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Increasing users' smart charging intention through information presentation and HMI-design

Madlen Günther[1], Bettina Kämpfe[1], Lana Mohr[1], Josef F. Krems[1]

[1] *Chemnitz University of Technology, Chemnitz, Germany, madlen.guenther@psychologie.tu-chemnitz.de*

Executive Summary

Within this contribution, we present a study that investigates whether user' intention to choose smart charging can be promoted by an appropriate HMI design with information presentation tailored to the user. To this end, a laboratory study was conducted, and a prototypical smart charging app was developed. Three different formats of information presentation were empirically tested: 1) informative texts and diagrams, 2) storytelling, and 3) statistics. The study comprised a total sample of $N = 91$ participants, who were randomly allocated to one of the three conditions and who were given a hypothetical charging scenario. Results showed that participants' intention to choose smart charging significantly increased through the interaction with the app, revealing that all conditions were beneficial presentation strategies. However, post-hoc comparisons revealed that the *statistics* condition led to the highest level of participants' intention to choose smart charging. Although the sample was not representative, useful recommendations for future HMI design can be derived.

Keywords: Electric Vehicles, Consumer Behaviour, Consumer Demand, Smart Charging, Human-Machine/Computer Interactions

1 Introduction

The transport sector is one of the largest emitters of greenhouse gases, accounting for around a quarter (23.8%) of global energy-related CO_2 emissions [1]. With the rapid increase in demand for mobility and private vehicle ownership, the problem of high greenhouse gas emissions is becoming more acute [2]. The gradual electrification of road transport and the shift to low-emission vehicles, in particular battery electric vehicles (BEVs), offer a promising alternative to conventional fossil fuel propulsion technologies.

To ensure that the electricity needed to power the rapidly growing number of BEVs comes from renewable sources, innovative technologies such as smart charging will play a crucial role [3]. This is because smart charging not only contributes to the efficiency of the charging process but also promotes the integration of renewable energy into the electricity grid. However, the challenges of introducing such technologies go beyond technical and organisational/political aspects. The attitudes and behaviour of those using the technology, i.e., the human factor, play a central role.

2 Smart charging and HMI-design

As the availability of electricity from renewable sources in the power grid can fluctuate greatly, smart BEV charging is one effective approach to balance the grid in times of 'green' energy shortage or overload [4]. This technology can minimise both peak loads and grid congestion due to increasing electricity demand and typical charging times while maximising the use of renewable energy. BEVs are charged in an efficient and controlled manner, taking into account all relevant factors and requirements of the grid system, as well as the needs of BEV users [5]. With smart charging, the charging process is regulated and controlled by an external entity that sets the charging schedule and keeps an eye on defined targets and framework conditions as well as the interests of all parties involved [5]. Smart charging technology thus enables a smoother integration of BEVs into the grid by maintaining grid stability and peak load management by controlling the charging process of BEVs depending on various parameters, such as the current electricity demand and the availability of renewable energy. This means that, based on signals from the grid, charging power can be reduced or charging can be shifted during peak loads [6, 7]. For example, the peak load, which is expected to increase by 30% with a BEV market penetration of 25%, can be reduced by 16% through the implementation of smart charging [8]. This peak load reduction also reduces the need for grid upgrades. Overall, smart charging is a promising solution for balancing the growth in the number of BEVs with the available grid capacity.

As smart charging allows the charging process to be switched on and off and generally slowed externally, the charging technology may require more flexibility from its users. This may be manifested, for example, in terms of charging time, as it may be necessary to wait longer for the available energy, or in the fact that a lower final state of charge is achieved in the same charging time compared to conventional, uncontrolled charging [9, 10]. Accordingly, these behavioural adjustments may be perceived as costs (e.g., in terms of time costs, loss of control, or cognitive and physical effort due to increased planning requirements) and affect the acceptance of this technology [11]. This raises the question of how to compensate users for these perceived behavioural costs and how to motivate them to use smart charging despite its disadvantages.

