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From conventional transport modes to V2G-Enabled vehicles: an analysis of mode substitution behaviour

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A B S T R A C T

Vehicle-to-grid (V2G) technology enables electric vehicles (EVs) to function as both energy consumers and suppliers, potentially improving power grid stability while offering economic benefits to users. Before large-scale implementation, however, the viability of V2G must be assessed, specifically, the extent to which people are willing to adopt it. This study investigates people's willingness to switch from their current mode of transport to two V2G-enabled options: private EVs with V2G, and carsharing EVs with V2G. To achieve this goal, a stated choice experiment was designed and conducted in the Netherlands. For the data analysis, we introduce a random-parameters rank-ordered logit model to capture preference heterogeneity and unobserved correlations between the two V2G options. The results indicate strong inertia towards retaining the current (status quo) travel mode compared with the two V2G alternatives. Cost savings from V2G participation significantly increase the likelihood of choosing both V2G options, whereas the minimum guaranteed battery range has a limited effect once trip-range requirements are satisfied. Preferences also differ systematically between respondents with different status quo travel modes and across socio-demographic groups. These findings support targeted policy design to accelerate V2G adoption.

1. Introduction

Vehicle-to-grid (V2G) technology offers a promising solution by allowing electric vehicles (EVs) to function as distributed energy storage units, storing excess renewable energy and feeding it back into the grid when it is needed during peak demand (Bakhuis et al., 2025; Geske and Schumann, 2018; Kempton and Tomić, 2005; Kester et al., 2019; Sturmberg et al., 2024; Van Heuveln et al., 2021). However, for V2G to realise its full potential to support power grid stability, large-scale participation is needed. This depends not only on technological readiness but also on behavioural shifts from the users' side. In other words, V2G cannot scale unless a large number of people are willing to adopt this technology and participate in bidirectional charging. Thus, understanding how V2G-enabled vehicles could change mobility behaviour is very important to encourage their wide adoption.

This makes mode choice analysis essential for V2G research because it identifies who can and will contribute to grid flexibility through V2G, and how different travel patterns may support or constrain large-scale adoption. The frequency, timing, and location of vehicle use directly determine the amount of energy that can be exchanged with the grid, and mode choice affects this availability. In

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this research, we aim to understand people's mode choice, more specifically, how and why individuals may shift from their current travel modes, which are not V2G-equipped in any way, to two V2G-enabled alternatives: private EVs and carsharing EVs.

V2G can be deployed through several distinct pathways, two of which are the focus of this paper. The first is V2G on privately owned EVs, which allows users to store electricity when prices are low and sell it back to the grid during peak pricing periods, creating opportunities for owners to earn income and reduce operational expenses (Noel et al., 2019). This helps offset the high upfront purchase cost of EVs, which remains a key barrier to adoption, and broadens the appeal of private EV ownership beyond higher-income users or those in high-end work and residential districts (Christidis and Focas, 2019). The second is V2G integrated into shared mobility services such as carsharing, where it can address the affordability barrier that limits widespread carsharing use (Ceccato et al., 2021) by enabling operators to generate revenue from energy services, which can be passed on as lower user fees and used to improve fleet financial sustainability (Prencipe et al., 2022). These two pathways are complementary, and the relative attractiveness of each across different user groups is one of the factors that shapes the scale of V2G participation and the equity of its distribution.

Mode choice analysis is the natural framework for studying both pathways, for reasons that go beyond what vehicle-purchase studies can offer. For private EVs with V2G, ownership is only a precondition for participation; it does not determine the actual grid value of the vehicle. This value depends on how the vehicle is used in daily life, including the frequency, timing, distance, and location of trips, as these factors shape when and where the vehicle may be parked, plugged in, and available for bidirectional charging. Vehicle-purchase studies can identify who may be willing to own a V2G-capable EV, but they cannot capture whether such vehicles would substitute existing travel modes in specific trip contexts. For V2G-enabled carsharing, the relevance of mode choice is also direct. Grid-service revenues may reduce user costs and improve the affordability of shared EV services, but users must still evaluate this option against their current mode in terms of travel time, access effort, and battery-range assurance. Whether these mobility and energy-service benefits are sufficient to attract current public transport users, internal combustion vehicle (ICV) drivers, EV drivers, or cyclists is therefore fundamentally a mode choice question.

The mode choice examined in this paper is unconventional because the utility of the V2G alternatives is jointly shaped by mobility performance and energy-service participation. In conventional mode choice studies, monetary attributes usually represent transport-related payments, such as fares, fuel costs, parking fees, or carsharing charges. In a V2G setting, however, the monetary component is partly generated through the vehicle's ability to provide grid services, while the mobility component depends on trip requirements, access effort, parking conditions, and minimum guaranteed battery range after charging and discharging. Travellers are therefore not only choosing how to travel, but also evaluating whether monetised grid-service benefits compensate for the practical constraints introduced by V2G operation. Existing V2G studies have mainly focused on vehicle-purchase decisions, contractual arrangements, or individual charging events, and therefore cannot show whether grid-service benefits induce substitution away from current travel modes for specific trips. Similarly, conventional carsharing and mode choice studies can capture responses to price, time, and access distance, but not how energy-service benefits and minimum guaranteed battery range jointly affect the attractiveness of shared electric mobility. This paper addresses this gap by integrating mobility and monetised energy-service attributes into a discrete choice model to estimate substitution toward private and shared V2G-capable modes.

We designed a survey incorporating a Stated Choice (SC) experiment to examine individuals' willingness to shift from their current travel modes to V2G-enabled alternatives for their daily commuting and non-commuting trips. The study deliberately investigates willingness to use V2G-enabled vehicles not only among current EV users but also among potential adopters from diverse socio-demographic backgrounds, offering a more inclusive perspective on the use of V2G-enabled modes and making the findings particularly relevant to the future adoption of this technology. The collected data are analysed using multiple choice models, through which we identify substitution patterns and derive policy implications for promoting large-scale and equitable V2G adoption.

The contributions of this paper are listed below:

(1) We develop a mode choice framework that integrates mobility attributes and monetised energy-service attributes, representing V2G-equipped private EVs and V2G-equipped carsharing EVs as distinct trip-level alternatives alongside respondents' current modes. This framework allows us to examine whether grid-service benefits, together with V2G-related constraints such as minimum guaranteed battery range, can induce substitution from existing travel modes. This behavioural mechanism cannot be captured by conventional EV adoption studies, which focus mainly on purchase or charging decisions, nor by standard mode choice studies, where vehicle-to-grid interactions are absent.
(2) We quantify how mode- and trip-specific attributes, including cost savings from V2G participation, walking time, parking convenience, and minimum guaranteed battery range, influence individuals' willingness to switch from their current modes to V2G-equipped private EVs and V2G-equipped carsharing services. We further examine how these effects differ between commuting and non-commuting trips and across current-mode user groups.
(3) We reveal heterogeneity in substitution patterns across current-mode user groups, including public transport, ICV, EV, and bike users, as well as across socio-demographic groups. These results support differentiated policy strategies by identifying where V2G adoption is more likely to be advanced through private ownership, where shared services may play a stronger role, and how targeting by income, age, or family composition can broaden access to electrified mobility.

The remainder of the paper is organised as follows. Section 2 presents the literature review. Section 3 describes the data collection process and provides a brief overview of the collected data. Section 4 outlines the model specification and estimation approach. Section 5 displays the estimation results. Section 6 discusses the findings and their policy implications. Finally, Section 7 concludes the paper and highlights directions for future research.

2. Literature review

This section reviews behavioural research on V2G from both private and shared mobility perspectives and concludes by synthesising the key limitations in the existing literature and identifying the gaps addressed in this study.

2.1. Behavioural studies on V2G adoption and participation

Behavioural studies of V2G adoption have examined consumers' willingness to adopt the technology using both qualitative and quantitative approaches. Qualitative research, such as expert interviews and focus groups (Van Heuveln et al., 2021), provides rich insights into the human side of V2G acceptance, capturing motivations and concerns that quantitative models may overlook. Quantitative studies, on the other hand, often rely on stated preference experiments to examine adoption behaviour from different user perspectives and to identify the relative importance of key attributes influencing V2G participation (Kubli, 2022; Parsons et al., 2014; Yun et al., 2025).

