Behavioral Interventions and Individual Factors Influencing Electric Vehicle Drivers' Willingness to Charge Grid-Friendly

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SHORT SUMMARY

The uptake of electric vehicles (EVs) poses new challenges to the electricity grid, as charging during peak demand hours leads to grid congestion, higher costs, and greater reliance on non-renewable energy sources. Grid-friendly EV charging strategies that encourage off-peak or renewable-abundant charging are essential for a sustainable transition. This study assesses nudging interventions – social framing with/without transparency of own action and with gamification – on EV owners' willingness to charge during grid-friendly times. The online experiment conducted with 1,178 EV drivers in Norway shows that social framing, regardless of transparency, significantly increases the likelihood of grid-friendly charging than with gamification. Individual characteristics such as female gender, flexibility in daily routine, and stronger moral values also play a decisive role towards grid-friendly charging. These findings provide insights into promoting sustainable charging behavior through non-monetary incentives, contributing to grid stability, renewable energy integration, and a successful transition to sustainable electric mobility.

Keywords: Grid optimization, Discrete choice modeling, Electric mobility, Nudging

1. INTRODUCTION

The rapid adoption of electric vehicles (EVs) is an important step in reducing greenhouse gas emissions and transitioning to a sustainable transportation system. By 2030, EVs will account for 30% of all vehicle sales globally (IEA, 2024). However, the widespread use of EVs introduces new challenges to the electricity grid. Charging EVs during peak demand hours can lead to increased grid congestion, higher electricity costs, and greater reliance on non-renewable energy sources (Das et al., 2020). Grid-friendly EV charging strategies — those that encourage users to charge during off-peak hours or when renewable energy is abundant — are essential to mitigating these issues and ensuring a sustainable transition. This approach can help balance supply and demand, reduce the need for expensive infrastructure, and improve the integration of renewable energy into the grid (Jaruwatanachai al., 2023).

According to several studies, incentive-based strategies, such as variable pricing and financial rewards for off-peak charging, play a crucial role in encouraging consumers to shift their energy usage patterns and reduce peak demand (Schey et al., 2012; Zhang et al., 2018). Also, combinations of monetary and environmental incentives have been found to be effective in changing behavior towards sustainable charging (Kacperski and Kutzner, 2020). However, integrating financial incentives into daily routines can be challenging due to price fluctuation and monitoring efforts (Dutta and Mitra, 2017). Non-monetary behavioral interventions, also known as nudges, have advantages over financial incentives in promoting long-term pro-environmental behavior and offering a more feasible solution for charging infrastructure providers who would otherwise pay monetary benefits (Steinhorst and Klöckner, 2017). Although financial incentives target the rational decision-making process, nudging aims to influence the automatic, intuition-based decisions that make up most of our daily choices, which are strongly guided by cognitive heuristics (Lehner et al., 2016; Thaler and Sunstein, 2008). A key challenge lies in understanding how different behavioral interventions interact and how individual characteristics affect users' decisions to engage in grid-friendly charging.

Research has shown that nudges based on social norms, such as social comparison and normative feedback, have positive effects in inducing pro-environmental behavior change, and nudging people to reduce energy consumption (Allcott, 2011). However, Jung et al. (2019) found that framing messages around the social aspects of shared electricity grid could intensify perceptions of electricity being a scarce commodity and thus, reduce the charging flexibility of EV drivers. Research on public goods suggests that removing the anonymity of individual contributions can increase cooperation (Bucciol et al., 2020; Samek and Sheremeta, 2014). Increased visibility appears to be effective because it can activate the enforcement of social norms through feelings of shame and social disapproval (Masclet et al., 2003). Further, using gamification elements, such as awarding points, ranks, or levels, has been found promising in environmental behavioral change (Günther et al., 2020; Wee and Choong, 2019) as well as in increasing contribution to grid flexibility combined with monetary incentives (Lee et al., 2024). However, gamification elements on their own have not yet been found significant in providing higher flexibility for smart charging (Marxen et al., 2023). Further reviews on nudging in different domains indicate more mixed effects, noting that their effectiveness is often conditional on prior beliefs of individuals, characteristics, timing, and context, making it hard to develop universally effective solutions (Byerly et al., 2018).

