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Are Norwegian car users ready for a transition to vehicle-to-grid technology?

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ABSTRACT

Vehicle-to-grid (V2G) is a technology which enables electric vehicles (EVs) to transfer electricity back to the power network. The V2G technology allows energy systems to balance renewable energy, thus contributing to climate change alleviation. Employing a self-report online survey among Norwegian car users (n = 929) in November 2021, the study aims to investigate how perceptions and beliefs towards the V2G system motivate both EV users and non-EV users (combustion engine car owners as potential future EV users) to utilise the V2G technology in the future. Understanding similarities and dissimilarities in future intentions of V2G use across two groups of car users (i.e., EV and non-EV users) may facilitate segment-specific marketing. The core theoretical framework in the study is a hypothesised model based on the Technology Acceptance Model and the Theory of Reasoned Action. The results show that the theoretical framework substantially explains future V2G use intentions. The model showed that behavioural beliefs related to the use of V2G technology and varying concerns and benefits about this system (e.g., concern over vehicle battery, usefulness in terms of financial and environmental benefits) explain V2G adoption among the groups. A multiple-group structural equation model showed structural stability in associations between the model constructs and intention across EV and non-EV users. However, non-EV users had lower means on central variables (i.e., trust in V2G, perceived ease of use, vehicle battery concern, perceived usefulness, subjective norm, and intention). In accordance with the postulated social cognitive theoretical framework, the study concludes that both groups of car users have a significant belief-behavioural intention to participate in V2G technology. When it comes to behavioural change campaigns, the same measures could be taken into account for both groups of car users. Non-EV users, however, should receive more attention in such campaigns. To promote V2G adoption among car users, particularly among non-EV users, a multifaceted policy approach is needed. This should include financial incentives like tax credits, educational campaigns highlighting EV benefits with V2G contracts, expanding EV charging infrastructure, and developing a public-private V2G infrastructure.

1. Introduction

Vehicle-to-grid (V2G) is a technology which enables electric vehicles (EVs) to transfer electricity back to the power network. The battery of the EV charges when power is inexpensive, typically in the evening and night-time, and will return electricity to the network during high traffic/peak hours (e.g., morning and early afternoon) buffering energy so that peak hours are shaved off. Many believe that the V2G system contributes to alleviation of climate change by allowing the energy system to balance renewable energy (Kempton and Letendre, 1997; Noel et al., 2018). The technology may also contribute to a reduced need for investments and expansion of the electrical grid. However, the V2G technology has not yet had the opportunity to make a significant impact in the transportation sector, despite its potential value for a wide variety of stakeholders. Although market-based mechanisms have been recently developed to promote the commercialisation of the V2G system in Europe, consumers' perceptions and their level of acceptance with respect to using this system also need to be analysed. A successful implementation of the V2G technology needs consumers' engagement from the introduction phase, both among those who already own an electric vehicle and among potential prospective users (i.e., current non-EV owners). Many barriers such as beliefs regarding battery degradation, range anxiety (i.e., worries about the availability of sufficient battery capacity in the electric car), and losing control over

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charging or discharging may negatively influence consumers' willingness to adopt this technology (van Heuveln et al., 2021). Therefore, a prosperous and stable V2G scheme needs to gain public acceptability before its implementation. A lack of knowledge about the level of public acceptability among different types of car users may adversely influence the efficiency of the V2G adoption.

Although several studies (e.g., Noel et al., 2019a,b; Geske and Schumann, 2018; van Heuveln et al., 2021) have tried to explain public acceptance of V2G technology either among EV or non-EV users (combustion engine car owners) little is known about (i) how different motivations underlying public acceptance of the V2G system are shaped. Employing a quantitative method, we develop a conceptual framework based on psychological theories and explain how different psychological constructs (e.g. attitudes, subjective norm, perceived ease of use, trust, concerns over vehicle batteries, and perceived usefulness of V2G adoption) explain the acceptance of the V2G technology, (ii) how perceptions and beliefs about V2G technology vary between the two segments of drivers: EV and non-EV drivers, and (iii) which group of car users are more willing to use this system.

By 2030, it is projected that the global EV park will increase to between 150 and 250 million vehicles (IEA, 2020). This is a significant leap from the 10 million EVs in 2021, with Norway leading the charge as a pioneer in EV adoption (Mersky et al., 2016), boasting a 64% market share for battery EVs in 2021. In 2022, out of a total of 174,000 passenger cars registered for the first time in Norway, an impressive 79% of them were electric cars.[1] Norway's ambitious national transport plan aims to exclusively sell zero-emission vehicles (electric and hydrogen cars) in 2025, further propelling EV market penetration and actively encouraging combustion engine car users to transition to EVs (Norwegian Ministry of Transportation, 2017). Therefore, understanding the attitudes and readiness of both current EV users and potential future EV adopters (non-EV users) towards V2G technology is paramount in the Norwegian context. In Germany (Geske and Schumann, 2018) and the United States (Parsons et al., 2014), previous studies have underscored the importance of evaluating non-EV users' willingness to embrace V2G technology, emphasising the need for comprehensive insights among non-EV users as well.

Since Norway is among the pioneering nations in EV uptake with substantial amounts of EVs in the car fleet already (IEA, 2016; Klöckner et al., 2013), behavioural change campaigns with respect to V2G may need to be disseminated based on specific target groups of car users. The knowledge and attitudes towards both benefits and barriers of the V2G system may be evaluated differently among current EV users (without V2G experience) compared to users who currently drive a combustion engine car and have no experience with EVs, yet. EV users can be considered early adopters of technology (Plötz et al., 2014). Hence, it might be assumed that EV users are also more prone to accept V2G technology than non-EV users. On the other hand, combustion engine car owners are an important group to influence as they might also consider buying an EV in the future and might then have to make the decision to opt in or out of V2G plans. However, it might also be assumed that there are no differences in behavioural intention of using the V2G system among both groups of EV and non-EV users in leading countries in EV uptake. There is, for instance, evidence that EV sales are maturing in Norway (Figenbaum and Nordbakke, 2019), meaning fewer reported problems when driving an EV and greater willingness to purchase one among previous combustion engine car owners from 2016 to 2018. This implies that the attitudes towards EVs become more homogenous in the group of car users. Despite this, however, there is as of yet no empirical studies which have demonstrated to what extent these two groups of car users respond to V2G application, which again is a rather new technology and might be perceived favourably by the more technology affine early adopters. Understanding similarities and dissimilarities of behavioural intentions (Mehdizadeh et al., 2019) in these two groups of car users (i.e., current EV and non-EV users) can have policy and planning implications. Such knowledge could facilitate policymakers in identifying whether behavioural change campaigns involving the commercialisation of the V2G technology should be segment-specific (e.g., targeting experienced EV users differently than first time users when addressing V2G questions).