Findings from qualitative research have identified several common facilitators and barriers to V2G participation. Key facilitators include financial compensation, transparent communication, user-friendly interfaces, and reliable control (Ghotge et al., 2022; Kester et al., 2019; Van Heuveln et al., 2021). On the other hand, the main barriers include concerns about battery degradation, range anxiety, privacy, increased trip planning complexity, and perceived inconvenience of participation. Importantly, these concerns evolve with experience: participants with little direct exposure to V2G tend to raise general or abstract worries, such as warranty and privacy issues (Kester et al., 2019). By contrast, users who participated in real-world trials shifted their attention to more concrete usability factors, such as charging flexibility and travel planning (Ghotge et al., 2022). Together, these qualitative studies demonstrate that acceptance of V2G is shaped not only by economic considerations but also by everyday usability and reliability. However, most existing research remains focused on individuals' willingness to participate, without addressing how such acceptance translates into actual travel behaviour in people's daily lives. In particular, they provide little insight into the role of V2G in mode-choice decisions.

Quantitative studies, which are primarily based on SC experiments, investigate people's willingness to use V2G from different perspectives: vehicle purchase decisions (Gschwendtner and Krauss, 2022; Hidrue and Parsons, 2015; Maeng et al., 2020; Noel et al., 2019) , contractual arrangements (Bailey and Axsen, 2015; Bakhuis et al., 2025; Geske and Schumann, 2018; Huang et al., 2021; Yun et al., 2025), choices about individual charging events (Fan et al., 2026; Kubli, 2022), and the influence of socio-demographic characteristics (Sovacool et al., 2018). Choices related to contractual arrangements and individual charging events typically arise only after an individual already owns a V2G-capable EV and therefore do not involve trade-offs with other travel modes. By contrast, vehicle purchase studies can reveal potential substitution between vehicle technologies, as respondents are usually asked to choose between different vehicle types, such as internal combustion engine vehicles, conventional EVs, and V2G-enabled EVs, based on both conventional vehicle attributes and V2G-specific features (Noel et al., 2019; Parsons et al., 2014; Philip et al., 2023). However, the resulting insight into modal substitution remains limited as these studies do not capture day-to-day mode use for specific trips as a function of trip characteristics.

Findings from these studies consistently show that cost savings and financial compensation positively influence willingness to adopt V2G. In addition to monetary incentives, factors such as mobility assurance (e.g., guaranteed minimum battery range), charger accessibility, acceptable plug-in requirements (e.g., minimum daily plug-in hours), and concerns about battery degradation are equally important. International comparison reveals considerable variation in preferences, with willingness to pay for V2G and preferences for related attributes varying across national contexts and user segments (Noel et al., 2019). Despite growing interest in V2G adoption, no existing research has examined how travellers may shift between travel modes when V2G-related benefits are explicitly introduced. This gap needs to be addressed because mode choice determines when, where, and how V2G-capable vehicles are used, and thus plays a central role in shaping large-scale adoption.

2.2. Behavioural studies on V2G-enabled carsharing services

Beyond studies on private EVs with V2G, only a limited number of papers have examined people's willingness of using carsharing services with the integration of V2G components (Gschwendtner and Krauss, 2022; Suel et al., 2024). Gschwendtner and Krauss (2022) investigated whether and how the inclusion of V2G components enhances the attractiveness of carsharing services. Their experiment offered three alternatives: conventional carsharing, EV carsharing, and V2G carsharing. They found that factors such as cost, minimum range, access and egress time, and service type (e.g. free-floating, round-trip, or station-based) significantly influence people's choices. Socio-demographic characteristics such as EV ownership and familiarity with V2G also increased the preference for V2G carsharing too. Suel et al. (2024) explored the extent of financial incentives required in V2G carsharing to encourage users to shift their reservation time slots. Their results indicate that older adults, lower-income groups, employed individuals, and those with a university degree exhibit lower time flexibility. In addition, work, leisure, or social trips involving other passengers, and those occurring on weekdays or during morning peaks, were found to be less flexible. No existing research has presented carsharing EVs with V2G as a distinct alternative within a mode choice framework with the existing conventional modes of transport, even though many V2G features align closely with user interests. These features include potential discounts for carsharing use, the opportunity to access electric mobility without the high upfront cost of vehicle ownership, as well as environmental and sustainability benefits. Moreover, users of V2G-enabled carsharing are less concerned about battery degradation than private EV owners. The insufficient attention to the role of V2G in mode choice behaviour leaves significant gaps in understanding intermodal substitution when travellers are explicitly informed of V2G's benefits and constraints.

2.3. Research gaps

In summary, to the best of our knowledge, no study has incorporated V2G-enabled private EVs and V2G-enabled carsharing EVs as distinct alternatives within a trip-based mode choice framework that explicitly accounts for monetised grid-service opportunities. Consequently, mobility-energy interactions remain only partially captured in the behavioural literature. In particular, although qualitative studies have highlighted the importance of cost savings and other V2G-related attributes in shaping acceptance and participation, these insights have rarely been translated into quantitative assessments of how these attributes affect day-to-day mode choice and substitution patterns. This paper addresses this gap by integrating mobility and energy attributes into a discrete choice model, thereby enabling quantitative estimation of substitution toward V2G-capable modes.

3. Methods of data collection and analysis

This section explains how the SC data were collected and analysed. It begins with an overview of the online survey developed using Qualtrics (Qualtrics, 2026) followed by a description of the data collection process and the main characteristics of the resulting sample.

3.1. Survey design

The survey begins with a brief introduction to V2G technology. An animation is provided to illustrate the bi-directional charging and discharging process and to help respondents understand how the system works. Because V2G has not yet been widely implemented, most respondents are unlikely to have firsthand experience with the technology; therefore, this introductory material is intended to establish a shared baseline of understanding. To minimise bias, the introduction presents both potential advantages and disadvantages of V2G. The advantages include possible monetary earnings or cost savings (e.g., buying electricity when prices are low and selling it when prices are higher), improved grid stability, and potential environmental benefits. The disadvantages include possible battery degradation and concerns about data privacy. A detailed version of this introduction is provided in Appendix A.

After the introduction, respondents were instructed to assume that they would have obtained a privately owned EV equipped with V2G technology when answering the survey questions. Although this is a strong assumption and may not hold for all individuals in the future, it can be relaxed in the subsequent analysis by excluding the private V2G-enabled EV alternative from the choice set, thereby representing scenarios in which respondents do not own a private V2G-capable EV. The procedure for implementing this adjustment is

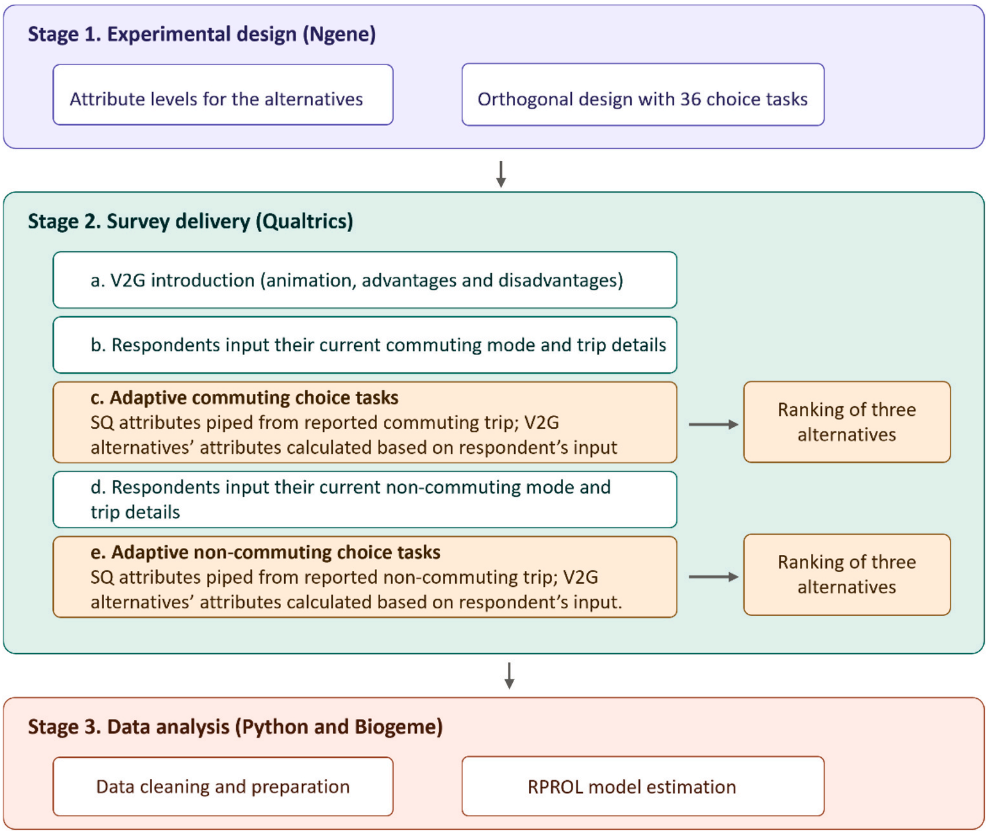


Fig. 1. Survey workflow and software implementation.

described later in this section. Note that we did not include car purchase decisions. Instead, we focused on mode choice, which reflects short-run, trip-level decisions about how to travel, conditional on having access to a car.