Previous results confirm the need to address the perceived lack of flexibility and control, which are the main barriers to adoption of smart charging. Various behavioural interventions and incentives can be used. Several studies have already shown how BEV user behaviour can be influenced by direct BEV-related incentives, such as priority at charging stations [12], free parking [13], monetary and environmental incentives [14, 15, 16]; individual adaptability of the technical system [14, 16]; technological incentives [16], but also through persuasive technologies implemented in the human-machine-interface (HMI) design, such as feedback and gamification [17]. For example, the implementation of this kind of information, feedback, and incentives could be integrated into a smart charging application where the charging process is initiated and managed by the user. In the study by Filipowicz et al. [18], the influence of information presentation on CO_2 emissions, social comparison, and incentives on the willingness to wait longer for a full charge led to a significant increase in the choice of smart charging when using the app. However, in order to show users the potential of smart charging and consequently motivate them to use it, it is first necessary to communicate the modern technology and its advantages in an understandable way. To present information, informative texts and diagrams [19], storytelling [20, 21], and statistics [22, 23] were previously proven to be useful strategies.

3 Present research

The aim of the following study was to investigate whether users' willingness to participate in smart charging practices can be promoted through HMI-design and to deepen the understanding of best practices for information presentation in apps. To this end, three formats of information presentation were developed and empirically tested: 1) informative texts and diagrams, 2) storytelling, and 3) statistics.

4 Methodology

In a lab study at Chemnitz University of Technology, Germany, study participants received a hypothetical charging scenario task and were asked to select their preferred charging setting. Thus, a prototypical smart charging app was developed, and the three conditions were implemented (see Figure 1). Participants had to use the app to solve a charging task and answered an evaluation survey before and after the interaction.

1.1 Study design

In this study, a 3 x 2 experimental cross-sectional design was used to determine the influence of the different forms of information presentation on the users' intention to choose smart charging. The information presentation comprised three conditions and differed in the presentation of informative texts and figures (*information* condition; see Figure 1, screens 3 and 4), the addition of storytelling (*storytelling* condition; see

Figure 1, screens 5, 6 and 7), and the combined presentation of information and statistics (*statistics* condition; see Figure 1, screens 9 and 10). The testing was carried out in a between-subjects design, as each person was assigned to exactly one condition. The start (screens 1 & 2) and end screens (screens 10 & 11) were the same for all participants.

In the *information* condition (screens 3 & 4) a comparison between instant and smart charging based on energy source, charging process, duration and price was presented. The *storytelling* condition (screens 5, 6 & 7) included a presentation of a fictitious EV user who is aware of the bottlenecks in the electricity grid and compares the advantages with disadvantages when deciding in favour of smart charging. In the *statistics* condition (screens 8 & 9), we implemented a presentation of statistics that include all charging processes and the proportion of smart charging in the referred community based on the charging scenario given. Further, an individual ranking with regard to utilized green energy and the saved CO_2 emissions and costs based on the statistics compared to all other users was visualised. A back and continue button allowed the user to navigate.

1.2 Participants

The laboratory study comprised a total sample of $N = 91$ participants, who were recruited both by email via the Chemnitz University of Technology study mailing list and through private distribution. The assignment of participants to one of the three conditions was randomised. As a result, 30 people each tested the prototype of the *information* and the *storytelling* condition, and 31 tested the prototype of the *statistics* condition.

The average age of all participants was 22.5 years ($SD = 5.5$, $Min = 18$ years, $Max = 60$ years). 27 people (30%) self-identified as male, 63 people (69%) self-identified as female, and one person (1%) stated that their gender identity was diverse. In terms of education attainment, 76 participants (84%) stated that they had a high school diploma and 15 (16%) a university or college degree; no other qualifications were mentioned. 79 participants (87%) reported to own a driver's licence and travelled with a car in the last 12 months on average 7,453.10 km ($SD = 22{,}847.32$, $Min = 0$ km, $Max = 200{,}000$ km). 23 participants (25%) stated that they have previous experience with BEVs, which corresponds to an average BEV mileage in the last 12 months of 1,328.48 km ($SD = 4{,}290.15$, $Min = 0$ km, $Max = 20{,}000$ km). The groups did not differ in terms of demographic variables (all p-values > .152).