From a policy perspective, our study aims to provide a holistic view of V2G acceptance in Norway, encompassing both existing EV users and prospective ones who may make the transition. This approach yields valuable insights for shaping policies, devising market strategies, and formulating educational campaigns related to V2G technology, even for those who are not current EV owners but prospective ones in the evolving EV landscape. Since electric cars make up approximately 80% of newly registered cars in Norway, and a significant portion of non-EV users will presumably be future car buyers, it is highly likely that the non-EV group will also be exposed to and consider V2G technology in the future. A study in Norway also highlighted the importance of comparing two clusters of EV and non-EV users in EV-related adoption policies (Simsekoglu, 2018). Moreover, V2G systems will be most likely included in EV contracts (Parsons et al., 2014), which will be a kind of EV option for current car owners who wish to purchase EVs under V2G contracts.

Incorporating non-EV users into the study offers a crucial baseline for gauging general awareness and attitudes towards V2G technology, as their views can serve as early indicators of future acceptance or resistance upon transitioning to EVs. Policymakers also require insights into the broader public's stance on V2G to craft effective policies and incentives that boost EV adoption and V2G integration. Furthermore, grasping the perspectives of non-EV users aids stakeholders, such as automakers and utilities, in anticipating market dynamics, which can inform marketing and product development strategies. Identifying misconceptions and information gaps among non-EV users can steer educational initiatives to disseminate accurate information about V2G benefits. Lastly, tracking the evolving attitudes of non-EV users over time may provide crucial data for understanding the changing landscape of V2G acceptance as EV adoption rates increase.

Who is ready for a transition to V2G technology? What group of car users does show a greater behavioural intention to V2G adoption? How do perceived benefits/barriers explain intention to use V2G among Norwegian car users? The current study will address these research questions. Using a self-report online survey among Norwegian car users ($n = 929$) in November 2021, the study investigates how a psychological framework might explain behavioural intention to the V2G technology, both among current EV drivers and non-EV drivers who may be EV purchasers in the future. The rest of the paper is organised as follows. Firstly, we review studies regarding the acceptance of V2G among both those with and without EVs. Then, we present our hypothesised model explaining the future intention to use V2G in these two groups. Section 2 deals with research methods including sampling, data, and statistical methods. Results are reported in section 3. We provide a discussion of the results and conclusions of the study in sections 4 and 5, respectively.

1.1. A review of the literature

A review of the state-of-the-art of the field shows that several studies aimed to reveal the extent to which people are inclined to accept the V2G technology or participate in V2G contracts. The commonly employed methods were expert interviews, choice experiments, and surveys. Concerning the place of study, related research has been mostly confined to the countries with a similar stage of EV technology adoption, such as Nordic countries (i.e., Norway, Sweden, Finland, Denmark, Iceland), the US, Germany, and the Netherlands. As for the target population, studies can be categorised into two main target groups: EV and non-EV users.

[1] https://www.ssb.no/transport-og-reiseliv/landtransport/statistikk/bilparken/artikler/fire-av-fem-nye-biler-i-2022-var-elbiler.

Using an online survey among non-EV drivers in the US, Parsons et al. (2014) reported that respondents are more willing to participate in a pay-as-you-go charging scheme for V2G rather than with contracts imposing specific charging behaviour. Pay-as-you-go schemes allow EV owners to use public charging points occasionally without the overhead of a monthly charge. Employing a discrete choice experiment in Germany, Geske and Schumann (2018) investigated combustion engine car users' willingness to participate in the V2G system. They found that "range anxiety" and "minimum range threshold" about the availability of battery capacity are the most important factors influencing V2G acceptance negatively. An interview study (Will and Schuller, 2016) among German EV users also showed that many interviewees had a high level of acceptance and motivation to transfer electricity back to the power grid. An interview study among EV experts in the Nordic region highlighted the role of dynamic pricing of electricity, flexible storage solutions and expanding pilot projects in the promotion of the V2G system (Kester et al., 2018). Noel et al. (2019a) showed that public acceptance of the V2G is context-dependent, i.e., residents in Norway and Finland, were more willing to pay for EVs with an V2G application (contract) compared to people in Denmark, Sweden, and Iceland. Employing an online survey among Dutch EV drivers, Zonneveld (2019) found that a higher remuneration, a higher amount of guaranteed energy in the battery when the car is used, a longer contract duration, smaller number of discharging cycles and a shorter plug-in duration were positively associated with public acceptance of the V2G. Meijssen (2019) also reported that the availability of fast charging facilities is the most important element in the V2G acceptance among EV users in the Netherlands.

As for unidirectional smart charging of EVs (charging which is steered automatically into off peak periods) which can be considered somewhat comparable with V2G, several studies also examined consumer acceptance. Using an interview study on smart charging behaviour among 16 EV users in Gothenborg, Sweden, Pettersson (2013) showed that most interviewees were satisfied with charging but found the experience slightly stressful because it was first-time use of an EV for some of them. An interview study among 10 EV users in Germany (Schmalfuβ et al., 2015) showed that charging control was unanimously accepted, though a few interviewees had challenges with the skills and knowledge required to use the interface.

More recently, van Heuveln et al. (2021) identified the most important incentives/barriers of V2G acceptance among EV drivers in the Netherlands. Their study highlights that most of the interviewees accept the technology albeit with some caution. According to van Heuveln et al. (2021) and other cited studies, the most important barriers/incentives of consumers' tendency to participate in the V2G scheme are compensation (e.g. discount on charging/parking tariff), beliefs regarding battery degradation, range anxiety, the ease of use of the user interface on the charging station, keeping control over charging or discharging, V2G charging point location, public relations and communication processes for promoting V2G, societal contribution to sustainable energy, and user-friendliness of the whole system.

A closer look at the abovementioned factors reveals that each factor can be structured under psychological dimensions, which are frequently investigated deploying theoretical frameworks such as the Technology Acceptance Model (TAM, Davis, 1989) and the Theory of Reasoned Action (TRA, Fishbein and Ajzen, 1975). This implies that employing an integrated framework, including all cited factors at the same time, can give better insights into the underlying behavioural motivation of public acceptance concerning the V2G system. Furthermore, the target population of the studies are exclusively EV or non-EV users. Little is known about how beliefs and perceptions among these two groups of car users can explain their intention to use the V2G system. We develop an integrated framework to examine the relative roles of different psychological constructs on intention to use V2G system among two groups of car users: current EV and non-EV users in Norway, which reflects different experience with EV technology and also – potentially – different levels of technology-related innovativeness. The findings of the study can help policymakers finding key aspects of behavioural change campaigns to promote consumers' participation in the V2G scheme.