The survey collected the following information:

- Respondents' mobility patterns for commuting and non-commuting trips, based on one typical trip of each type, including current travel mode and trip characteristics such as distance, travel time, and travel cost;
- Responses to the stated choice experiment on mode choice between respondents' current mode and the two V2G-related alternatives; and
- Socio-demographic characteristics and information on the current mobility profile, including vehicle ownership and accessibility to private and public transport.

This study employs a stated adaptation experiment as its methodological approach. Instead of asking respondents to choose among all existing transportation modes, we first asked them to indicate their current mode of transport for a typical commuting trip and a non-commuting trip based on the assumption that they have already chosen their most preferred mode among all available options. This approach helps reduce respondents' cognitive burden and makes the choice situations more relatable to their own typical commuting and non-commuting trips. Then, respondents were asked whether they would switch from their current mode to one of the V2G-related alternatives under a series of hypothetical scenarios. The design is therefore anchored in current travel behaviour, which serves as the reference alternative (Liao et al., 2024; Pan et al., 2019).

Therefore, respondents were asked to rank three alternatives: their current mode of transport, a private EV with V2G, and a carsharing service with V2G. The current mode of transport was thus individual-specific. For this alternative, respondents provided the attribute values, which remained constant across all choice tasks. Based on the trip information they provided, the attribute levels for the two V2G-related alternatives were then designed accordingly. The detailed survey flow and software implementation are shown in Fig. 1.

3.1.1. *Attributes for respondents' current travel mode*

To collect information on respondents' current travel behaviour, the survey first asked about their usual mode of transport for commuting to work or school on a typical day, as well as for non-commuting trips to shopping areas or leisure activities. The respondents whose current mode is PT, private ICV, private EVs, or bikes were then asked to provide detailed trip information. These four conventional modes were selected because they are the most frequently used modes of travel among the Dutch population (Centraal Bureau voor de Statistiek, 2025). Other modes account for only a small proportion of all respondents, resulting in very limited sample sizes. Such small samples would not allow for the reliable estimation of taste parameters (Liao et al., 2024). Walking was not considered in the experiment because respondents who walk typically make short trips and are unlikely to switch to car-based modes for such distances.

The required trip information included travel time, approximate travel distance, total walking time (to and from the vehicle), travel cost (for PT users only), waiting time (for PT users only), parking search time (for car and bicycle users only), and parking costs (for car users only). This information was then used as the attribute values for the status quo (SQ) alternative. For ICVs and EVs, respondents might not always know their actual trip costs accurately, as these costs include fuel or electricity expenses, maintenance, and depreciation. Therefore, trip costs were estimated by multiplying the reported travel distance by the average per-kilometre cost: €0.311/km for ICVs and €0.2295/km for EVs, both based on typical real-world driving costs in the Netherlands.

In addition to the attributes above, we included the State of Charge (SOC) because it directly constrains the feasible use of a private EV and can therefore affect mode choice when the SQ mode is a private EV. As SOC fluctuates daily and is difficult for respondents to report for a specific trip, we specify SOC as an attribute with four levels to represent different battery ranges: 5% (15 km), 30% (90 km), 60% (180 km), and 90% (270 km), assuming a full battery range of 300 km. If a respondent's current mode did not fall into any of the four main modes of transport (for example, bike-sharing, motorcycle, walking) or they did not make any trips, they were assigned a reference trip using public transport. Their subsequent stated choice tasks were then based on this reference trip.

3.1.2. *Attributes for the two V2G-enabled alternatives*

Travel times and costs for private EVs with V2G and carsharing EVs with V2G were derived from respondents' trip information (travel distance and travel time). When the SQ alternative was a private car (ICV or EV), the travel time of the V2G-enabled EVs was set equal to the reported actual travel time. Otherwise, travel time was estimated based on the reported travel distance, assuming an average driving speed of 50 km/h (Government of the Netherlands, 2024). These values were used as a reference. In the experimental design, the reference travel time was varied across three levels (reference × 80%, 100%, 120%) to represent travel time fluctuations in real-world conditions, such as peak and off-peak periods. Similarly, the reference travel cost was varied by three levels (reference × 30%, 60%, 90%) to reflect potential cost savings from future V2G participation. The use of such fixed reference alternatives in experimental design is well established in stated preference research (De Luca and Di Pace, 2015; Liao et al., 2024; Yan et al., 2019).

Another key attribute of V2G is the minimum guaranteed battery range after charging and discharging, which ensures that EVs retain sufficient range to meet upcoming trip requirements. This attribute was specified at three levels: 20%, 40%, and 60% of battery capacity, corresponding to driving ranges of 60 km, 120 km, and 180 km, respectively, assuming a full vehicle range of 300 km. These levels were selected to represent different degrees of mobility assurance within a realistic battery-management range. For example, in Utrecht Energized, a V2G-enabled EV carsharing service operated by MyWheels, the SoC is maintained between 20% and 80% during V2G cycles to limit battery degradation (Letcher et al., 2026). Therefore, the 20%, 40%, and 60% levels used in this experiment should be interpreted as hypothetical service-guarantee levels within an operationally realistic SoC range, rather than as existing Dutch legal requirements or fixed guarantees provided by all carsharing operators. In addition, walking time to and from the vehicle was included to capture physical inconvenience, with attribute levels set at 0, 5, and 10 minutes.

Parking cost can be an important attribute in mode choice. However, previous research has discussed the possibility of providing discounted or exempted parking fees (Geske and Schumann, 2018; Philip et al., 2023; Wang et al., 2017) to encourage V2G participation. Extended parking durations can benefit both participants and power grid systems by enabling vehicles to charge and discharge across multiple demand intervals. Thus, in this study, we do not explicitly model the relationship between parking duration and potential parking discounts or incentives, as the design of parking-cost policies under V2G conditions is beyond the scope of our research. Instead, we assume that respondents who choose to participate in V2G receive parking-fee exemptions. Regarding parking search time, we specify three levels for private V2G-enabled EVs: 0, 5, and 10 minutes. For V2G-enabled carsharing EVs, we assume that services provide dedicated parking spaces, making parking-searching time negligible relative to searching for a space in public parking areas.

Table 1 summarises all attribute levels used in the experimental design. Based on these attributes and levels, we constructed an orthogonal design with 36 choice tasks. We did not adopt an efficient design because reliable prior parameter estimates were unavailable; without priors that are reasonably close to the true values, a D-efficient design may perform poorly and lack robustness (Walker et al., 2018).

Each respondent was assigned six choice tasks in total: three for commuting scenarios and three for non-commuting scenarios. In each choice task, respondents were asked to rank the three alternatives from most to least preferred. Rank-ordered data provide richer information than a single nominal choice, as they capture the relative preference ordering across all alternatives and can be decomposed into sequential choices within a rank-ordered logit framework. This approach has been applied in transport mode choice studies (Mondal and Bhat, 2022; Srinivasan et al., 2006), as well as in studies of emerging transport technologies (Shahadat Hossain and Rahman Fatmi, 2022). In our study, the first-ranked alternative is interpreted as the respondent's preferred mode, while the lower-ranked alternatives provide additional information on substitution patterns among the remaining options. A further reason for using ranking is the ownership assumption: in the experiment, respondents were asked to consider a scenario in which they own a private EV with V2G. However, this assumption may not always hold in practice. By collecting rankings, the private EV with V2G alternative can be excluded from the analysis, if necessary, while retaining preference information between the status quo and V2G-equipped carsharing alternatives. Fig. 2 shows an example of a choice task shown to the respondents.

3.2. Data collection and sample characteristics

The survey was distributed in the Netherlands through anonymous links and QR codes, with both English and Dutch versions available. Data were collected between February and April 2025 via three channels: (i) 6.14% of responses were obtained through on-street distribution in Utrecht's Kanaleneiland district, a multicultural neighbourhood with a high share of social housing and low-income households that is actively involved in sustainability initiatives; (ii) 67.23% of responses were collected through collaborations with panel companies to ensure broader population coverage in the country; and (iii) 26.63% of responses were obtained through a partnership with the Dutch Association of EV Drivers (VER) to reach a higher proportion of EV owners. This sampling strategy allowed us to include not only current EV owners but also potential future adopters, thereby capturing a broader range of socio-demographic groups.

