider told us that, "it is very very difficult to really invest money in this very uncertain market situation. To date, a home energy management system has no business case" (interview 10). Another market-based barrier is the current lack of interoperability between the V2X car models and bidirectional charging infrastructures that do exist today.

Lastly, there are socio-political barriers that consist, among others, of a lack of acceptance due to the fear of not being able to use the EV as desired if the charging process is slowed down or even interrupted. Financial incentives to participate in smart charging are rare today. Reduced network charges alone may not reduce electricity prices substantially enough to make smart charging financially attractive. A distribution grid operator told us that, "our technicians are on site and are told that the customer doesn't want [smart charging]. Or the technician needs to tell the customer that their electricity meter can't cope with the new technique and they need to install a new one for 3,000€. There will be several cases where the customers will be reluctant" (interview 4). There is also the fear of data leakages or cyber-attacks that are partly reinforced by national media and prevent many EV users from adopting smart charging.

Furthermore, politics for regulation and for designing attractive infrastructure are too slow regarding decision and implementation. Actors thus need a consistent strategy and goal-oriented behavior, which is not easy to establish until there is a certain balance of interests and power within the system.

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[1] In Germany, to date, providers of public charging infrastructure often charge fees for charging EVs longer than, e.g., four hours. This would make leaving the car longer to benefit from flexibility services highly unattractive.

3.1.4 Feasibility

Despite these barriers, our interviewees agreed on the general technical and legal feasibility to implement smart charging and were optimistic that it will be applied on a large scale in the near future. A state politician deemed it, "very realistic, it will come. Otherwise one use case of [electric vehicles] would be completely neglected" (interview 2). The main use case is seen for single-family homes and probably mainly for private charging (e.g., at home or at work). In addition, first implementations for public charging locations are expected (e.g., park and ride facilities).

To increase usage by and acceptance from EV users, our interviewees suggested primarily transparent information and honest communication about the design and impact of smart charging, as well as hands-on experiences such as trial-phases. A consumer advocate said that, "there is the big block of transparency, that people are informed to begin with. What is possible? What are the options? Why are they there? And why is it useful for me as an EV driver, but also for me as a resident in a street, a city, to behave in a way that is beneficial to the grid? There is still a lot of room for improvement that consumers are informed about the different options by their electricity providers" (interview 6). Other strategies to increase acceptance include subsidizing the purchase of the corresponding charging infrastructure, real financial savings associated with smart charging (e.g., through reduced charging tariffs), and guaranteed minimum charging power to prevent complete interruption of the charging process.

3.2 Consumer study

3.2.1 Importances

Importances indicate the difference each attribute could make in the total utility of a product [37]. Figure 1 shows the average importances of the attributes characterizing the charging tariffs. It can be observed that the opportunity to realize financial savings has the highest importance and is more than twice as important as pricing scheme and charging mode, which follow next with an approximately equal importance. The possibility to intervene with the smart charging process ranks fourth in importance, while the ability to charge bidirectionally is associated with the smallest level of importance.

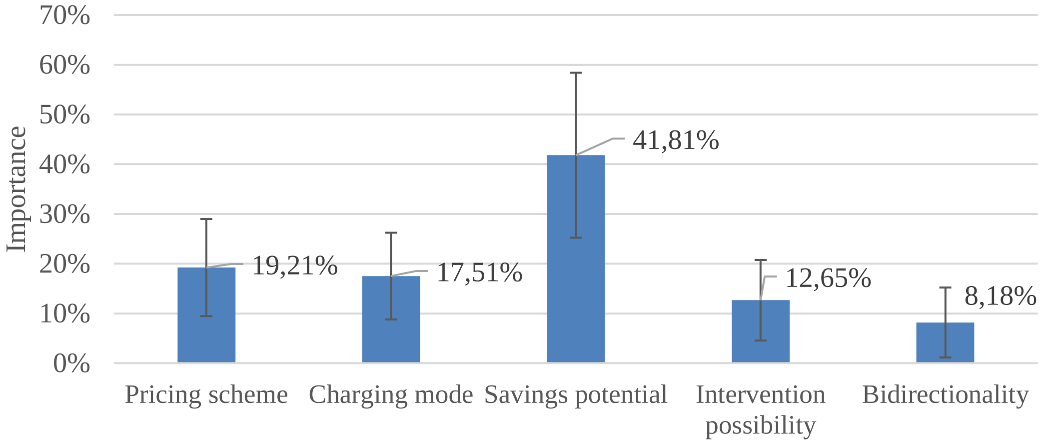

Figure 1. Importances of attributes (N = 689). Error bars are standard deviations.