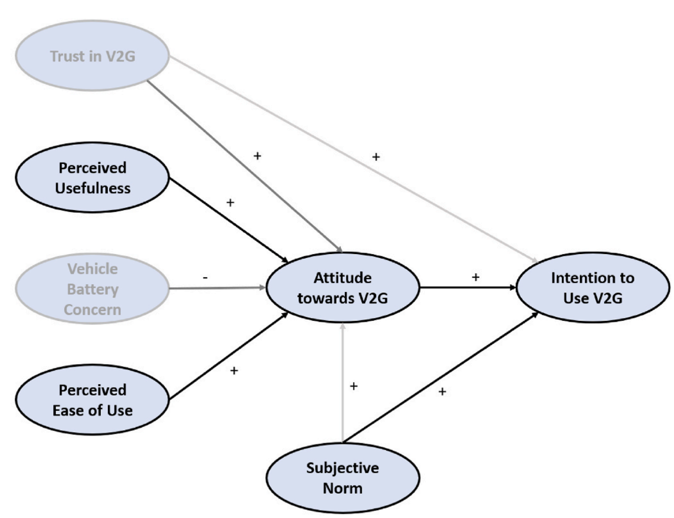
1.2. Conceptual modelling framework

In studying user acceptance and use of technology, the TAM (Davis, 1989) is one of the most cited models. The theoretical basis of the model was Fishbein and Ajzen's (1975) TRA. In the present study, we thus employ a model based on the TAM and the TRA to investigate the motivations underlying public acceptance of the V2G system. Fig. 1 illustrates the hypothesised relationships between people's beliefs/concerns related to V2G use and their intention to adopt such technology.

The TAM attempts to explain the psychological determinants of attitude and subsequent acceptance behaviour towards new technology. The TAM suggests that perceived ease of use and perceived usefulness are the two most important factors in explaining attitude of usage and actual system use. The TAM defines perceived ease of use as "to the degree to which the prospective user expects the system to be free of effort" (Davis, 1989, p.319), while perceived usefulness is defined as the extent to which a technology is expected to improve a potential user's performance (Davis, 1989) and thus to benefit the user. Therefore, it is hypothesised that favourable perceived ease of use and perceived usefulness (e.g., potential economic and environmental benefits of using V2G) may lead people to evaluate the V2G system more positively.

Since the V2G technology has not yet been widely adopted, we examine the role of attitudinal factors on intention to adopt such technology in the future, which is also important as current combustion engine car users are not faced with the choice of allowing V2G in their current vehicle (most currently owned EVs in Norway are also not technically prepared for V2G). However, attitude towards a behaviour is not the sole determinant of either behavioural intention or behaviour as pointed by Fishbein and Ajzen (1975). Subjective norm (i.e., perceived social pressure to perform or not perform the behaviour) is also one of the key determinants of behavioural intention (Klöckner, 2013; Zavareh et al., 2020) according to the TRA. In addition, it is assumed that people's attitudes towards the V2G system would also be influenced by others' expectations and people's beliefs about the trustworthiness of the V2G system.

In line with the literature (e.g., van Heuveln et al., 2021; Geske and Schumann, 2018), it is also hypothesised that vehicle battery concern, i.



+ = positive hypothesised association

- = negative hypothesised association

* Variables and arrows in grey are not part of the TAM or TRA.

Fig. 1. The hypothesised model explaining intention to use V2G.

e., belief that V2G affects battery capacity negatively over time, would make people hold a less favourable attitude towards the V2G system. Moreover, a meta-analysis conducted by Wu et al. (2011) also shows that trust can have direct impacts on attitudes and intention to accept technology. Aside from the relationship between trust and attitudes, previous studies and relevant theories suggest that trust may also be associated with behavioural intentions (e.g., Hooda et al., 2022; Waung et al., 2021). Trust is a fundamental component of human interactions that holds significant sway over behavioural intentions (Morgan and Hunt, 1994). When individuals place their trust in someone or something, they are effectively lowering the perceived risks associated with their actions. This reduction in perceived risk often encourages people to engage in behaviours they might otherwise avoid. Therefore, it is also hypothesised that stronger trust in the V2G system would positively affect attitudes and intention to use the V2G system.

2. Method

2.1. Sample

A self-report online survey was conducted among 1000 Norwegian car users in November 2021. In total, 929 car users (EV and non-EV) were retained after excluding observations with missing values on all variables investigated in this study. Data were gathered from 11 counties in Norway. Participants were informed that the survey was voluntary and that their data would remain anonymous.

Using the latest official statistics in Norway,[2] we compared the characteristics of the sample to those of the population. Using this comparison, we can see that the sample characteristics are largely in accordance with the population. As illustrated in Fig. 2, Viken is the most populous county, which has the highest percentage of respondents (22.3%). Approximately 50% of Norway's older than 16-year-old population consists of women. Of the participants in the study, 50.9% were female. Of the 929 respondents, 31.65% (N = 294) were EV users, and the remaining 68.35% were non-EV users.

2.2. Measures

The questionnaire was part of a larger survey investigating mobility innovations in Norway. There were several validated scales included in the questionnaire, originally developed in English and translated into Norwegian by researchers who were proficient in both languages. By using statements as indicators, we examined trust in V2G, perceived usefulness, vehicle battery concern, perceived ease of use, attitudes towards V2G, subjective norm, and intention to use V2G in the future. A number of studies about V2G adoption have identified these factors as important and had tested them in previous studies (van Heuveln et al., 2021; Geske and Schumann, 2018).

Before asking about psychological items concerning V2G, a short description (using simple non-technical language) of the V2G was also provided in the survey. We explained that "Vehicle-to-grid (V2G) is a system where electric vehicles will be able to transfer electricity back to the power network. The battery of the car will charge when power is cheap and will return power to the network during high traffic/peak hours saving both energy and money." The following text was also included in the questionnaire in addition to the V2G description: "Assuming that you have an electric car or are planning to buy one, to what extent do you agree or disagree with the V2G statements?"

Most indicators of psychological factors were measured on a 5-point Likert scale (1 = strongly disagree; 2 = disagree; 3 = neither disagree nor agree; 4 = agree; 5 = strongly agree). Two statements such as "I think that V2G is a good technology" were used to measure attitudes towards V2G technology (see Table 1). Trust in V2G was assessed by two indicators, e.g., "I trust V2G system designers". Perceived ease of use was evaluated by two statements such as "I want to keep control of the V2G system by using a smartphone". By answering two items such as, "I think that the V2G system can lead to battery degradation in the long term", respondents expressed their concern over vehicle battery. Perceived usefulness of V2G was assessed by two statements such as "A monetary compensation (e.g., free parking, discount on charging) encourages me to use V2G." Subjective norm was assessed by administering two items such as "I think people who are important to me want me to use the V2G system". Finally, intention to use V2G in the future was evaluated by three statements, e.g., "I plan to use V2G in the future."