To improve data quality, incomplete responses and those completed in under five minutes were removed. The filtered dataset comprised 743 respondents. Sample characteristics are summarised in Table 2. In the table, it shows that male and higher-educated groups are overrepresented relative to the Dutch population. We decided not to apply sample weights in model estimation. Instead, we included socio-demographic variables in the model to capture their influence on preferences. Including these variables helps mitigate potential bias associated with sample non-representativeness (Mo et al., 2021). For the commuting and non-commuting analyses, we additionally removed respondents who reported implausible status quo trips, such as bicycle trips with implied speeds above 40 km/h (Liao et al., 2024). This resulted in final samples of 730 respondents for the commuting scenario and 716 respondents for the non-commuting scenario.

In addition to socio-demographic characteristics, respondents were asked to indicate which public and private transport modes were available to them. The results are presented in Fig. 3. For private transport, 68% of respondents reported having access to a bicycle, reflecting the Netherlands' strong cycling culture. Private cars also accounted for a substantial share of the sample, with 46.4%

Table 1
Attribute levels.

Attributes	Private EV with V2G	Carsharing with V2G
Travel cost	Reference[1]*30%, 60%, 90%	Reference[2]*30%, 60%, 90%
In-vehicle travel time	Reference[3]*80%, 100%, 120%	
Walking time to and from the vehicle	0, 5,10 mins	0, 5,10 mins
Parking searching time	0, 5,10 mins	–
Minimum guaranteed battery range	20%, 40%, 60% (60 km, 120 km, 180 km)	

Note: Reference[1] is calculated based on distance, assuming 0.2295 euro/km. Reference[2] is calculated based on distance and time, assuming 0.27 euros/km and 2.07 euros/hour. Reference[3] is calculated based on distance, assuming 50 km/h.

	Public Transport	Private EV with V2G	Carsharing EV with V2G
Trip cost	€ 4	€ 1.79	€ 2.43
Travel time in vehicle	16 min	15.6 min	15.6 min
Walking time to vehicle and from vehicle to destination	10 min	10 min	20 min
Waiting time for public transport	10 min		
Parking searching time		10 min	0 min
Battery level before departure		More than 60% (180 km)	More than 60% (180 km)

Please click on the radio buttons to rank all three options from your most preferred (1) to your least preferred (3).

	1	2	3
Public transport	○	○	○
Private EV with V2G	○	○	○
Carsharing EV with V2G	○	○	○

Fig. 2. Example of a choice task.

Table 2
Sample characteristics.

Variable	Category	Percentage in sample	Percentage in population
Gender	Female	39.97%	50.4%
	Male	59.62%	49.6%
	Prefer not to say	0.4%	
Age	18–24	8.75%	10.6%
	25–34	18.44%	16.6%
	35–44	15.88%	15.4%
	45–54	15.61%	14.9%
	55 – 65	21.53%	17%
	65 and older	19.78%	25.5%
Education	No higher education	33.64%	52.0%
	Higher education	66.36%	48.0%
Household monthly income	Low (≤ €3000)	28.13%	Not available
	Middle (≤ €6000 and >€3000)	53.03%	Not available
	High (>€6000)	18.84%	Not available
Number of children	0	74.29%	68.5%
	1 and more	25.71%	31.5%
EV ownership	Having EVs	40.24%	Not available
	Do not have EVs	59.76%	Not available

Source: CBS.

reporting access to an ICV and 40.2% to an EV. As private EVs and the private EV with V2G alternative are closely related, respondents with access to an EV may view the private V2G option as more familiar or easier to contextualise within their existing mobility experience. In contrast, only a small number of respondents reported access to motorcycles or other types of cars, and only 0.1% reported no access to any form of private transport. For public transport, buses and trains are the primary means of accessibility, followed by taxis. Notably, 41.5% of respondents reported having access to carsharing services in their daily lives, suggesting that such services are already familiar to many and provide a promising basis for future adoption of V2G-enabled carsharing. Other modes, such as trams, ride-hailing services, e-scooter sharing, and the subway, were available to a smaller proportion of respondents.

Among all accessible transport modes, respondents were asked to indicate which modes they most frequently used on a typical day for commuting and non-commuting trips. Fig. 4 presents the shares of current modes chosen by the respondents. For commuting, the most frequently used modes are private EVs as a driver (19.5%), bicycles (18.6%), public transport (17.2%), and private ICVs as a driver (16.3%). Additionally, 17.8% of the respondents reported that they do not go to work or school, which is a considerable share that may reflect individuals working from home, stay-at-home parents, unemployed individuals, or retirees. For non-commuting trips, the leading modes are bicycles (34.7%), private EVs as a driver (19.9%), private ICVs as a driver (11.3%), and private e-bikes (10.2%). The share of private EVs is higher than the national average in the Netherlands, which is expected, given that the Dutch Association of EV Drivers (VER) was involved in the recruitment to ensure sufficient participation from EV users. A notable difference between the

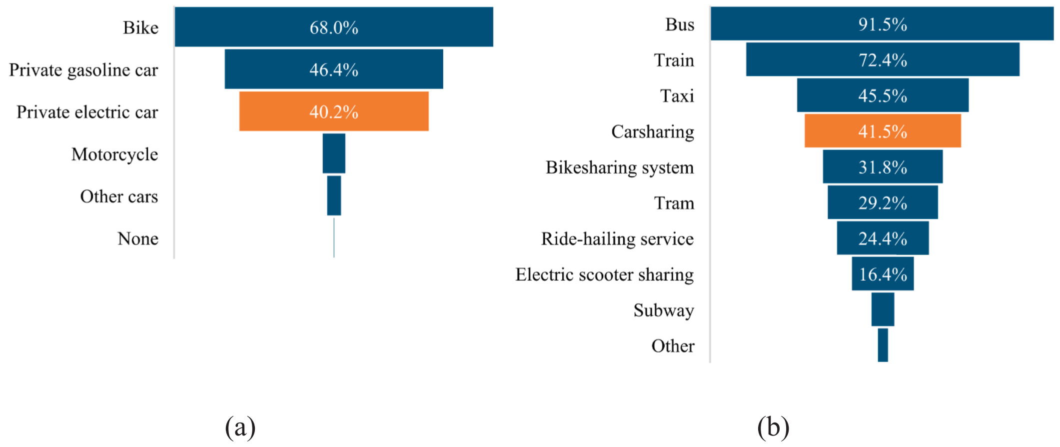


Fig. 3. Access of private and public transport modes among survey respondents: (a) Private transport access, (b) Public transport access.

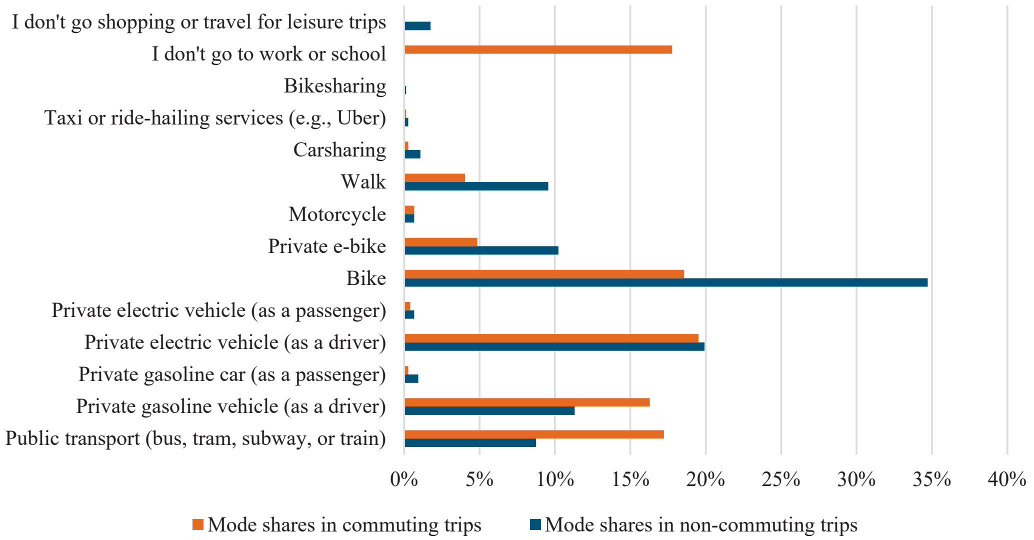


Fig. 4. Respondents' current modes of transport for commuting and non-commuting trips.

two trip purposes is that public transport use nearly doubles from non-commuting (8.8%) to commuting (17.2%), highlighting its stronger role in work and school travel. Private vehicles, including both EVs and ICVs, account for substantial shares in both trip types, with EVs slightly more prevalent than ICVs. Overall, bicycles predominate among non-commuting trips, suggesting that cycling is particularly popular for leisure and shopping. More broadly, active modes (bicycle, e-bike, walking) account for a much higher share of non-commuting than commuting trips.