Due to the lack of experimental studies that investigate various non-monetary incentivization measures in the context of grid-friendly charging, we aim to assess the effectiveness of nudging on EV owners' charging decisions in an online experiment. Specifically, we investigate how treatment groups — social framing without transparency, with transparency, with gamification, and a control treatment — compare in terms of choosing to charge during a grid-friendly time. By using the explorative approach, we posed the following research questions:

(1) How does behavioral intervention through social framing differ by the presence of gamification regarding willingness to charge during grid-friendly times?

(2) How do individual characteristics of EV drivers influence their willingness to charge during grid-friendly times?

The study was conducted with EV drivers in Norway, which is the leading country in EV sales share, at almost 95% (IEA, 2024). The EV market in Norway has moved beyond the early adopter phase. EVs are now the dominant choice of cars among the general population, making it a particularly suitable market for EV- and charging-related studies. By understanding the factors that influence grid-friendly charging behavior, the current study seeks to provide insights into how behavioral interventions can be designed and implemented to encourage sustainable energy use among EV drivers.

2. METHODOLOGY

This work is based on an online experiment conducted from November to December 2024 in Norway. In total 1,318 EV drivers were contacted of which 1,178 respondents completed the survey. The sample exclusively included individuals who indicated that they possessed an EV. Our sample had an average age of 48.9 years (*SD* = 18.5, *MIN* = 18, *MAX* = 91) and 89.6% drove an EV that was owned either by themselves or a family member. In terms of representativity of the Norwegian population, we compare the sample characteristics to those of the population: Approximately 50% of Norway's adult population is female (compared to 46.8% in our study), whereas 36.9% of all Norwegian citizens possess higher education (compared to 61.2% in our study) which can be explained by the overall higher education level in the Norwegian EV driver population (Bjørge et al., 2022).

To analyze the effects of three non-monetary incentives, participants were randomly assigned to one of four groups: control (N = 286), social framing with no transparency (N = 300), social framing with transparency (N = 297), social framing with gamification (N = 295). The experiment consisted of a scenario informing participants that the next grid-friendly charging time window to contribute to the grid stability of the local network is between 11 am and 3 pm. Additionally, participants in the first treatment group were informed that yesterday, 3 out of 5 EV users in their neighborhood charged an EV within a grid-friendly timeslot and that participants' score of grid-friendly charging is visible to them in the charging application. In the second treatment group, participants received the same information in addition to that their grid-friendly charging score was also visible to other users in the charging application. The third treatment group was offered a reward point for every grid-friendly charging minute. After reaching 300 points (= 5 hours of grid-friendly charging) these points can be donated for environment protection purposes. Afterwards, participants of all four groups were asked to select if they were willing to charge their EV within the grid-friendly charging timeslot (no = 0, yes = 1).

Additionally, we asked all respondents to evaluate how much knowledge they have about grid-friendly charging and how flexible they are to integrate grid-friendly charging into their routine on a 7-point Likert scale (1 = not at all, 7 = strongly agree). Participants were also asked to rank five different items in order of importance, from 1 (the most important) to 5 (the least important), in terms of their willingness to participate in grid-friendly charging. In this study, we focused solely on the item "economic benefit" as it was deemed the most interesting based on the previous literature. For socio-demographics, we considered EV drivers' age (in years) and gender (male = 0, female = 1). To cover further individual characteristics, we measured respondents' biospheric values (modified from Steg et al., 2014), importance of social environment and morality (adapted from Chang, 2023) on a 7-point Likert scale (1 = not at all, 7 = strongly agree). We applied binary logit regression to predict willingness to charge in a grid-friendly timeslot and created a model with the gamification group being the reference group.

3. RESULTS AND DISCUSSION

Table 1 presents a statistical summary of the main variables included in the analyses, divided by treatment condition. We compared these variables between groups to ensure that possible differences in willingness to charge within grid-friendly time were not caused by them. Overall, there were no differences in the main variables between treatments based on the Kruskal-Wallis test ($p < .05$).