2.3. Analytical procedures

R version 4.1.2 (R Core Team, 2021) was used for data management and preliminary descriptive analyses. Missing data patterns for measurement items and background variables were examined first. Observations with missing values on all items were excluded, together with observations with missing values on the grouping variable (i.e., the question about having access to a battery-electric car). As a result, the dataset analysed contains 929 observations.

Before testing the hypothesised model using the dataset, all model variables were examined for the assumptions of multivariate analysis (Tabachnick et al., 2007). R-packages psych (Revelle, 2021) was utilised for this purpose. Mplus version 8 (Muthén and Muthén, 2017) was used to test the hypothesised model using the structural equation modelling (SEM) approach. Confirmatory factor analyses (CFA) were performed to examine if the assumed measurement model fits the observed data matrix, as well as separate datasets for the groups. Subsequently, a SEM analysis was performed to test the hypothesised model using the complete dataset.

To further examine if the hypothesised model differs among EV and non-EV users, the multiple group structural equation modelling (SEM) approach was applied. The multiple group analyses involved several steps sequentially testing the invariance of model parameters between the groups. In addition to model fit statistics, which were applied for all CFA and SEM analyses, chi-square difference testing using the Satorra-Bentler scaled chi-square (Satorra and Bentler, 2010) was used to assess the difference between nested models.

Maximum likelihood with robust standard errors (MLR), which is robust to non-normality and non-independence of observations, was applied under all CFA and SEM analyses. All models were evaluated using several criteria for model fit assessment. For example, non-significant χ^2-test, and/or Root Mean Squared Error of Approximation (RMSEA) value smaller than 0.06, Comparative Fit Index (CFI) and Tucker-Lewis Index (TLI) values greater than 0.95 are considered good fit (Barrett, 2007; Hu and Bentler, 1999; Schumacker and Lomax, 2004).

3. Results

3.1. Measurement model of latent variables

Measurements were examined for missing values and fit between their distributions and the assumptions of multivariate analysis. There were no extreme outliers, large skewness or kurtosis evident in the dataset. Table 1 shows the descriptive information of the measures and their internal consistency. Guttman's Lambda 6 (G6) ranges from 0.43 to 0.79, i.e., acceptable to good internal consistency.

The measurement model of latent variables was then examined using CFA with maximum likelihood with robust standard errors (MLR) estimation method. The model fit indexes indicate good fit of the model to the data for the complete sample (N = 929), i.e., χ^2 (105) = 5426.596, p < .0001; RMSEA = 0.048, 90% CI [0.041–0.055]; CFI = 0.972; TLI = 0.958; SRMR = 0.045. CFA were run as well for the datasets for two groups, i.e., the sample reported having access to EV (N = 294) and the sample having no access to EV (N = 635), separately. For the first group,

[2] https://www.ssb.no/en.

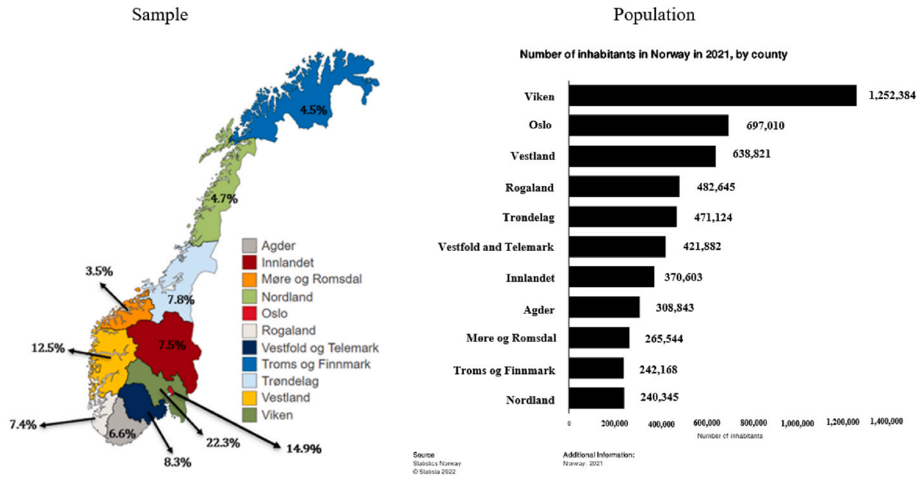


Fig. 2. Geographic distribution of respondents across 11 counties in Norway.

Table 1
Descriptives of the measurements (N = 929).

	Min. – Max.	M	S.D.	G6
Trust in V2G				.76
v01. I trust V2G system designers.	1–5	3.06	1.00	
v02. I think that V2G is a reliable system.	1–5	3.02	1.00	
Perceived Usefulness				.62
v03. A monetary compensation (e.g., free parking, discount on charging) encourages me to use V2G.	1–5	3.33	1.09	
v04. I think that the V2G can contribute to sustainability	1–5	3.29	1.02	
Vehicle Battery Concern				.43
v05. I think that the V2G system can lead to battery degradation in the long term.	1–5	3.30	0.93	
v06. When using the V2G system I would be worried about the battery capacity in my electric car.	1–5	3.30	0.99	
Perceived Ease of Use				.62
v07. I want to keep control of the V2G system by using a smartphone.	1–5	3.44	1.04	
v08. Charging or discharging of the battery in the electric car should be controllable in the V2G system.	1–5	3.53	0.93	
Attitude towards V2G				.70
v09. I think that V2G is a good technology.	1–5	3.32	0.98	
v10. I think that using the V2G can be beneficial for me.	1–5	3.11	1.06	
Subjective Norm				.73
v11. I think people who are important to me want me to use the V2G system.	1–5	2.87	1.04	
v12. I think my social network encourages me to use the V2G system.	1–5	2.83	1.08	
Intention to Use V2G				.81
v13. I expect that I would use V2G in the future.	1–5	2.97	1.05	
v14. I plan to use V2G in the future.	1–5	2.82	1.10	
v15. If you have an electric car or are planning to buy one, to what extent would you be willing to enable V2G technology for your electric car?[a]	1–5	2.87	1.04	

M = mean, S.D. = standard deviations, G6 = Guttman's Lambda 6 (i.e., squared multiple correlations).
[a] Response options: 1 = very low extent, …, 5 = very high extent.

the statistical fit of the measurement model is excellent (i.e., χ^2 (105) = 1539.509, p < .0001; RMSEA = 0.025, 90% CI [0.000–0.044]; CFI = 0.991; TLI = 0.986; SRMR = 0.036). Good model fit is evident for the latter group as well, i.e., χ^2 (105) = 3872.682, p < .0001; RMSEA = 0.060, 90% CI [0.051–0.068]; CFI = 0.959; TLI = 0.937; SRMR = 0.054. All standardised factor loadings are greater than 0.5 for the complete dataset (see Table 2) as well as for the data for the groups (see Table A1 and Table A2 in the appendix).