3.2.2 Part-worth utilities

Part-worth utilities measure the attractiveness of the different attribute levels relative to the remaining levels within the same attribute, i.e., comparisons can be made for the levels within one attribute, but not for levels across attributes. Also, part-worth utilities do not allow for ratio operations, so while we can say which level within an attribute is most attractive to users, we cannot quantify by how much. For the present calculations, we used effects coding, meaning that the utility values sum to zero within each attribute [37].

Figure 2 shows the part-worth utilities for each attribute level. The high dispersion observed in the part-worth utilities of savings opportunity reflects the attribute's high importance depicted in Figure 1. The corresponding part-worth utility curve is almost linear, indicating that the attractiveness of savings increases linearly as the savings increase from no savings to 20-30% savings compared to the current charging tariff. Regarding pricing scheme, the respondents preferred a price corridor that includes an emergency price for critical grid situations the most, while a price corridor without an emergency price was the least preferred. Constant and HT/LT pricing schemes are approximately equally preferred, with the HT/LT option slightly less attractive than a constant pricing scheme. Regarding the charging mode, there are only minor utility differences between the different levels. Participants seem to prefer most the option where the charging process is shifted to less critical times, but a safety buffer is charged at the beginning of the charging process. The other two smart charging modes (i.e., charging with lower power but guaranteed SOC and the shifted charging process without safety buffer) seem to be slightly less attractive to participants than status quo charging. Lastly, it seems that participants prefer having the possibility to opt out of the smart charging process (intervention possibility) rather than not having it, and they also prefer the option to charge bidirectionally compared to unidirectionally.

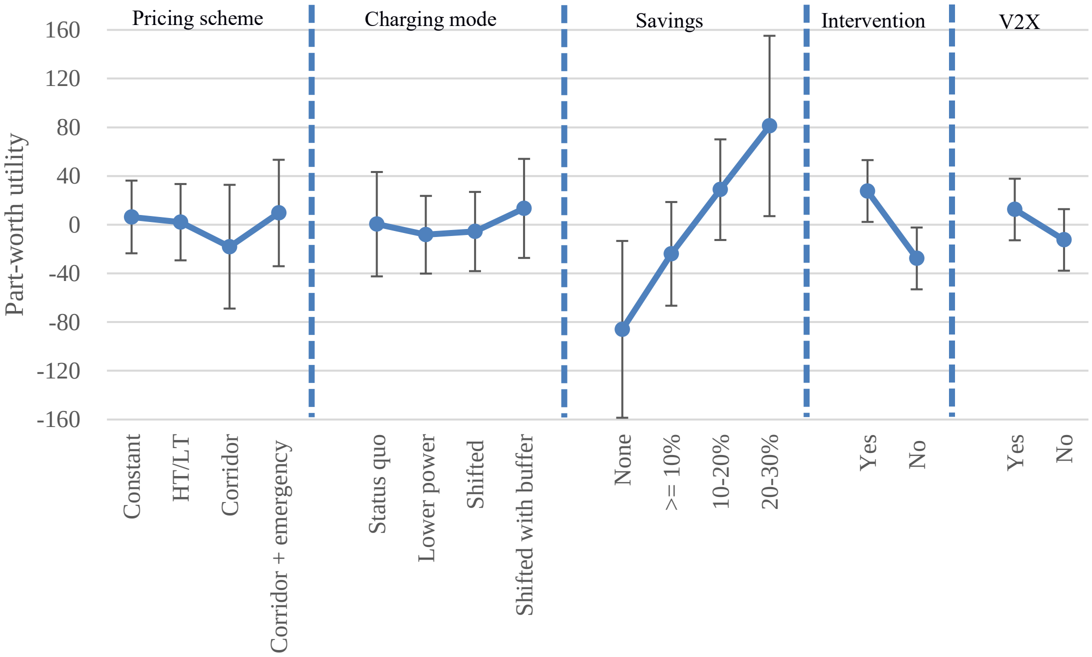

Figure 2. Part-worth utilities of attribute levels (N = 689). Error bars are standard deviations.

