Quantifying Consumer Preferences for Vehicle-to-Grid Charging Across Europe

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Short summary

The transition to electrified transport is reshaping the environmental and economic landscape, driven by technological advancements in electric vehicles (EVs) and charging infrastructure. Smart charging systems and vehicle-to-grid (V2G) technologies offer opportunities to improve grid reliability, reduce costs, and mitigate environmental impacts through bidirectional energy flows. Implementing V2G presents challenges, including potential limitations on user flexibility and the need for strong coordination among all involved parties. Previous research has quantified consumer preferences for unidirectional smart charging, revealing compensationn needs, but studies on V2G-specific preferences remain scarce. This study quantifies individual trade-offs for V2G across multiple European countries using stated preference experiments. We find that consumers prefer to charge at night and that higher-income drivers require more compensation for V2G contracts than low-income drivers, with preferences varying by country and demographics. This cross-country analysis provides novel insights into the challenges and opportunities for V2G technologies and how these vary between countries.

Keywords: Smart charging, Choice experiment, Electric vehicles, Vehicle-to-grid charging

1 Introduction

Motorised transport is undergoing a significant transformation towards electrification, which will have major consequences for our world's environmental and economic landscape. Recent technological and innovative enhancements have advanced individual vehicle capabilities, increased the availability of car models, and significantly expanded charging possibilities in public and private settings. These developments carry significant implications for consumer mobility, emissions, and the economy. Specifically, advanced smart charging systems and wireless communication between vehicles and grid services have the potential to improve the charging process, improve the reliability of the grid Sagaria et al. (2024), and reduce operating expenses and environmental impact Sovacool et al. (2020). Future smart charging solutions with vehicle-to-grid (V2G) solutions enable electric vehicles to be recharged from the grid and send electricity back to the grid when needed. This bidirectional energy flow allows electric vehicles to act as mobile energy storage units and actively participate in the supply-demand balance of the electric grid. However, depending on the business model, such a system will likely require reduced flexibility for the BEV user. Sovacool et al. (2020) found a strong business case for V2G but concluded that a sustainable implementation depends on the integration of interests from a large number of actors, which, from the consumer perspective, includes attractive tariffs and product design specifications.

Thus, gaining deeper insights into BEV user's preferences for these potential products is important, but so far, there exists no such products ready for the market, and research on preferences is sparse. A few studies previously quantified different types of smart charging features, which mainly focused on the circumstances in which BEV users would allow charging of their vehicles to be delayed until a moment more optimal for the grid. In a stated choice experiment, Daziano (2022) found that a consumer would require $2.66 per hour where control of (one-directional) charging was yielded to the grid provider and that the compensation could be reduced with higher emission reductions. In another choice experiment, Kubli (2022) found that a consumer would require CHF4.33 (about $5) to accept a so-called eco-charging mode where, in some cases, the BEV will only be charged with up to 5% after half the charging period. Similarly, Lagomarsino et al. (2022) found that compensation

and emission reductions are important for consumers' willingness to use smart charging, and they furthermore discuss the importance that car drivers put on having control over the charging process and their mobility freedom. At the same time, results from a demonstration project found that technical issues and lack of understanding of the charging system were more important as barriers than incentives were as enablers Kämpfe & Braun (2023).
In this study, our objective is to provide detailed quantitative measures of individual preferences for V2G charging across several European countries. We use stated preference experiments since there are currently no V2G products in the market, and our objective is to thoroughly assess factors that are challenging to evaluate directly within a real market environment or demonstration projects, particularly when conducting cross-country comparisons. To our knowledge, there are no previous studies that quantitatively investigate individual trade-offs for V2G products across several countries.

2 Methodology

We focus on individual willingness to enter a long-term agreement with a grid provider and consider several factors relevant to the individual's control of the charging process and mobility freedom. In a stated choice experiment, we ask the respondents to imagine that they have the option to make a contract for vehicle-to-grid charging at their main charging location, which can be either at home or public chargers nearby, at work or public chargers nearby, or it can be public chargers not located nearby home or work. As part of the contract, the respondents will need to make sure their electric vehicle is connected to the electricity network during a period defined by several variables that describe the contract's flexibility level. The attributes included in the experiment are described in Table 1.