1.3 Measurements

Participants' intention to choose smart charging was assessed with a two-item scale before (Pre) and after (Post) interacting with the developed prototype. The instruction was, "Please evaluate the concept of smart charging at the present time. Indicate your level of agreement with the following two statements." The items were "I would favour smart charging over uncontrolled charging." and "I would like to use smart charging as often as possible.". The items were answered on a 6-point rating scale from 1 = "completely disagree" to 6 = "completely agree". A mean score for the pre and post-evaluation was obtained.

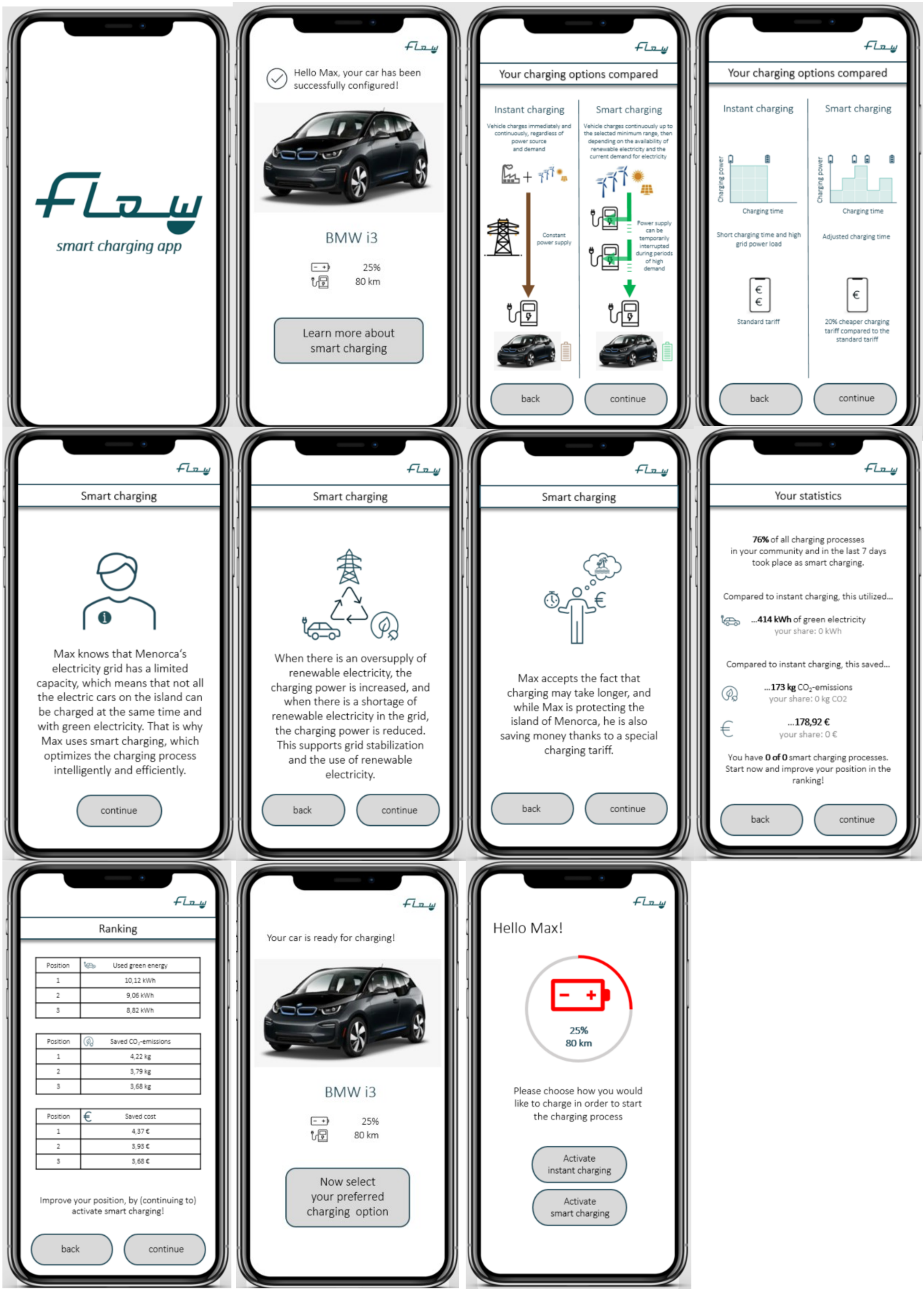

Figure 1: Presentation of the developed prototypical smart charging app with start and welcome screen (screens 1 & 2), *information* condition (screens 3 & 4), *storytelling* condition (screens 5, 6 & 7), *statistics* condition (screens 8 & 9) and the end screens leading to the (smart) charging decision (screens 10 & 11).

5 Results

Participants' intention to choose smart charging significantly increased through the interaction with the developed prototype ($F(1, 88) = 60.17$, $p < .001$, $\eta^2_p = .41$). There were no significant interaction ($F(2, 88) = .06$, $p = .9421$, $\eta^2_p = .00$) and no significant differences in participants' intention to choose smart charging between the three conditions before ($F(2, 88 = 2.28$, $p = .108$, $\eta^2 = .05$) and after dealing with the developed prototype ($F(2, 88) = 2.73$, $p = .071$, $\eta^2_p = .06$). However, post-hoc comparisons revealed a significant difference between the *statistic* and *information* condition after interacting with the developed prototype ($p = .035$). The strongest improvement could be observed in the *statistics* condition. There were no significant differences between the *storytelling* and *information* condition ($p = .063$) nor the *statistic* and *storytelling* condition ($p = .804$). The results (see also Figure 2) revealed that all conditions were useful presentation strategies and led to a strong increase in participants' smart charging usage intention. However, the *statistics* condition led to the highest level of participants' intention to choose smart charging.

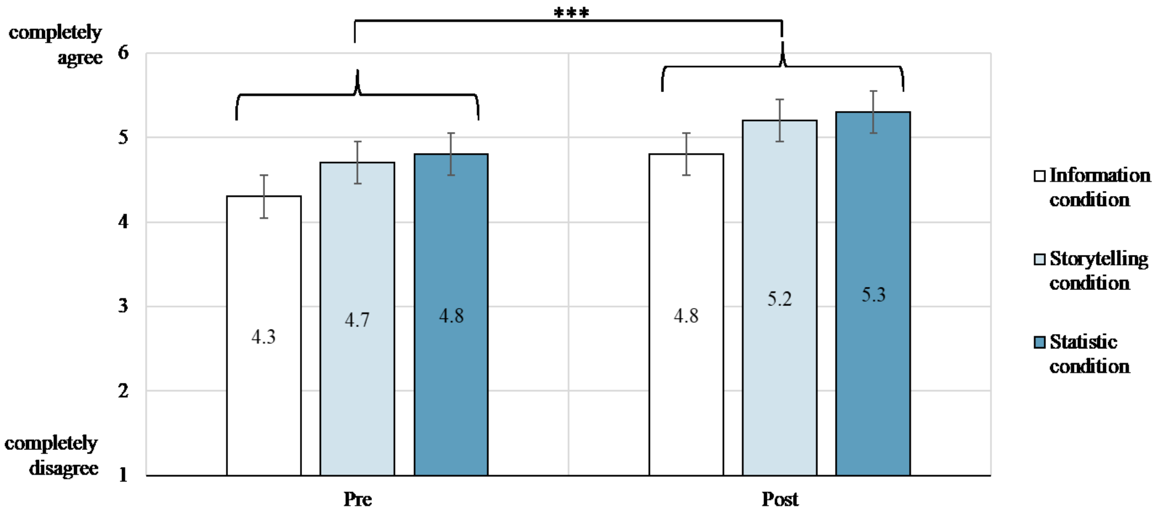

Figure 1: The influence of presentation format on participants' intention to choose smart charging before (Pre) and after (Post) dealing with the developed prototype.