Table 3 shows the correlation matrix of the latent variables in the measurement model using the complete sample. The correlations, for example, showed that individuals with higher trust in and a more favourable attitude toward V2G technology reported greater intentions to use this technology in the future.

3.2. Test of the model with structural equation modelling (SEM)

After the establishment of an acceptable measurement model for the complete dataset as well as for separate datasets for the groups, the hypothesised structural model depicted in Fig. 1 was first tested using the complete dataset (N = 929). Maximum likelihood with robust standard errors (MLR) estimation method was used. The model fit indexes reveal good fit of the model to the dataset, i.e., χ^2 (105) = 5426.596, p < .0001; RMSEA = 0.047, 90% CI [0.040–0.055]; CFI = 0.972; TLI = 0.959; SRMR = 0.045. All hypothesised structural relationships are statistically significant and in the expected direction (see Fig. 3). 91 % and 81 % of the variances in attitudes and intention respectively are explained by the model.

Table 2
Factor loadings from the measurement model with complete dataset (N = 929).

	B	S.E.	β	P
Trust in V2G				
- > v01	1.000	.000	.864	<.001
-> v02	1.010	.031	.875	<.001
Perceived Usefulness				
- > v03	1.000	.000	.749	<.001
-> v04	1.035	.042	.831	<.001
Vehicle Battery Concern				
- > v05	1.000	.000	.800	<.001
-> v06	0.708	.127	.532	<.001
Perceived Ease of Use				
- > v07	1.000	.000	.769	<.001
-> v08	0.954	.046	.816	<.001
Attitude towards V2G				
- > v09	1.000	.000	.813	<.001
-> v10	1.127	.0037	.855	<.001
Subjective Norm				
- > v11	1.000	.000	.863	<.001
-> v12	1.010	.031	.845	<.001
Intention to Use V2G				
- > v13	1.000	.000	.892	<.001
-> v14	1.018	.020	.864	<.001
-> v15	0.780	.037	.704	<.001

B = unstandardised coefficient; S.E = standard error; β = standardised coefficient; p = significance value.

Table 3
Correlation matrix of the latent variables.

	1	2	3	4	5	6	7
1. Trust in V2G							
2. Perceived Usefulness	.723***						
3. Vehicle Battery Concern	.319***	.482***					
4. Perceived Ease of Use	.579***	.687***	.604***				
5. Attitude towards V2G	.834***	.869***	.354***	.691***			
6. Subjective Norm	.735***	.695***	.356***	.450***	.822***		
7. Intention to Use V2G	.834***	.705***	.304***	.550***	.829***	.842***	

***p ≤ .001.

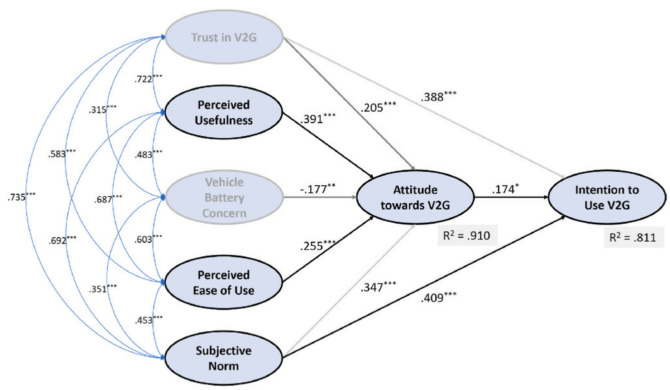


Fig. 3. Summary results of structural equation modelling predicting intention to use V2G
(*p ≤ .05, **p ≤ .01, ***p ≤ .001).

3.3. Multiple group structural equation modelling (SEM) approach

To examine if the hypothesised model differs for the groups, the multiple group structural equation modelling (SEM) approach using the MLR estimation method was applied subsequently. For this purpose, it was first tested if a configural model without any invariances (i.e., the same structural model in both groups, but all parameters may vary across groups) is a reasonable model. The model fit reveals the extent to which the underlying structure fits the data when no constraints across groups are added. The results indicated that the configural model fits the data well, χ^2 (240) = 5526.903, p < .0001; RMSEA = 0.051, 90% CI [0.043–0.058]; CFI = 0.967; TLI = 0.953; SRMR = 0.050, indicating that the model structure is stable across the groups.

After confirming an equal model structure across the groups, several tests of parameter invariance were conducted to reveal if the hypothesised model parameters differ for the groups. Since equal factor loadings across groups are prerequisites for testing any further invariance of model parameters, invariance of factor loadings across groups was tested as the first step. To do this, all factor loadings from the respective latent variables on their indicators were constrained to be equal across groups while allowing the remaining parameters to vary. The next step involved constraining indicator intercepts equal across the groups in addition to equal factor loadings, i.e., equal indicator intercepts. Subsequently, the following model parameters were sequentially tested for invariance across groups: structural paths, residuals of endogenous variables, variances of exogenous variables, covariances between exogenous variables, intercepts/means of endogenous/exogenous variables, and error variances of indicators. In this process, a latter step has the constraints of all previous steps.

Table 4 shows the summary of model fit with invariances and chi-square difference testing using the Satorra-Bentler scaled chi-square between pairs of models in sequence. The results, i.e., model fit indexes and no significant chi-square difference test (i.e., $\Delta\chi^2(8) = 3.479$, p = .901), show that factor loadings can be constrained to be equal across groups. This suggests that the model with equal factor loadings is as good as the configural model. In addition to the invariance of factor loadings (i.e., metric invariance of measurements), the model fit indexes also indicate a good fit of the model with equal indicator intercepts to the data. The chi-square difference test indicates a slight reduction of the model fit with indicator intercepts constrained equal (i.e., $\Delta\chi^2(8)$ = 15.359, p = .053). However, the difference is not statistically significant. Thus, the results suggest that scalar invariance of measurements can be established, which provides a strong precondition for testing further invariance of structural parameters of the model.