Table 1: Descriptive Statistics of Main Variables by Treatment

Variable	Min	Max	Control *N* = 286	Social framing w/o transparency *N* = 300	Social framing w/ transparency *N* = 297	Social framing w/ gamification *N* = 295
			M (SD)	*M (SD)*	*M (SD)*	*M (SD)*
Knowledge	1	7	3.24 (1.67)	3.12 (1.75)	2.92 (1.58)	3.01 (1.72)
Flexibility	1	7	4.40 (2.03)	4.34 (2.04)	4.32 (2.03)	4.26 (2.12)
Economic benefit	1[a]	5[b]	1.43 (.84)	1.25 (.98)	1.64 (1.00)	1.60 (1.00)
Biospheric values	1	7	5.06 (1.34)	5.12 (1.39)	4.98 (1.35)	5.07 (1.41)
Social norms	1	7	2.66 (1.64)	2.67 (1.69)	2.72 (1.70)	2.71 (1.73)
Morality	1	7	4.10 (1.62)	4.16 (1.61)	4.07 (1.47)	4.15 (1.54)

Note: 1 = not at all, 7 = strongly agree
a = the most important factor, b = the least important factor

Table 2: Binary Logit Model on Willingness to Charge Grid-Friendly

Variable	Coefficient	*OR*	*z*	95% *CI*
Treatment				
Control	.34	1.40	1.65	[.94; 2.11]
Social framing w/o transparency	.74**	2.10	3.47	[1.38; 3.19]
Social framing w/ transparency	.45*	1.57	2.19	[1.05; 2.34]
Gender (1 = female)	.36*	1.43	2.25	[1.05; 1.95]
Age	-.01	.99	-1.62	[.98; 1.00]
Knowledge	.03	1.03	0.50	[.93; 1.13]
Flexibility	.28***	1.32	6.78	[1.22; 1.43]
Economic benefit	-.22**	.80	-2.92	[.69; .93]
Biospheric values	.04	1.04	0.63	[.91; 1.20]
Social norms	.09	1.09	1.46	[.97; 1.23]
Morality	.46***	1.58	5.92	[1.36; 1.84]
Constant	-2.16	.12	-5.52	[.05; .25]

Note: N = 1,178.
Reference group = social framing with gamification
*** $p < .001$ ** $p < .01$ * $p < .05$

The binary logit model in Table 2 shows the results for the groups control, social framing without transparency and with transparency in relation to the group with gamification. The model shows a significant positive effect on willingness to charge grid-friendly in social framing groups with and without transparency compared to the group with gamification. This suggests that social framing, regardless of transparency, can be an effective strategy in encouraging EV drivers to charge their vehicles during grid-friendly times. Due to the additional presence of gamification, there could be a dilution effect while addressing too many motives at once, whereas a single intervention could be more successful (Kramer et al., 2023). Also, being a female EV driver increases the likelihood of charging in grid-friendly times. This finding could be attributed to gender-based differences in environmental awareness, risk aversion, or a stronger sense of social responsibility (Stern et al., 1993). Although having more knowledge about grid-friendly charging did not have any association with charging grid-friendly, there was a strong positive relation with being flexible to integrate grid-friendly charging in own routine. This is also aligned with the previous research that charging grid-friendly requires additional time flexibility (Jung et al., 2019) and is particularly crucial for charging-related decision-making (Libertson, 2022). Interestingly, by exploring the importance of the economic benefit of grid-friendly charging, we found that despite ranking this factor as high, EV drivers were more likely to charge grid-friendly in the given scenario. Hence, aligned with previous research, monetary incentives are important in motivating grid-friendly charging (Schey et al., 2012; Zhang et al., 2018), but they are not crucial and could be potentially substituted by non-monetary ones. The intrinsic motivation to participate in grid-friendly charging was particularly supported by a sense of morality that could be fostered by environmental and social values (Chang, 2023), which on their own were not found to be significant factors.

4. CONCLUSION

Our experimental research investigated differences between various non-monetary behavioral interventions on willingness to charge in grid-friendly time windows. Particularly, based on the analysis, social framing (regardless of the transparency of own decision in the community) leads to higher readiness to charge grid-friendly as opposed to drivers who receive a gamification nudge in combination with social framing. Moreover, we found that being female, having more flexibility in daily routine to integrate grid-friendly charging and having stronger morality towards grid-friendly charging are individual characteristics that are associated with grid-friendly charging decisions. Also, we found evidence that despite economic benefit being the most important factor for many EV drivers, they were still willing to charge in grid-friendly windows in the given non-monetary scenario. The current research provides insights and implications for policies and industry on how to motivate grid-friendly charging through non-monetary signals. This in turn is an important contribution to the stability of the local electricity grid, the balance of electricity demand and supply, as well as increased usage of renewable energies.

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