Table 3 presents descriptive statistics for trip attributes reported by respondents across all transport modes, for both commuting and non-commuting contexts. Overall, average travel distances are longer for commuting than for non-commuting trips across all modes. For public transport, travel costs are noticeably higher for commuting, and waiting and walking times together constitute a substantial share of the total travel time. For ICVs and EVs, the mean parking cost is higher for non-commuting than for commuting trips. During commuting, parking costs are almost always zero, likely due to employer-provided parking facilities, whereas commercial parking in non-commuting situations tends to be more expensive. Similarly, average parking search times are higher for non-commuting trips, with some cases showing particularly long search durations and high costs. As expected, bicycle trips are considerably shorter than trips made by other modes; however, their total travel times are non-trivial because of lower travel speeds. Nevertheless, cycling remains competitive for short-distance trips. Overall, parking search times are generally low for both cars and bicycles, with only a few exceptional cases.

Table 3
Descriptive statistics of reference trip attributes.

Mode	Purpose	Attribute	Mean	Std	Min	25%	50%	75%	Max
Public transport	Commuting	Travel distance (km)	33.3	25.8	1.0	10.0	30.0	50.0	100.0
		Travel cost (€)	8.5	10.5	0.0	2.0	5.0	11.0	70.0
		Walking time (min)	12.6	11.9	0.0	5.0	10.0	15.0	60.0
		Waiting time (min)	7.0	5.4	0.0	5.0	5.0	10.0	40.0
		Travel time (min)	36.8	23.9	1.0	20.0	35.0	50.0	120.0
	Non-commuting	Travel distance (km)	12.4	15.8	1.0	3.8	6.0	14.3	80.0
		Travel cost (€)	4.9	5.7	0.0	2.0	3.0	5.0	28.0
		Walking time (min)	7.5	5.1	0.0	3.8	7.0	10.0	25.0
		Waiting time (min)	6.3	4.1	0.0	4.8	5.0	7.8	21.0
		Travel time (min)	15.7	11.2	3.0	9.5	14.5	20.0	60.0
Internal combustion vehicle	Commuting	Travel distance (km)	28.6	20.2	2.0	12.0	23.5	41.0	95.0
		Walking time (min)	4.7	8.5	0.0	1.0	2.0	5.0	60.0
		Travel time (min)	30.4	16.3	3.0	19.0	30.0	44.0	90.0
		Parking cost (€)	1.5	4.9	0.0	0.0	0.0	0.0	30.0
		Parking searching time (min)	2.1	2.8	0.0	0.0	1.0	2.0	18.0
	Non-commuting	Travel distance (km)	12.7	19.7	1.0	4.0	5.5	12.0	100.0
		Walking time (min)	3.7	6.9	0.0	1.0	2.0	5.0	60.0
		Travel time (min)	15.0	14.9	1.0	5.0	10.0	20.0	100.0
		Parking cost (€)	2.2	4.7	0.0	0.0	0.0	3.0	31.0
		Parking searching time (min)	2.6	2.6	0.0	0.0	2.0	4.3	13.0
Electric vehicle	Commuting	Travel distance (km)	44.1	29.7	1.0	19.0	40.0	65.0	100.0
		Walking time (min)	3.6	7.4	0.0	1.0	2.0	4.0	60.0
		Travel time (min)	41.5	24.2	1.0	24.0	40.0	60.0	120.0
		Parking cost (€)	0.6	2.2	0.0	0.0	0.0	0.0	12.0
		Parking searching time (min)	1.0	1.7	0.0	0.0	0.0	1.0	9.0
	Non-commuting	Travel distance (km)	20.2	23.6	1.0	5.0	10.0	25.0	100.0
		Walking time (min)	2.7	4.0	0.0	1.0	2.0	4.0	38.0
		Travel time (min)	20.9	18.6	2.0	10.0	15.0	25.0	100.0
		Parking cost (€)	1.9	4.0	0.0	0.0	0.0	2.0	20.0
		Parking searching time (min)	1.5	2.1	0.0	0.0	1.0	2.0	11.0
Bike	Commuting	Travel distance (km)	5.2	4.3	1.0	3.0	4.0	7.0	33.0
		Walking time (min)	4.5	8.1	0.0	1.0	1.0	5.0	59.0
		Travel time (min)	18.6	11.7	5.0	10.0	15.0	24.0	93.0
		Parking searching time (min)	0.6	1.4	0.0	0.0	0.0	1.0	10.0
	Non-commuting	Travel distance (km)	3.7	2.9	1.0	2.0	3.0	5.0	20.0
		Walking time (min)	2.7	4.4	0.0	0.0	1.0	3.0	26.0
		Travel time (min)	12.2	9.0	2.0	7.0	10.0	15.0	60.0
		Parking searching time (min)	0.9	1.5	0.0	0.0	0.0	1.0	10.0

4. Model specification and estimation

In this study, we develop a Random Parameters Rank-Ordered Logit (RPROL) model to analyse the collected ranking preference data. The RPROL is similar to a mixed logit model, in that it introduces random parameters, allowing to capture both preference heterogeneity among respondents and the correlation between the two V2G-related alternatives. This specification relaxes the independence of irrelevant alternatives (IIA) assumption by allowing taste parameters to vary across individuals and by allowing correlation between similar alternatives. These features cannot be explicitly modelled with either a Multinomial Logit or a Latent Class Logit model.

We estimate two models: one including private V2G-enabled EVs as an alternative and one excluding them. In the model that includes private V2G-enabled EVs, respondents face three alternatives (current mode, private EV with V2G, and V2G-enabled carsharing). In the second model, respondents are assumed not to own a private EV with V2G in the future, so only two alternatives remain (current mode and V2G-enabled carsharing).

The modelling approach adopted in this study is a switching model (De Luca and Di Pace, 2015; Liao et al., 2024), which conditions individuals' choices on their current mode of transport and analyses the likelihood of switching to alternative V2G-enabled options. Instead of estimating separate models for each current mode, the data are pooled across all modes within a single framework. This approach allows investigating whether key parameters are the same across current-mode groups when evaluating V2G-related alternatives.

The utility for using the current mode of transport is defined as:

$$U_{SQ_{nt}} = V_{SQ_{nt}} + \epsilon_{SQ_{nt}} = \sum_{k=1}^{K} I_{knt}\beta_k^X X_{knt} + \epsilon_{SQ_{nt}} \tag{1}$$

where $U_{SQ_{nt}}$ denotes the utility for using the current mode, Status Quo (SQ), for respondent n in choice task t. $V_{SQ_{nt}}$ represents the deterministic part of the utility which is constructed as a weighted sum of the attribute values X_{knt} associated with mode k. β_k^X denotes the estimated parameters associated with attribute X, where X refers to a specific attribute rather than its value. The indicator I_{knt} takes the value 1 if mode k is respondent n's current mode in choice task t, and 0 otherwise, ensuring that only the attributes of the SQ alternative contribute to the utility. The error term $\epsilon_{SQ_{nt}}$ captures unobserved factors and is assumed to follow an independently and identically distributed extreme value type I distribution.

The utility of using the other two V2G-enabled alternatives is defined as follows:

$$U_{jnt} = V_{jnt} + \epsilon_{jnt} = \sum_{k=1}^{K} I_{knt}ASC_{jk} + \beta_{jk}^X X_{jnt} + \beta_j^S S_n + \mu_{\text{shared}} + \mu_{jn} + \epsilon_{jnt} \tag{2}$$

Here, ASC_{jk} denotes the alternative-specific constant for alternative j when the current mode of transport is k. The index $j \in \{PRV, CS\}$, where PRV represents the private EV with V2G and CS represents the carsharing EV with V2G. The parameters β_{jk}^X are associated with the attribute vector X. These parameters are specified as alternative-specific and conditional on current mode usage, rather than being generic across alternatives. This specification is motivated by two considerations. First, previous studies have shown that alternative-specific parameters may improve model fit compared with generic ones (Liao et al., 2024; Mo et al., 2021; Reck et al., 2021). Second, individuals currently using different modes may have distinct tastes or perceptions regarding the same attributes.

The variables of the socio-demographic characteristics are denoted as S_n, with corresponding parameters β_j^S capturing their influence on choosing the two V2G-enabled options. These effects are included for both alternatives, since socio-demographic characteristics may affect preferences for each option differently.