As shown in Table 4, further constraining structural paths, residuals of endogenous variables, variances of exogenous variables, and covariances between exogenous variables equal across the groups did not worsen model fit as indicated by the model fit indexes and chi-square difference test of the models. The results thus suggest that these model parameters can be estimated equally across the groups. Put in another way, these models are not different across the groups. However, the invariance tests of intercepts/means of endogenous/exogenous variables, and error variances of indicators showed significant chi-square difference test results (i.e., p < .001). This indicates that imposing equality constraints on these model parameters across the groups worsens the model fit to the data. Although other model fit statistics indicate even the model of complete invariance (i.e., the last model where all the above parameters in the groups are set equal) is an acceptable model (i.e., χ^2 (210) = 5526.903, p < .0001; RMSEA = 0.055, 90% CI [0.049–0.062]; CFI = 0.944; TLI = 0.944; SRMR = 0.103), it seems that the model, which allows factor intercepts/means and

Table 4
Summary of model fit with invariances and chi-square difference testing.

Model	$\Delta\chi^2$	Δdf	p	RMSEA	CFI	TLI	SRMR
Configural (equal form)	–	–	–	.051	.967	.953	.050
Equal factor loadings	3.479	8	.901	.049	.968	.955	.051
Equal indicator intercepts	15.359	8	.053	.049	.966	.956	.052
Equal structural paths	7.767	8	.457	.048	.966	.958	.053
Equal endogenous residuals	8.674	2	.013	.049	.965	.957	.053
Equal exogenous variances	8.958	5	.111	.049	.964	.957	.067
Equal exogenous covariance	15.127	10	.128	.048	.963	.958	.069
Equal factor intercepts/means	91.2856	7	<.00001	.054	.952	.947	.113
Equal indicator error variances	49.630	15	.000014	.055	.944	.944	.103

$\Delta\chi^2$: Satorra-Bentler scaled chi-square difference test TRd; Δdf: difference in the degree of freedom; p: significance value.

indicator error variances to vary across the groups, is the best balance between a parsimonious and a best-fitting model – the model with equal exogenous covariance (i.e., χ^2 (210) = 5526.903, $p < .0001$; RMSEA = 0.048, 90% CI [0.041–0.055]; CFI = 0.963; TLI = 0.958; SRMR = 0.069).

Further inspection of the parsimonious and best-fitting model results indicated that intercepts and means of the latent variables in the model, except attitude towards V2G, differ significantly between the groups. As shown in Table 5, the EV group showed significantly higher values on the latent variables (more positive beliefs and higher concerns) than the non-EV group. The structural relationships between the model constructs are, however, unchanged across the groups. The estimated parameters of the model with equal exogenous covariance can be found in Table A3 in the appendix.

4. Discussion

Using a structural framework, we investigated whether the hypothesised psychological factors can be used to explain intention to use V2G. In addition, we also investigated whether such a framework is stable for explaining intentions across two groups of car users (EV and non-EV users).

The findings show that the theoretical framework of the study substantially explains intended future V2G use among Norwegian car users. Behavioural beliefs related to the use of V2G technology and varying concerns and benefits about this system (e.g., vehicle battery concern, battery degradation, financial compensation) explain V2G adoption among the groups. Intriguingly, the results indicate no significant differences between EV and non-EV users in terms of structural relationships that lead to behavioural intention. All links within the model have similar patterns of influence (i.e., strengths and directions) on the adoption of V2G between these two groups. In other words, the structural relationships between the model constructs were estimated equally across the groups. The intention to use V2G technology also follows the same mechanisms in both groups.

Despite stability in structural relationships between groups, most psychological factors, except attitude towards V2G use, were perceived statistically stronger among EV users than non-EV users. In other words, non-EV users had lower means on central variables (i.e., trust, perceived usefulness, vehicle battery concern, perceived ease of use, subjective norm, and intention). This finding implies that current EV users are more inclined to believe that V2G advantages/barriers are greater, as these early adopters have already been confronted with benefits/problems associated with charging EVs. This result ties well with previous studies wherein early adopters of technologies care about features of upcoming and novel technologies (Berliner et al., 2019; Bühler et al., 2014; Egbue and Long, 2012). To facilitate V2G adoption among non-EV users, a multifaceted policy approach is warranted, addressing key barriers identified in trust, usability, and perceived benefits. Firstly, the introduction of financial incentives, such as tax credits and rebates, specifically targeting non-EV users transitioning to electric vehicles can make EV ownership more financially attractive while addressing concerns about vehicle battery capacity. A recent study in Norway has also shown that financial incentives and minimum guaranteed charges could significantly increase V2G adoption among both EV and non-EV users (Mehdizadeh et al., 2023). Simultaneously, comprehensive education and awareness campaigns should emphasize V2G's financial advantages, ease of use, and environmental benefits to reshape perceptions and intentions. Investments in expanding EV charging infrastructure, both publicly and at homes, are crucial to alleviate concerns about accessibility and range, further incentivizing EV adoption. Moreover, developing a robust V2G infrastructure accessible via public-private partnerships could level the playing field, ensuring that both EV and non-EV users have equal access to V2G benefits and building trust in the technology. Lastly, promoting the environmental advantages of V2G, particularly its role in reducing greenhouse gas emissions and supporting renewable energy, can motivate non-EV users to make the transition and embrace V2G as a responsible choice, influenced by the subjective norm within Norway's evolving energy landscape.

When it comes to changing behaviour, structural stability in associations between the model constructs and intention across EV and non-EV users could imply that specific-segment campaigns are not necessary as both groups may respond in the same way. There is a possibility that non-EV owners/users in Norway may be aware of V2G and its environmental benefits to a similar extent as EV owners as also EV technology is now well-known in Norway. Nevertheless, the mean difference analysis of central latent variables shows that non-EV users (combustion engine car owners) still deserve more attention. Accordingly, the same kind of structural stability could be expected in countries with high electric vehicle penetration rates, such as Sweden, Denmark, Iceland, and Finland. However, generalisations to these contexts warrant further studies.

In general, an increase in trust in V2G, a favourable subjective norm, and positive attitudes towards the system could directly (positively) explain an increase in intention to use V2G. People who strongly agreed that V2G was beneficial, either from their own perspective or from the perspective of their social networks (friends, family, peers), had stronger intentions to use the technology in the future. Moreover, a person whose trust in the system is stronger is more likely to use the technology in the future. These results are broadly in line with a prior study (van Heuveln et al., 2021), who reported that greater trust and favourable behavioural beliefs are associated with a greater intention to use V2G among Dutch EV drivers.

Attitudes could serve as a mediator between numerous exogenous factors (including vehicle battery concern, perceived usefulness, perceived ease of use, trust and subjective norm) and the outcome variable (i.e., intention to use V2G). This assumption also aligns with preconditions in the TAM (Davis, 1989). People who had greater concerns about the battery degradation over time and concerns about the battery capacity when using V2G exhibited unfavourable attitudes towards the usefulness of V2G. Additionally, these people indirectly showed a lower willingness to use V2G. Range anxiety and battery degradation have also been identified as barriers to V2G adoption (Geske and Schumann, 2018; van Heuveln et al., 2021). Another novel finding of our research is that such concerns undermine attitudes towards V2G's usefulness. Addressing these concerns could be the focus of policy and practice. Further estimation of range anxiety thresholds is warranted in light of these results. These estimations can provide policymakers with new insights into how to develop efficient policies and incentives to encourage V2G adoption.