Attribute	**Description**
Charging cost	The cost per kilowatt hour for charging the vehicle at the indicated main charging location.
Compensation	Monthly compensation for making the electric vehicle battery available for the electricity grid within the contract terms.
Duration	The minimum duration the car must be available within the V2G time period.
Frequency	The minimum number of days the car must be connected to live up to the V2G time restrictions.
Range - During period	Guaranteed driving range available during the V2G time period, e.g., driving range available if the owner suddenly needs to go to the hospital.
Range - End of period	Guaranteed driving range available by the end of the V2G time period, e.g., driving range available in the morning if the car has been available for V2G during the night.
Additional battery degradation per year	This attribute reflects to which extend the battery will degrade with time (have a lower driving range) as V2G causes more charging cycles.

Table 1: Attributes of the choice experiment

The respondent is asked to indicate a choice in four scenarios, where these variables vary across each experiment according to a pre-defined experimental design. In each scenario, there are six alternatives, and there will always be two alternatives where the period is during the day (10-15), during the evening (17-22) or the night (22-06). In exchange for providing battery capacity to the electricity network, the respondent will receive compensation. As the income level varies across the participating countries, we varied the compensation according to the level of pricing previously found on car prices, operation costs and electricity prices, as well as on discussions with partners[1] in each country. Electricity prices were based on statistics from Eurostat[2]. For the respondent to have a better understanding of the costs of charging their car, we also provide a suggestion for the average charging cost at the primary charging location, which also depends on the country. An example of a choice experiment is illustrated in Figure 2, and an overview of the experimental

[1]This analysis was part of a larger European project with partners in each country
[2]https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_price_statistics

design is found in Table 2.

	Contract options					
V2G time period	Day (10-15)	Day (10-15)	Evening (17-22)	Evening (17-22)	Night (22-06)	Night (22-06)
Cost						
Average charching cost (at main charging location) ⓘ	4.39 DKK/kWh					
Vehicle-to-grid (V2G) characteristics						
Car should be plugged in ⓘ	5 hours (between 10-15) 7 days out of 10	5 hours (between 10-15) 7 days out of 10	1 hours (between 17-22) 5 days out of 10	1 hours (between 17-22) 7 days out of 10	6 hours (between 22-06) 8 days out of 10	6 hours (between 22-06) 7 days out of 10
Compensation ⓘ	469 DKK/month Provided as reduced electricity bill	375 DKK/month Provided as reduced electricity bill	750 DKK/month Provided as reduced electricity bill	500 DKK/month Provided as reduced electricity bill	312 DKK/month Provided as pay-out	125 DKK/month Provided as reduced electricity bill
Guaranteed range ⓘ - End of period: - During period:	100 km 62.5 km	125 km 37.5 km	125 km 37.5 km	150 km 37.5 km	200 km 100 km	100 km 25 km
Battery degradation per year (due to V2G) ⓘ	1.5%	0%	1.5%	0.5%	0.5%	1%
Which of these would you prefer?	○	○	○	○	○	○

Figure 1: Choice experiment example

Description	Mean	Min	Max	Unit
Task ID	2.5	1	4	-
Alternative ID	3.5	1	6	-
ID of chosen alternative	3.66	1	6	-
Time the car has to be plugged in	4.01	1	8	Hours
X/10 days the car has to be plugged in	7.33	5	9	Days
Guaranteed range after V2G period	124	50	250	km
Guaranteed range during V2G period	56.8	25	125	km
Additional battery degradation	1	0	2	%
Electricity cost	0.34	0.14	0.7	Euro/kWh
Monthly compensation	36.2	10	100	Euro

Table 2: Summary of design attributes

Data was collected with an online survey tool, and during the development, several tests were conducted to test the technical setup and the clarity of the survey. The survey structure follows a standard structure for a choice experiment. As the choice experiment is rather complex, it is included as early in the survey as possible to avoid respondent fatigue. Before each experiment, an introduction page introduces the choice experiment in detail so that the respondent is well prepared for the task. In the final part of the survey, the respondent is asked for further information about, e.g., their age, gender and car usage.

A professional market analysis company was hired to code the online survey and to reach participant samples from six countries: Denmark, Germany, Italy, Spain, the Czech Republic, and Ireland. After two rounds of pilot testing in Denmark with approximately 250 respondents each, samples of 250 individuals were collected in each of the mentioned countries. Each individual answered four choice experiments.