4 Discussion

In this study, we (1) investigated the feasibility and obstacles of implementing smart and bidirectional charging in Germany from a comprehensive perspective, encompassing many relevant stakeholders, and (2) analyzed the preferences of German BEV users regarding tariff design and the (psychological) factors that shape these preferences. We conducted 12 semi-structured interviews with representatives from different smart charging stakeholder groups and a consumer study with 689 German BEV users.

Our findings from the interviews suggest that most stakeholders are optimistic about the technical and legal feasibility of smart charging in Germany. However, the main barrier to widespread adoption and acceptance of smart charging appears to be the presence of multiple stakeholders with diverging interests and the lack of a clear regulatory framework that allows for experimenting with different design options before settling on one or several dominant designs. Providing the opportunity to experiment would also enable users to gain experiences with smart charging systems, potentially reducing some of the associated fears that currently hinder social acceptance. These fears include a form of range anxiety (i.e., not being able to complete a desired trip due to reduced charging power) and concerns about data breaches or cyber-attacks. Gaining experiences and improving the infrastructure's necessary safeguards could help alleviate these fears.

Despite the generally optimistic view, our interviewees also identified a number of further barriers and risks that cannot easily be tackled. These include, above all, the risk of overcoordination that could lead to grid instabilities – the very risk that smart charging is supposed to tackle. A significant barrier for bidirectional charging is the lack of global standards that harmonize the design of smart charging infrastructure (e.g., plugs, power outlets, car interfaces, etc.) and thus ensure the interoperability of systems from different providers. As a result, a short-term solution to these barriers, which would allow a quick deployment and market ramp-up of smart charging in Germany, is therefore seen as unlikely. While §14a of the German Energy Industry Act is due to become effective starting January 1st, 2024, interviewees were skeptical that all (or at least most) of the remaining issues will be solved by then. Nevertheless, there was a consensus among the interviewees that smart charging is a 'must-have' for the future if we are serious about addressing the energy and mobility transition.

The deployment of smart charging poses substantial social challenges, particularly in relation to home owners versus tenants and car owners versus non-car owners. In Germany, to date, legal issues have made it more difficult for tenants to install private charging infrastructure than for homeowners. Furthermore, non-car owners cannot benefit from smart charging if benefits are restricted to charging EVs. While one could argue that non-car owners do not have the same financial burden related to charging their car as car owners and therefore do not need to benefit from smart charging, one could still raise the issue of designing the energy and mobility transition as socially inclusive as possible.

Several of our interviewees suggested two ways of increasing the share of society benefiting from smart charging or smart electricity usage in general. Firstly, smart charging could also be implemented in public spaces allowing EV owners with difficulties to install private charging infrastructure to benefit from smart charging in the same way as other EV owners. Examples of this could include curbside infrastructure for overnight charging, or park and ride facilities for charging during the day, for example when people commute to work. This would, however, require regulatory changes such as the elimination of blocking fees. Secondly, the concept of smart electricity usage could be expanded to other daily activities. For example, financially remunerating customers for switching on their washing machine during times of high (renewable) energy supply and refraining from using it during in times of tense grid situations, similarly to charging an EV in a grid-beneficial way. Thus, there is a significant potential to create an environment that incentivizes consumers, empowers them as prosumers and allows them to participate in the energy and mobility transition as beneficiaries [38, 39].

Based on the data from the consumer study, we can conclude that an attractive smart charging tariff for the average user would include a pre-defined price corridor with an emergency price for grid bottlenecks, which would result in 20-30% savings compared to participants' current charging tariff. The charging mode would start with a safety buffer of 20-30% SOC, and the rest of the charging process would be shifted to less critical times for the grid, with bidirectional charging as an option. Additionally, participants preferred to have the option to opt out of smart charging and charge their vehicle as they wish.