People who believe that charging and discharging batteries should be controlled by smartphones or automatization algorithms are likely to be supportive of V2G. In addition, people who believe that financial compensation such as free parking, a discount on charging, or a reduction in electricity bills will encourage them to use the V2G system hold positive attitudes towards it. In Germany, financial compensation was not found to be an important incentive for using V2G (Geske and

Table 5
Intercept/mean differences in latent variables between the groups (non-EV vs. EV[a]).

	ΔM	S.E.	*p*
Trust in V2G	0.575	.075	<.001
Perceived Usefulness	0.392	.080	<.001
Vehicle Battery Concern	0.178	.090	<.05
Perceived Ease of Use	0.343	.082	<.001
Attitude towards V2G	−0.051	.051	.321
Subjective Norm	0.575	.079	<.001
Intention to Use V2G	0.171	.048	<.001

ΔM = difference in means/intercepts; S.E = standard error; p = significance value.

[a] Non-EV sample as reference group.

Schumann, 2018). Of note, the difference in the perception of financial incentives could indeed be related to the type or design of the incentives. Different types of incentives, such as tax credits, rebates, subsidies, or discounts on electricity bills may have varying impacts on users' willingness to adopt V2G technology. However, the evidence base is mixed as a study in the Netherlands reported financial compensation to be an important factor for both EV and non-EV users to adopt V2G (van Heuveln et al., 2021). Our findings in Norway show that such financial drivers/benefits (demand for financial compensation) are indirectly (through attitudes) associated with a higher intention to use V2G. More research is needed to estimate financial compensation, including elasticities and thresholds, for the V2G system.

5. Conclusions

The study concludes that both groups of car users (EV and non-EV users) have a significant belief-behavioural intention to participate in V2G technology through the same theoretical framework. When it comes to behavioural change campaigns, the same measures/mechanisms could be taken into account for both groups of car users. However, non-EV users (combustion engine car owners), deserve more attention in such campaigns. Norwegian EV users have stronger beliefs and intentions about using this system than non-EV users. Generally speaking, there are some concerns or demands that can be targeted to positively influence V2G adoption among both groups. Concerns about battery degradation or worries about the battery capacity of EVs reduced the probability of V2G adoption.

On the other hand, financial incentives may be needed to compensate for the investment in V2G. Both types of car users can be encouraged to adopt V2G by providing monetary compensation. Norway's electricity prices increased dramatically in 2021, based on the latest statistics. Consequently, Norway's average electricity bill increased from 362 NOK (40.75 USD) to 1765 NOK (199 USD) in the study year. In order to promote V2G technology, policymakers may offer some discounts on electricity bills to V2G users. However, further studies should be conducted to determine the financial compensation for investments in V2G. For example, a recent study conducted in Norway has estimated that, on average, individuals expect a reduction of $144 in their electricity bills (equivalent to 72% of the average monthly electricity bill) as a form of compensation for their investment in V2G technology (Mehdizadeh et al., 2023).

We found that the establishment of behavioural change campaigns including several psychological packages can be a good policy to address V2G barriers among both electric vehicle and non-electric vehicle users. Policymakers could take steps to reduce misinformation among EV users around battery degradation in the long run and stop worrying about the battery capacity. Campaigns should also indicate that the charging and discharging of electric vehicles' batteries can be controlled through V2G systems. Manufacturers and policymakers are also called on to develop technical apps for smartphones to support V2G systems.

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Milad Mehdizadeh: Idea, Writing - Original Draft, Writing - Review & Editing; Conceptualization, Methodology, Investigation, Data Curation, Visualization, Validation, Project administration, Supervision.

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Declaration of competing interest

The authors have no conflict of interest to report.

Data availability

Data will be made available on request.

Appendix

Table A.1
Factor loadings from the measurement model: the sample having access to EV (N = 294).

	B	S.E.	β	P
Trust in V2G				
>v01	1.000	.000	.779	<.001
>v02	1.063	.071	.812	<.001
Perceived Usefulness				
>v03	1.000	.000	.667	<.001
>v04	1.091	.102	.826	<.001
Vehicle Battery Concern				
>v05	1.000	.000	.805	<.001
>v06	0.836	.165	.615	<.001
Perceived Ease of Use				
>v07	1.000	.000	.729	<.001
>v08	1.026	.078	.809	<.001
Attitude towards V2G				
>v09	1.000	.000	.778	<.001
>v10	1.072	.061	.802	<.001
Subjective Norm				
>v11	1.000	.000	.800	<.001
>v12	1.015	.062	.800	<.001
Intention to Use V2G				
>v13	1.000	.000	.831	<.001
>v14	1.052	.051	.777	<.001
>v15	0.810	.089	.666	<.001

Table A.2
Factor loadings from the measurement model: the sample having no access to EV (N = 635).

	B	S.E.	β	P
Trust in V2G				
>v01	1.000	.000	.879	<.001
>v02	1.026	.038	.897	<.001
Perceived Usefulness				
>v03	1.000	.000	.784	<.001
>v04	0.995	.046	.824	<.001
Vehicle Battery Concern				
>v05	1.000	.000	.781	<.001
>v06	0.685	.169	.507	<.001
Perceived Ease of Use				
>v07	1.000	.000	.784	<.001
>v08	0.922	.061	.813	<.001
Attitude towards V2G				
>v09	1.000	.000	.823	<.001
>v10	1.126	.037	.865	<.001
Subjective Norm				
>v11	1.000	.000	.883	<.001
>v12	1.007	.037	.852	<.001
Intention to Use V2G				
>v13	1.000	.000	.907	<.001
>v14	1.005	.024	.888	<.001
>v15	0.769	.044	.691	<.001

B = unstandardised coefficient; S.E = standard error; β = standardised coefficient; p = significance value.