To capture individual-level unobserved heterogeneity and the unobserved similarity between the two V2G alternatives, we specify an error-components structure. A shared random parameter μ_{shared} enters the utility function of both V2G alternatives, while an alternative-specific random term μ_{jn} captures additional unobserved heterogeneity for alternative j. These primitive random terms are assumed to follow normal distributions with zero means and estimated standard deviations. They are assumed to be independent across individuals and mutually independent at the primitive level. However, because μ_{shared} enters both V2G alternatives, it induces covariance between the private EV with V2G and carsharing EV with V2G alternatives. Thus, the model captures the main inter-alternative correlation of interest without estimating a fully unrestricted variance-covariance matrix. The random terms are held constant across the repeated choice tasks of the same respondent, thereby accounting for panel effects.

In the scenario where all the three alternatives are available, the status quo (SQ), and two switches, we define the choice set $C_{nt} = \{SQ, PRV, CS\}$. We suppose a_{nt}^i represents the i^{th} ranked alternative in choice task t for individual n. By construction, the ranking satisfies the following inequalities: $U_{a_{nt}^1} > U_{a_{nt}^2} > U_{a_{nt}^3}$. Therefore, a complete ranking can be expressed as two sequential choices: the respondent first selects the most preferred alternative from the full set of three and then selects the second most preferred alternative from the two remaining. Thus, the conditional probability that individual n provides the ranking $(a_{nt}^1, a_{nt}^2, a_{nt}^3)$ in choice task t is given by:

$$P_{nt} = \prod_{i=1}^{2} \frac{\exp\left(V_{a_{nt}^i}\right)}{\sum_{a\in C_{nt}\left\{a_{nt}^1,\cdots,a_{nt}^{i-1}\right\}}\exp(V_a)} \tag{3}$$

Since each individual completes multiple choice tasks, panel effects are incorporated to capture the correlation between the choices from the same individual. Thus, the conditional probability that individual n produces ranking across tasks $t = 1, \cdots, T_n$ is:

$$P_n = \prod_{t=1}^{T_n}\prod_{i=1}^{2} \frac{\exp\left(V_{a_{nt}^i}\right)}{\sum_{a\in C_{nt}\setminus\left\{a_{nt}^1,\cdots,a_{nt}^{i-1}\right\}}\exp(V_a)} \tag{4}$$

Finally, the unconditional probability is obtained by integrating over the distribution of random parameters μ:

$$P_n = \int \left(\prod_{t=1}^{T_n}\prod_{i=1}^{2} \frac{\exp\left(V_{a_{nt}^i}\right)}{\sum_{a\in C_{nt}\setminus\left\{a_{nt}^1,\cdots,a_{nt}^{i-1}\right\}}\exp(V_a)} \right) f(\mu)d\mu \tag{5}$$

where $f(\mu)$ denotes the probability density function of the random parameters.

In the scenario where only two alternatives are available, we define the choice set as $C_{nt} = \{SQ, CS\}$. In this case, the respondent selects the preferred alternative between the two, which is equivalent to the standard binary logit formulation. Importantly, the shared random parameter that captures correlation between the two V2G-enabled modes is excluded from the utility specification (2), as a private EV with V2G is no longer part of the choice set. Alternatively, the task can be interpreted as a ranking of two alternatives, although only a single choice is required. The unconditional probability that individual n makes a sequence of choices across tasks $t =$

Table 4
Estimated parameters and model summary for the commuting scenario with three alternatives.

Parameters	Value	Std err	p-value
Alternative specific constants (reference is the status quo)			
V2G_PRV: ASC (current PT users)	−0.58	0.78	0.46
V2G_PRV: ASC (current ICV users)	**−1.00**	0.37	0.01
V2G_PRV: ASC (current EV users)	*−0.87*	0.53	0.10
V2G_PRV: ASC (current Bike users)	**−3.97**	0.71	0.00
V2G_CS: ASC (current PT users)	**−1.68**	0.78	0.03
V2G_CS: ASC (current ICV users)	**−2.91**	0.41	0.00
V2G_CS: ASC (current EV users)	**−2.82**	0.51	0.00
V2G_CS: ASC (current Bike users)	**−5.19**	0.77	0.00
Standard deviation (μ)			
V2G_BOTH: standard deviation	**1.22**	0.09	0.00
V2G_PRV: standard deviation	**1.19**	0.10	0.00
V2G CS: standard deviation	**1.02**	0.11	0.00
Mode attributes for the status quo alternative (β_k^X)			
SQ: Travel cost (all respondents)	**−0.07**	0.03	0.01
SQ: Travel time (current PT users)	**−0.04**	0.01	0.01
SQ: Travel time (current Bike users)	−0.03	0.05	0.53
SQ: Waiting time (current PT users)	**−0.23**	0.07	0.00
SQ: Parking cost (current ICV and EV users)	0.04	0.07	0.56
SQ: Parking searching time (current ICV, EV, and Bike users)	−0.01	0.07	0.91
SQ: Walking time (all respondents)	*−0.03*	0.02	0.08
SQ: SoC (current EV users)	**0.01**	0.00	0.01
Mode Attributes for the V2G alternatives (β_{jk}^X)			
V2G_BOTH: Travel cost (current PT users)	**−0.15**	0.03	0.00
V2G_BOTH: Travel cost (current ICV and EV users)	**−0.08**	0.03	0.00
V2G_PRV: Travel cost (current Bike users)	**−0.51**	0.24	0.03
V2G_CS: Travel cost (current Bike users)	−0.25	0.25	0.32
V2G_BOTH: Travel time (current PT users)	**−0.08**	0.01	0.00
V2G_BOTH: Travel time (current Bike users)	−0.15	0.12	0.22
V2G_BOTH: Walking time (all respondents)	**−0.06**	0.01	0.00
V2G_BOTH: Minimum guaranteed battery range (all respondents)	0.00	0.00	0.11
V2G_PRV: Parking searching time (all respondents)	−0.02	0.01	0.13
Socio-demographic variables (β_j^S)			
V2G_PRV: owning EVs	**1.62**	0.34	0.00
V2G_PRV: having kids	*−0.26*	0.16	0.10
V2G_CS: monthly household income < = €3000	**0.60**	0.15	0.00
V2G_CS: Age < = 35	**0.32**	0.15	0.03
V2G_CS: owning EVs	**1.20**	0.33	0.00
Model summary	**Value**		
Nr. of parameters	33		
Sample size	730		
Null log likelihood	−3035.99		
Final log likelihood	−2586.42		
Likelihood ratio test (null)	899.14		
Rho square (null)	0.15		
Rho bar square (null)	0.14		
Akaike Information Criterion	5238.83		
Bayesian Information Criterion	5390.40		

Note:
Estimates in bold are significant at $p < 0.05$. Estimates in italic are significant at $p < 0.10$.
SQ refers to the status quo alternative (respondent’s current mode).
V2G_PRV, V2G_CS, and V2G_BOTH denote the private EV with V2G, the carsharing EV with V2G, and parameters shared across both V2G alternatives, respectively.

$1, \cdots, T_n$ is then given by:

$$P_n = \int \left(\prod_{t=1}^{T_n} \frac{\exp\left(V_{a_{nt}^1}\right)}{\sum_{a \in C_{nt}} \exp(V_a)} \right) f(\mu) d\mu \tag{6}$$

Using this model, we are able to obtain parameter estimates by maximising the log-likelihood of the observed choice data.

5. Results

This section presents the estimation results for two main scenarios: one in which all individuals are assumed to own a private EV with V2G capability, and another in which they are assumed not to own such a vehicle. The analysis is conducted separately for commuting and non-commuting trips.

For all the scenarios, we estimated the models using Biogeme (Bierlaire, 2020) with 2,000 normal Halton (based 2) random draws. As described earlier, the model was initially specified with alternative-specific parameters conditional on the current mode of transport. During estimation, several of these parameters were found to be statistically indistinguishable based on Wald tests and likelihood-ratio tests. The corresponding parameters were therefore estimated as a single coefficient in the final specification. The results presented in this section refer to this final specification. Moreover, all parameters are retained in the reported estimation table regardless of statistical significance, to ensure transparency and to show the full set of behavioural mechanisms tested in the model (Hess et al., 2025). This is important because statistically insignificant parameters may still provide useful behavioural information, particularly when they relate directly to the research questions.

5.1. Scenarios assuming ownership of a private EV with V2G

5.1.1. Estimation results for commuting trips

Table 4 reports the estimated parameters and the model summary. Variable names follow the format [Alternative label]: [Attribute] (user group), where the user group refers to respondents' status-quo mode. For alternative abbreviations, SQ denotes the status quo alternative (the respondent's current mode). V2G_PRV, V2G_CS, and V2G_BOTH denote the private EV with a V2G alternative, the carsharing EV with a V2G alternative, and the parameters shared across both V2G alternatives, respectively. PT, ICV, EV, and Bike denote respondent groups by status-quo mode: public transport, internal combustion vehicle, electric vehicle, and bicycle, respectively. For example, V2G_BOTH: travel cost (PT users) denotes the travel-cost parameter shared across both V2G alternatives and is estimated for respondents whose status quo mode is public transport.