Data collected from the choice experiments was analysed with discrete choice models to quantify the preferences of the decision-makers, see e.g. Train (2009). These models assume underlying utility functions for each alternative. It is standard to decompose the utility that individual n obtains from alternative j into V_{nj}, which is a function of variables x describing the alternative j and the decision maker n, and a random variable ε_{nj} that is independent from x. We applied mixed logit models that account for the panel structure of the data. We assume utility to be linear in the parameters β such that $V = \beta \cdot x$, where β follows some distribution. The choice probabilities can then be written as:

$$P_{ni} = \int \frac{e^{V_{ni}}}{\sum_j e^{V_{nj}}} f(\beta) d\beta \tag{1}$$

To quantify and compare preferences for different variables of the model, it is common to calculate

willingness-to-pay (WTP) measures, which usually represent the trade-off between the preference for a specific attribute and an attribute describing the cost of the alternative.

$$\text{WTP}_x^i = \frac{MU_x^i}{MU_C^i} \tag{2}$$

3 Results and discussion

The data collection was conducted between 16. April 2024, and 2. May 2024. Table 3 presents a description of the sample across the countries. Within each country, there is a fairly even gender distribution, and the average age is between 45 years and 52 years. The average income is lowest in the Czech Republic and highest in Denmark and Ireland.

Table 3: Overview of survey respondents by country.

Country	Number of Respondents	Share Female (%)	Avg. Age	Avg. Household Income (€/month)
Czech Republic	275	48.4%	47.5	2,455
Denmark	284	50%	46.4	5,558
Germany	276	49.3%	49.6	3,545
Ireland	275	48.7%	43.8	5,544
Italy	277	50.2%	49	2,962
Spain	278	48.2%	46.4	3,321

Figure 2 shows the share of choices in the daily charging experiment. For those who cannot charge at home, the share of charging during the day is in general higher than those who can charge comfortably at home at a private charger during the evening or the night. This effect seems particularly relevant in Denmark, Germany, Ireland and Italy. Interestingly, the share of night charging for those who cannot charge at home is as high as those who can charge at home in the Czech Republic and Spain.

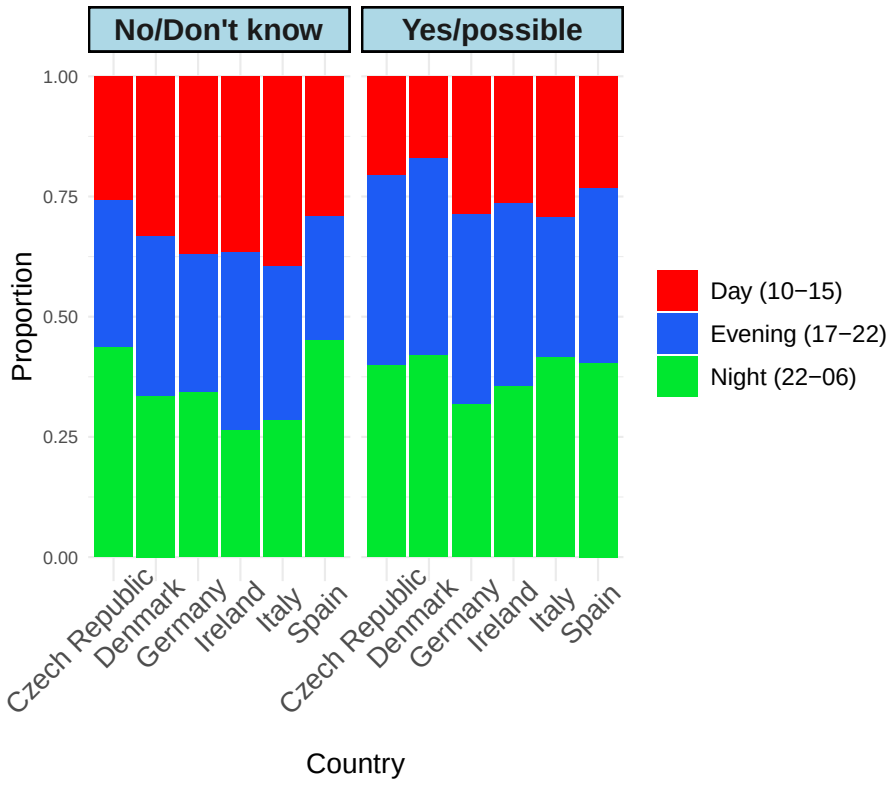

Figure 2: Choice experiment example. Responses are classified based on the answer to whether they already have a charger or can install a charger that can be used privately at home.