Note. $N = 91$; $n_{information} = 30$, $n_{storytelling} = 30$, $n_{statistic} = 31$. ***$p < .001$. Error bars represent standard error.

6 Discussion

Within this study, we were able to demonstrate that participants' intention to use smart charging can be significantly increased by an appropriate HMI design with information presentation tailored to the user. The formats of presentation tested (information, storytelling, and statistics) are all beneficial. However, the *statistics* condition led to the significant highest level of participants' intention to choose smart charging, indicating the added complexity of statistical elements provided substantial incremental advantages.

Nevertheless, several limitations should be considered when interpreting the results to make broader claims. First, because our sample consisted of individuals from similar professional and social backgrounds, it is not representative of the general population. Second, although we presented detailed information on smart charging, it is not guaranteed that all participants had the same understanding of this concept. Finally, we have investigated participants' charging decisions only in a hypothetical charging scenario with a prototypical smart charging app with very limited functionality. Thus, the study should be replicated under realistic conditions with a more diverse and larger sample. Future studies should also investigate the effects of different preferences and personality traits (e.g., BEV and driving experience, environmental-friendly attitudes, affinity for technology, cultural differences) on the effectiveness of information presentation as well as practical implications and long-term effects of different HMI-designs.

However, for the promotion of smart charging and the widespread adoption of BEVs, the role of the government as a central provider of policy, information and education must be emphasised. In future, the challenge will therefore be to mature the prototypes with their basic functions into charging apps that fulfil user needs and thus form the basis for continuous use and preferred smart charging decisions. For the implementation of a successful charging app, it seems fruitful to combine the different formats of information presentation in order to benefit from their respective advantages. It is conceivable that storytelling could be used for the onboarding in order to provide information quickly and create interest at first glance. The basic information should always be available in the form of informative texts and diagrams in a separate menu point. The statistics on ecological and economic savings could also be listed in a separate menu section in order to appeal to users who are interested in them or who are motivated by the idea of competition and possibly also to increase the hedonic quality of the charging app. Finally, further functions could be implemented, such as the entry of charging schedules for a longer period or an embedded map with surrounding charging points, including the current charging prices.

However, considering the effort of creating beneficial HMI-designs, the simplest visualisation is associated with the presentation of informative texts and illustrations (*information* condition). More complex forms, such as the integration of storytelling, statistics and gamified elements, are associated with more demanding programming efforts and data processing. This raises questions about the cost-benefit trade-offs of more complex designs. Nevertheless, our results showed that the *statistic* condition appeared to contribute to a trend towards a greater increase in the intention to use smart charging. Based on the results and our previous user research, we highly recommend user-centred HMI designs to increase users' intention to choose smart charging. Thus, we recommend considering the following aspects:

- provide meaningful information regarding the benefits of smart charging compared to conventional and/or instant charging
- use a wording that is easy to understand for users (non-technicians or experts)
- include feedback regarding individual charging and energy consumption behaviour
- add gamification elements, such as rankings, scores, and leaderboards for the comparison with oneself and other users

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Presenter Biography

Madlen Günther studied psychology and has been a researcher at the research group Cognitive and Engineering Psychology at Chemnitz University of Technology since 2013. Her research interests lie in the areas of human-technology interaction, electromobility and sustainable mobility as well as driving behaviour. She is currently working on an EU-funded project (https://theflowproject.eu/) focusing on the user perspective of smart charging.