5.1.1.1. Alternative-specific constants (ASCs) and random parameters. The ASC for the SQ alternative is normalised to zero and therefore not estimated, allowing the ASCs for the V2G options to be interpreted relative to the respondent's current mode. Overall, the results indicate strong inertia towards the current mode: all significant ASCs for the V2G alternatives are negative, indicating that after controlling for cost, travel time, walking time, and other observed attributes, respondents derive lower utility from both V2G options than from their SQ. Because the SQ alternative and the set of mode-specific attributes differ across current-mode user groups, the utility specification is not identical between groups; therefore, the magnitudes of the ASCs cannot be compared to derive preference differences between groups. However, the sign and statistical significance of the ASCs remain informative within each group, as they capture the residual (unexplained) component of utility after controlling for the observed attributes, rather than providing evidence that one group prefers V2G more than another.

Across current-mode groups, the ASC results show a consistent pattern: the carsharing EVs with V2G are associated with a more negative (and often significant) ASC than the private EV-with-V2G alternative, while both V2G options typically have negative ASCs relative to respondents' current modes. For PT users, the ASC for private EVs with V2G is not significantly different from the SQ, whereas the carsharing option has a significant negative ASC, indicating a negative residual utility for carsharing after accounting for observed attributes. ICV and EV users exhibit a strong tendency to retain private vehicle ownership, reflected in particularly negative ASCs for the carsharing alternative. Bike users show strong resistance to both V2G alternatives, reflecting the high attractiveness of cycling compared with switching to any V2G-based car mode.

All estimated standard deviations for the three random parameters are statistically significant. In particular, the significant standard deviations of the alternative-specific error terms show substantial taste heterogeneity across individuals for both private EVs with V2G and carsharing EVs with V2G. The significant standard deviation for the shared error component suggests that respondents perceive the two V2G options as similar: individuals inclined to choose a private V2G-enabled EV are also more likely to consider the carsharing V2G alternative.

5.1.1.2. Attributes for SQ alternatives. Most estimated coefficients for the SQ attributes have the expected signs. The coefficients for cost, travel time, waiting time, and walking time are significantly negative, indicating that higher values of these attributes reduce the utility of the current mode. For current EV users, the coefficient on the SOC variable in the SQ utility is positive and statistically significant, indicating that higher SOC increases the attractiveness of their current EV.

Some SQ attributes are not statistically significant, such as parking cost and parking search time, possibly because many commuting trips involve free or predictable parking at workplaces. The travel time coefficient for bike users is also insignificant, even though cycling speeds are lower than those of car modes. This suggests that habitual cyclists are less sensitive to travel time, likely due to the short, predictable nature of cycling trips and the intrinsic benefits of cycling (health, enjoyment, independence), which reduce the importance of time compared with other modes (Cornet et al., 2022). For the SQ, attribute values are respondent-specific and do not vary across tasks for the same individual. Consequently, parameter identification relies on between-person variation (differences in

Table 5
Estimated parameters and model summary for non-commuting scenario with three alternatives.

Parameters	Value	Std err	p-value
Alternative specific constants (reference is the status quo)			
V2G_PRV: ASC (current PT users)	−0.64	1.07	0.55
V2G_PRV: ASC (current ICV users)	−0.38	0.52	0.46
V2G_PRV: ASC (current EV users)	−0.71	0.50	0.15
V2G_PRV: ASC (current Bike users)	**−4.38**	0.74	0.00
V2G_PRV: ASC (shopping)	−0.26	0.38	0.49
V2G_CS: ASC (current PT users)	−0.84	1.08	0.43
V2G_CS: ASC (current ICV users)	**−1.38**	0.55	0.01
V2G_CS: ASC (current EV users)	**−1.59**	0.48	0.00
V2G_CS: ASC (current Bike users)	**−5.12**	0.74	0.00
V2G_CS: ASC (shopping)	−0.55	0.40	0.17
Standard deviation (μ)			
V2G_BOTH: Standard deviation	**1.56**	0.13	0.00
V2G_PRV: Standard deviation	**1.15**	0.09	0.00
V2G_CS: Standard deviation	**1.41**	0.12	0.00
Mode attributes for the status quo alternative (β_k^X)			
SQ: travel cost (all respondents)	−0.05	0.04	0.20
SQ: travel time (current PT users)	0.00	0.06	0.96
SQ: travel time (current Bike users)	0.05	0.05	0.34
SQ: waiting time (current PT users)	**−0.27**	0.09	0.00
SQ: parking cost (current ICV and EV users)	**−0.13**	0.04	0.00
SQ: parking search time (current ICV and EV users)	−0.05	0.08	0.55
SQ: parking search time (current Bike users)	**−0.09**	0.02	0.00
SQ: walking time (all respondents)	−0.02	0.04	0.64
SQ: SOC (current EV users)	0.00	0.00	0.11
Mode Attributes for the V2G alternatives (β_{jk}^X)			
V2G_BOTH: travel cost (current PT users)	**−0.23**	0.07	0.00
V2G_BOTH: travel cost (current ICV and EV users)	**−0.11**	0.04	0.00
V2G_BOTH: travel cost (current Bike users)	**−0.90**	0.29	0.00
V2G_BOTH: travel time (current PT and Bike users)	−0.02	0.03	0.40
V2G_BOTH: walking time (all respondents)	**−0.06**	0.01	0.00
V2G_BOTH: minimum guaranteed battery range (all respondents)	0.00	0.00	0.18
V2G_PRV: parking searching time (current PT, ICV, and EV users)	−0.01	0.02	0.59
V2G_PRV: parking searching time (current Bike users)	**−0.09**	0.02	0.00
Socio-demographic variables (β_j^S)			
V2G_PRV: owning EVs	**1.17**	0.21	0.00
V2G_PRV: age>65	*0.31*	0.17	0.06
V2G_BOTH: having kids	**−0.79**	0.35	0.02
Model summary	**Value**		
Nbr of parameters	33		
Sample size	716		
Null log likelihood	−2977.76		
Final log likelihood	−2269.42		
Likelihood ratio test (null)	1416.69		
Rho square (null)	0.238		
Rho bar square (null)	0.227		
Akaike Information Criterion	4604.83		
Bayesian Information Criterion	4755.77		

Note:
Estimates in bold are significant at $p < 0.05$. Estimates in italic are significant at $p < 0.10$.
SQ refers to the status quo alternative (respondent’s current mode).
V2G_PRV, V2G_CS, and V2G_BOTH denote the private EV with V2G, the carsharing EV with V2G, and parameters shared across both V2G alternatives, respectively.

attribute values across respondents) rather than within-person variation (variation across repeated tasks for the same respondent). This makes them less strongly identified than parameters based on experimentally varied attributes. The coefficients can still be reliable if there is sufficient variation in reported SQ values across the sample, which is generally acceptable when these variables are treated as exogenous (Chorus and Kroesen, 2014; Liao et al., 2024).

5.1.1.3. Attributes for the two V2G-enabled alternatives. The two V2G-enabled alternatives share several attributes, such as travel costs, travel time, walking time, and minimum guaranteed battery range, as in essence both alternatives are EVs with V2G capability. However, these attributes are estimated separately for each user group to capture differences in perceptions.

Regarding travel costs, we observe that current ICV and EV users perceive the costs of the two V2G-related alternatives as equivalent, likely due to prior experience with car ownership and driving. In contrast, PT users and bike users show negative but different sensitivities to travel cost. Bike users, in particular, perceived the cost of using private EVs with V2G negatively but were indifferent to the cost of carsharing services, likely due to their limited usage experience of carsharing in their daily mobility choices.

Regarding travel time, PT users perceived travel time in V2G options more negatively than in their current mode, indicating greater time sensitivity when considering a switch. Bike users were insensitive to travel time for V2G alternatives, consistent with the short, predictable, and self-controlled nature of cycling trips. No travel time parameters were estimated for ICV or EV users, since these modes would have identical travel times across alternatives for the same trip.

Interestingly, the minimum guaranteed battery range for both V2G alternatives is insignificant. In practice, this guaranteed range is typically suggested to keep within a safe SOC window between 20% and 80–90% to protect battery health, as deep discharges and full charges can accelerate degradation (Wei et al., 2022). Given that most commuting distances fall well within the available range even at a 20% guaranteed charge, respondents are unlikely to experience range anxiety when making mode choice for a specific trip, which helps explain the lack of significance.