In the following, we provide model results estimated on the dataset with indicated choices from 6,016 observations from 1,504 respondents across all countries. We tested interaction effects of respondent age groups, gender and country using dummy coding for whether a respondent belongs to a specific segment or not and whether a respondent lives in a specific country or not, but, we did not test higher-order interactions (i.e., whether women in one country have other preferences than women in another country). For simplicity in the output, we define a dummy called "apartment" for those who cannot charge at home, although not everybody in this segment lives in an apartment. The model specification is shown below. Consider an individual n who decides in scenario t. The utility she obtains from contract type i is:

$$
\begin{aligned}
V_{nikt} = {} & ASC_i + ASC_{i,\text{Apartment}} \cdot \text{Apartment} + ASC_{ik} \cdot i \cdot k + \eta_{ni} \\
& + ASC_{i,\text{AGE}} \cdot i \cdot \text{AGE} + ASC_{i,\text{FEM}} \cdot \text{FEM} + ASC_{i,\text{EDU}} \cdot \text{EDU} \\
& + \beta_{\text{Compensation(INC,NO\_INC)}} \cdot \text{Compensation}_{nikt} \cdot (1 + \text{INC} + 1_{\text{INC=NaN}}) \\
& + \beta_{\text{BatDeg},k} \cdot \text{BatDeg}_{nikt} \cdot k \\
& + \beta_{\text{Duration}(k,\text{AGE,FEM,EDU})} \cdot \text{Duration}_{nikt} \cdot (k + \text{AGE} + \text{FEM} + \text{EDU}) \\
& + \beta_{\text{Frequency}(k,\text{AGE,FEM,EDU})} \cdot \text{Frequency}_{nikt} \cdot (k + \text{AGE} + \text{FEM} + \text{EDU}) \\
& + \beta_{\text{GuarRangeDur}(k,\text{AGE,FEM,EDU})} \cdot \text{GuarRangeDur}_{nikt} \cdot (k + \text{AGE} + \text{FEM} + \text{EDU}) \\
& + \beta_{\text{GuarRangePost}(k,\text{AGE,FEM,EDU})} \cdot \text{GuarRangePost}_{nikt} \cdot (k + \text{AGE} + \text{FEM} + \text{EDU}).
\end{aligned}
$$

The result of the model is found in Table 4. We find that respondents require compensation to enter a V2G contract, which is also expected as a contract might restrict the daily use of their car. Our findings indicate that an additional 14 Eurocents in compensation is required for every 1000 Euro increase in individual income. As also expected, daytime charging is less preferred than charging at nighttime and during evenings. On average, an additional monthly compensation of 223 Euro is required to charge during the day compared to charging during the night. However, lower compensation is required if respondents lack home charging capabilities, potentially due to the availability of public chargers at their daytime parking locations. The required compensation for daytime charging is also, on average, significantly lower in Germany, Ireland, and Italy, as well

as for the youngest age group in the sample. Interestingly, we find no significant difference between night and evening charging, except for Ireland and Germany, where respondents seem to prefer evening charging. For each percentage of additional battery degradation the respondents will experience from being part of a V2G contract, they require an additional monthly compensation of 42.5 Euro (for Denmark, Italy, Spain and the Czech Republic in the reference group). In contrast, respondents in Germany and Ireland will only need about 19 euros.