Table A.3
Estimated parameters of the model with equal factor loadings, indicator intercepts, structural paths, endogenous residuals, exogenous variances, and exogenous covariance

	Non-EV group (*N* = 635)					EV group (*N* = 294)				
	B	S.E.	β	*p*	R^2	B	S.E.	β	*p*	R^2
Trust in V2G										
>v01	1.000	.000	.873	<.001	.762	#*	#	.833	#	.695
>v02	1.009	.032	.882	<.001	.779	#	#	.841	#	.708
Perceived Usefulness										
>v03	1.000	.000	.774	<.001	.599	#	#	.701	#	.492
>v04	1.019	.041	.822	<.001	.676	#	#	.822	#	.676
Vehicle Battery Concern										
>v05	1.000	.000	.794	<.001	.631	#	#	.809	#	.654
>v06	0.711	.129	.529	<.001	.280	#	#	.539	#	.291
Perceived Ease of Use										
>v07	1.000	.000	.773	<.001	.598	#	#	.750	#	.563
>v08	0.952	.046	.821	<.001	.673	#	#	.797	#	.635
Attitude towards V2G										
>v09	1.000	.000	.811	<.001	.657	#	#	.795	#	.632
>v10	1.128	.037	.857	<.001	.734	#	#	.834	#	.696
Subjective Norm										
>v11	1.000	.000	.880	<.001	.775	#	#	.815	#	.664
>v12	1.010	.032	.850	<.001	.722	#	#	.814	#	.662
Intention to Use V2G										
>v13	1.000	.000	.899	<.001	.808	#	#	.873	#	.762
>v14	1.010	.020	.879	<.001	.773	#	#	.808	#	.653
>v15	0.765	.036	.680	<.001	.462	#	#	.677	#	.458
Attitude towards V2G					.905					#
<- Trust in V2G	0.201	.059	.216	<.001		#	#	#	#	
<- Perceived Usefulness	0.377	.078	.393	<.001		#	#	#	#	
<- Vehicle Battery Concern	−0.193	.072	−.182	<.01		#	#	#	#	
<- Perceived Ease of Use	0.255	.075	.258	≤.001		#	#	#	#	
<- Subjective Norm	0.302	.049	.336	<.001		#	#	#	#	
Intention to Use V2G					.780					#
<- Trust in V2G	0.391	.073	.367	<.001		#	#	#	#	
<- Attitude towards V2G	0.211	.094	.184	<.05		#	#	#	#	
<- Subjective Norm	0.420	.066	.408	<.001		#	#	#	#	
Trust in V2G										
<-> Perceived Usefulness	0.486	.039	.713	<.001		#	#	#	#	
<-> Vehicle Battery Concern	0.189	.047	.304	<.001		#	#	#	#	
<-> Perceived Ease of Use	0.372	.039	.562	<.001		#	#	#	#	
<-> Subjective Norm	0.517	.038	.709	<.001		#	#	#	#	
Perceived Usefulness										
<-> Vehicle Battery Concern	0.287	.049	.478	<.001		#	#	#	#	
<-> Perceived Ease of Use	0.435	.044	.678	<.001		#	#	#	#	
<-> Subjective Norm	0.487	.039	.689	<.001		#	#	#	#	

(*continued on next page*)

Table A.3 (*continued*)

	Non-EV group ($N = 635$)					EV group ($N = 294$)				
	B	S.E.	β	p	R^2	B	S.E.	β	p	R^2
Vehicle Battery Concern										
<-> Perceived Ease of Use	0.350	.039	.601	<.001		#	#	#	#	
<-> Subjective Norm	0.221	.048	.343	<.001		#	#	#	#	
Perceived Ease of Use										
<-> Subjective social norm	0.297	.040	.433	<.001		#	#	#	#	
Means										
Trust in V2G	0.000	.000	.000			0.483	.064	.575	<.001	
Perceived usefulness	0.000	.000	.000			0.319	.064	.392	<.001	
Vehicle battery concern	0.000	.000	.000			0.132	.070	.178	<.05	
Perceived ease of use	0.000	.000	.000			0.270	.065	.343	<.001	
Subjective norm	0.000	.000	.000			0.500	.068	.575	<.001	
Intercepts										
v01	2.903	.039	3.020	<.001		#	#	2.883	#	
v02	2.869	.039	2.989	<.001		#	#	2.850	#	
v03	3.232	.042	3.076	<.001		#	#	2.788	#	
v04	3.184	.040	3.160	<.001		#	#	3.160	#	
v05	3.261	.038	3.507	<.001		#	#	3.571	#	
v06	3.266	.035	3.292	<.001		#	#	3.356	#	
v07	3.350	.040	3.283	<.001		#	#	3.187	#	
v08	3.447	.036	3.767	<.001		#	#	3.658	#	
v09	3.200	.038	3.326	<.001		#	#	3.263	#	
v10	2.973	.041	2.896	<.001		#	#	2.819	#	
v11	2.704	.039	2.736	<.001		#	#	2.534	#	
v12	2.670	.041	2.584	<.001		#	#	2.474	#	
v13	2.770	.040	2.780	<.001		#	#	2.700	#	
v14	2.617	.041	2.543	<.001		#	#	2.337	#	
v15	2.718	.038	2.694	<.001		#	#	2.683	#	
Attitude towards V2G	0.000	.000	.000			−0.040	.040	−.051	.321	
Intention to Use V2G	0.000	.000	.000			0.153	.042	.171	<.001	
Variances										
Trust in V2G	0.704	.048	1.000			#	#	#		
Perceived usefulness	0.661	.055	1.000			#	#	#		
Vehicle battery concern	0.545	.093	1.000			#	#	#		
Perceived ease of use	0.622	.053	1.000			#	#	#		
Subjective norm	0.757	.050	1.000			#	#	#		
Residuals										
v01	0.220	.029	0.238	<.001		0.310	.043	0.305	#	
v02	0.204	.030	0.221	<.001		0.296	.050	0.292	#	
v03	0.443	.045	0.401	<.001		0.683	.083	0.508	#	
v04	0.329	.041	0.324	<.001		0.329	.046	0.324	#	
v05	0.319	.088	0.369	<.01		0.289	.093	0.346	#	
v06	0.708	.075	0.720	<.001		0.672	.088	0.709	#	
v07	0.419	.046	0.402	<.001		0.483	.073	0.437	#	
v08	0.273	.040	0.327	<.001		0.324	.053	0.365	#	
v09	0.317	.038	0.343	<.001		0.354	.046	0.368	#	
v10	0.280	.034	0.266	<.001		0.339	.047	0.304	#	
v11	0.220	.031	0.225	<.001		0.382	.059	0.336	#	
v12	0.296	.045	0.278	<.001		0.394	.064	0.338	#	
v13	0.191	.026	0.192	<.001		0.250	.040	0.238	#	
v14	0.240	.031	0.227	<.001		0.435	.061	0.347	#	
v15	0.548	.042	0.538	<.001		0.556	.064	0.542	#	
Attitude towards V2G	0.058	.019	.095	≤.001		#	#	#	#	
Intention to Use V2G	0.176	.026	.220	<.001		#	#	#	#	

B = unstandardised coefficient; S.E = standard error; β = standardised coefficient; p = significance value; R^2 = variances explained.

* # means the same estimation value in each row as reported for the non-EV group.

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