This finding has interesting implications regarding EV users' attitudes. Firstly, EV users seem to be slightly risk averse because they prefer the possibility to opt out of smart charging and a charging mode that ensures a buffer SOC before the charging process is controlled in a grid-beneficial way. This interpretation is consistent with the results from the risk aversion scale that was included at the end of the questionnaire. Here, participants had an average score of 4.49 (see section 2), which indicates moderate risk aversion.

Secondly, EV users' preference for a charging mode with safety buffer indicates that it is not too important to them how the charging process itself is designed. As long as the SOC is high enough for spontaneous departures (thus the safety buffer), the further charging process can be shifted to less critical times or be otherwise controlled without EV users feeling overly restricted by it. However, EV users do not seem to accept a continuous charging process with a lower power than today, i.e., a longer duration of the charging process, even if they were guaranteed their desired SOC at the end of the charging process. Our interpretation of this finding is that if EV users are to accept smart charging, they prefer maximum benefit for the grids (flexible charging) without substantially compromising their own needs. "Just" slowing down the charging process through lower power seems unacceptable as an implementation of smart charging.

Thirdly, we found that EV users prefer a pricing scheme with an emergency price over the same corridor without an emergency price. This preference could be interpreted as a certain degree of care for the electricity grids among EV users, because it means that they prefer a penalty for charging in particularly critical grid situations. Their preference for including bidirectional charging in the tariffs taps into the same vein, as that would mean capitalizing on another benefit that EVs can offer for the electricity grids, as long as the users are financially compensated for providing the flexibilities associated with smart and bidirectional charging.

A word of caution is needed regarding the technology-optimistic view of smart charging as the only solution to increasing the share of renewable energies and managing the grid integration of the rapidly growing number of EVs. As outlined above, smart charging deployment bears the risk of social inequities that must be considered when designing regulations to ensure it benefits society as a whole. Moreover, smart charging could become a solution to cope with the increasing number of EVs in the electricity grids, potentially undermining efforts to reduce private car ownership and trips, as advocated in the sufficiency debate [e.g., 40]. Efficiency and consistency measures, under which smart charging could be classified, sometimes tend to neglect sufficiency and the behavioral changes required to achieve a low-carbon transition [e.g., 41]. Finally, technological solutions could trigger rebound effects, whereby users change their behavior after a technological improvement and contribute to, for instance, a growth of overall car usage, thus contributing to negative effects regarding the sustainability goals [e.g., 42]. Better integration of renewable energies through smart charging could lead to more or longer trips since users can recharge their car more often with 'clean' electricity.

5 Conclusion

We conducted expert interviews with smart charging stakeholders in Germany and a consumer study with German EV users to understand stakeholders' and EV users' perceptions and preferences related to smart and bidirectional charging in general, as well as potential tariff designs. Despite various barriers, stakeholders view smart charging positively in terms of necessity and feasibility. EV users, who are slightly risk-averse, generally support smart charging and prioritize financial incentives for the flexibility they provide with their EVs.

Smart and bidirectional charging can make an important contribution to a sustainable mobility transition by enabling a larger number of EVs to be charged without endangering existing electricity grids. However, it is crucial to keep in mind the caveats mentioned above to ensure its potential is realized without causing social inequities, neglecting sufficiency, or inducing rebound effects.

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Presenter Biography

Dr. Annegret Stephan is a senior researcher at the Fraunhofer Institute for Systems and Innovation Research ISI in Karlsruhe (Germany). Her research centers on technological innovation for a clean energy system, specifically on the coupling of the energy and transport sectors. After studying business engineering at Karlsruhe Institute of Technology (KIT), she conducted her doctoral thesis with a focus on energy technology innovations, specifically batteries, in the Group for Sustainability and Technology (SusTec) at ETH Zurich (2013-2016), and continued working in this group as postdoctoral and senior researcher (2017-2021) before joining the Competence Center Energy Technologies and Energy Systems of Fraunhofer ISI in 2022.

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