Description	**Value**	**Rob. t-test**	**WTP**	**Unit**
ASC for daytime charging, REF	-1.50	-6.92	223.3	-
Std. Dev. for ASC day	2.59	20.12	-384.8	-
ASC for daytime charging, Apartment	0.84	3.10	-123.9	-
ASC for daytime charging, DE	1.46	4.07	-216.5	-
ASC for daytime charging, IR	1.00	2.92	-148.1	-
ASC for daytime charging, IT	0.88	3.45	-130.0	-
ASC for daytime charging, age_1	0.46	2.34	-68.0	-
ASC for evening charging, REF	-0.14	-0.86	20.6	-
Std. Dev. for ASC evening	3.39	22.09	-503.4	-
ASC for evening charging, Apartment	-0.02	-0.09	3.0	-
ASC for evening charging, DE	0.83	2.67	-122.9	-
ASC for evening charging, IR	0.60	2.02	-89.6	-
Additional battery degradation, REF	-0.29	-9.05	42.5	Percentage
Additional battery degradation, IR and IT	0.16	2.91	-23.7	-
Additional compensation at higher income	0.00	1.67	-0.14	€/Month/€1000
Monthly compensation at avg. income	0.67	4.08	-1.0	€/Month
Monthly compensation for no income	-0.15	-0.35	0.2	€/Month
Time the car has to be plugged in, REF	-0.07	-5.07	10.1	Hours
Time the car has to be plugged in, DE and IR	0.05	2.10	-6.9	-
Time the car has to be plugged in, age_1	-0.05	-1.94	6.9	Hours
Days the car has to be plugged in, REF	-0.51	-3.41	7.6	Days
Days the car has to be plugged in, CZ and IT	0.66	2.50	-9.8	-
Guaranteed range during V2G period, REF	0.19	2.04	-0.28	km
Guaranteed range during V2G period, Female	-0.25	-2.15	0.37	km
Guaranteed range during V2G period, edu_1	0.30	2.46	-0.44	km
Guaranteed range after V2G period, REF	0.21	4.86	-0.31	km
Guaranteed range after V2G period, DE	0.36	3.51	-0.53	km
Guaranteed range after V2G period, age_3	0.20	2.35	-0.30	km
Correlation	2.96	13.76	-439.4	-

Table 4: Estimation Results and Willingness to Pay (WTP) for Different Attributes

The choice experiment included attributes describing the flexibility of the V2G contract, which is defined by how many hours during a period the car needs to be plugged in per day, how many days out of a 10-day period the car must be plugged in in this period as well as how much range the owner of the car is always guaranteed during the contract period and after the contract period. Our results show that respondents would require an additional 10 Euro monthly compensation for each extra hour of required availability, but only about 3 Euros (6.9 Euros less) for respondents in Ireland and Germany. On the other hand, the youngest segment requires about 17 Euros per additional hour per day. On average the respondents require 7.6 Euros per additional day in a 10-day period the car has to be plugged in. The interaction effect with the Czech Republic and Italy indicates a negative compensation when the interaction is summed with the main effect. However, this sum appears not to be significantly different from zero, which indicates that respondents in these two countries do not care about the number of days.

Overall, a lower compensation is needed for each extra km of driving range that the vehicle's driver is guaranteed both during (0.28 Euro less per km). After the contract period (0.31 Euro less per km), it is more important for the driver to have an extra kilometre of driving range guaranteed after the contract period than an extra kilometre of driving range guaranteed during the period. Women do not care about the guaranteed driving range during the contract period, but individuals in the lowest education segment value this feature as much higher than the average. The guaranteed

driving range at the end of a contract period is much more important for individuals in Germany and age group 3 than the reference category.

4 Conclusions

In this study, we analyse consumers' preferences for factors relevant to vehicle-to-grid products and how they vary across six European countries. The scenarios were described by different levels of flexibility and how much compensation a BEV driver requires to use a V2G product. On average, higher-income respondents require higher compensation to enter a V2G contract with an electricity provider. Respondents prefer the V2G charging period at night, but it is less important for young drivers and drivers in Germany, Italy, and Ireland. Drivers require an additional compensation of 7.6 Euros for each extra day in a 10-day period the car needs to be plugged in and 10 Euros for each extra hour the car needs to be plugged in for each day it is required to be plugged in. This duration is more important for young drivers than the rest of the sample. It is more important for drivers to have a guaranteed level of driving range when the charging period ends than a guaranteed level of driving range during the charging period. For these factors, a lower compensation of 0.31 Euro and 0.28 Euro per km of guaranteed driving range is needed, with several significant differences across the countries and respondent characteristics. Men and respondents with the lowest level of education focus more on the level of guaranteed range during the charging period. In contrast, women are not affected at all by this factor.

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