5.1.1.4. Socio-demographic characteristics. We tested all socio-demographic variables and report only the significant ones in Table 4. Results show that individuals who own a private EV show a stronger preference for both V2G-enabled EV options, reflecting their existing knowledge and experience with EV usage. However, they are more likely to favour private EVs with V2G over carsharing. Lower-income households (monthly household income$\leq$€3000) are more likely to adopt a V2G-enabled carsharing EV, as the cost savings associated with V2G make the service more accessible across different socio-economic groups. Younger respondents are also more inclined towards carsharing with V2G, likely due to their greater openness to adopting new technologies. Having children shows a marginally significant effect (–0.26, $p = 0.10$), indicating a negative influence, although the relationship is not strongly significant.

5.1.2. Estimation results for non-commuting trips

In the non-commuting scenario, the model further distinguishes between specific trip purposes, namely leisure and shopping trips. Compared with the commuting scenario, additional explanatory variables are introduced to examine whether the trip purpose affects individuals' choices between the two V2G-enabled options. The estimation results and model summary are presented in Table 5.

5.1.2.1. ASC values and random parameters. In the non-commuting scenario, the estimated ASCs that are statistically significant remain negative, which is consistent with the results for the commuting scenario. This indicates a negative residual utility for the V2G-enabled alternatives relative to the SQ, after accounting for the attributes included in the model. These findings suggest that respondents generally exhibit reluctance to switch from their current modes to V2G-enabled alternatives.

However, several ASCs that were previously significantly negative in the commuting scenario become insignificant in the non-commuting scenarios, including the ASC for private EVs with V2G among ICV and EV users, and the ASC for carsharing EVs with V2G among PT users. This suggests that respondents' evaluation criteria differ by trip purpose. Commuting behaviour tends to be more habitual and reliability-oriented, whereas non-commuting decisions are more flexible and context-dependent. Overall, respondents show greater openness to V2G-enabled alternatives for non-commuting trips. PT users exhibit a significantly negative ASC for carsharing in commuting scenarios, but not in non-commuting scenarios, indicating a greater willingness to consider carsharing for occasional travel. For ICV and EV users, resistance to private EVs with V2G disappears in non-commuting scenarios, although carsharing remains strongly disfavoured. This suggests that car-ownership habits persist, but may be relaxed for discretionary trips. Bike users exhibit significantly negative ASCs for both V2G options across all scenarios, which is consistent with a strong tendency to remain with cycling.

The results further indicate that, for non-commuting trips, the specific trip purpose, whether shopping or leisure, does not significantly influence preferences for V2G alternatives. This is reflected in the insignificant ASC values for shopping across both V2G alternatives. All three standard deviations of the random parameters remain significant in the non-commuting scenarios, confirming the presence of taste heterogeneity across respondents and the perceived similarities of the two V2G options.

5.1.2.2. Attributes of the SQ alternative. Overall, SQ attribute sensitivities differ notably for non-commuting trips. Travel cost and travel time become less important, whereas parking-related factors gain prominence. This suggests that respondents pay greater attention to monetary costs and travel time for routine and repeated trips, but less so for discretionary trips, which occur less frequently and may be influenced by other factors, such as enjoyment. Compared with commuting trips, parking cost has a significant negative effect on the choice of using respondents' current cars. This suggests that parking expenses weigh more heavily in discretionary trips, which aligns with the relatively high cost of public and commercial parking in the Netherlands. The coefficient for parking search time among bike users becomes significant in the non-commuting scenarios, whereas it is insignificant in the commuting scenarios. This indicates that cyclists value parking convenience when travelling to shopping or leisure destinations, where secure bicycle parking may be more difficult to find. For current EV users, SOC no longer has a significant impact on the choice of the SQ alternative in the non-commuting scenarios.

5.1.2.3. Attributes of the V2G-enabled alternatives. For the V2G alternatives, the results show that the behavioural relevance of V2G attributes differs between commuting and non-commuting scenarios. The cost coefficients remain negative and significant for both V2G-enabled alternatives and for all user groups. In addition, the travel time coefficients for PT and bike users become insignificant, suggesting that time considerations are less influential in leisure and shopping contexts than in daily commuting. The walking time coefficient remains negative and significant for all groups, reflecting its persistent disutility, while the coefficient for minimum guaranteed battery range remains behaviourally irrelevant. The parking search time coefficient for bike users becomes significant and negative, indicating that parking convenience becomes a barrier when cyclists occasionally consider car use for discretionary trips. By contrast, parking search time remains insignificant for PT, ICV, and EV users. Taken together, these results indicate that, for non-commuting travel, cost, walking time, and, for bike users, parking convenience are the primary factors shaping respondents' evaluations of V2G alternatives.

5.1.2.4. Socio-demographic characteristics. For the socio-demographic variables, the effect of EV ownership remains positive but is now significant only for the private V2G alternative, indicating that EV owners prefer to rely on their own vehicles rather than shared options for leisure or shopping trips, where flexibility and convenience are valued more. The influence of having children also becomes more pronounced in the non-commuting context, suggesting that family-related constraints weigh more heavily on discretionary travel, where certainty and simplicity are prioritised. Income is no longer a significant factor, implying that price sensitivity diminishes for occasional leisure or shopping trips. Finally, older adults show a greater inclination towards using private EVs with V2G for non-commuting purposes, likely reflecting higher purchasing power and an interest in the environmental or comfort-related advantages of V2G.

5.2. Scenarios without private EV ownership with V2G

In this experiment, the choice set is reduced to two alternatives: the SQ and a carsharing EV with V2G. This setup reflects a future scenario in which individuals do not own a V2G-capable private EV. In this context, the carsharing option captures all variation in respondents' willingness to engage with V2G services. Although the two-alternative scenario provides some additional insights, its overall patterns are broadly consistent with those of the main three-alternative model. This section, therefore, highlights only the key results; full estimation results are presented in Appendix B (Table B.1 for commuting and Table B.2 for non-commuting).

5.2.1. Estimation results for commuting trips

For commuting trips, the reduced model yields mostly negative and statistically significant ASCs for the V2G alternatives, indicating a negative residual utility relative to the SQ and hence a continued reluctance to switch away from the current mode, conditional on the included attributes. The only exception is PT users, whose ASC for carsharing becomes insignificant, indicating greater openness to carsharing when private V2G ownership is unavailable. At the same time, the ASC values for carsharing become more negative than in the three-alternative model. This pattern does not necessarily indicate a stronger aversion to carsharing; rather, it reflects that in the absence of a private EV with V2G, the ASC value of a carsharing EV with V2G absorbs the full residual attitude towards V2G.

The standard deviation of the carsharing ASC increases substantially compared to the three-alternative model, reflecting wider behavioural heterogeneity when only one V2G alternative is offered. Some respondents shift towards carsharing, while others move away from V2G entirely.

When private EVs with V2G options are unavailable, the cost coefficient for carsharing with V2G among ICV and EV users becomes similar to that of PT users. Socio-demographic patterns remain broadly consistent with the main model: EV ownership remains the most influential factor, and carsharing continues to attract low-income users, supporting the view that V2G-enabled carsharing can serve as a socially inclusive entry point to electrified mobility. All other attributes follow the same patterns as in the three-alternative specification.

5.2.2. Estimation results for non-commuting trips

For non-commuting trips, the ASC for carsharing remains negative and significant for all user groups, with PT users now also displaying a significantly negative ASC. This indicates that, in the absence of a private V2G option, carsharing with V2G is not an attractive alternative for public transport users. The substantial increase in the estimated standard deviation for the carsharing alternative reflects the greater preference heterogeneity when only one V2G option is available for non-commuting travel.

In the two-alternative non-commuting model, several parameters lose significance compared with the three-alternative specification. Walking time for the SQ becomes weakly significant, suggesting that access and convenience gain importance when respondents compare their current mode directly with a shared V2G option, while cost sensitivity to carsharing becomes insignificant for ICV and EV users, implying that their decisions are driven less by the price differences and more by preferences for ownership.

In this scenario, the socio-demographic variables show limited statistical significance. This does not imply homogeneous preferences; rather, part of the individual heterogeneity is likely captured by the random ASC term, reducing the explanatory power of observed socio-demographic variables.

5.3. Aggregation of estimation results

To obtain aggregate insights into the distribution of choice probabilities across alternatives, we use the estimated model to calculate choice probabilities for each respondent and choice task. These probabilities are generated using the specified utility functions, the estimated parameters, and Monte Carlo simulation over the random taste parameters. The task-level probabilities are first averaged across the choice tasks of each respondent to obtain person-level choice probabilities and then averaged across respondents to derive aggregate shares for each alternative. For the aggregation analysis, a reduced specification was re-estimated after removing clearly insignificant parameters, and this reduced model was used to calculate the aggregate shares. This approach maintains transparency in the behavioural interpretation of the full model while reducing the influence of noisy parameters in the prediction stage.

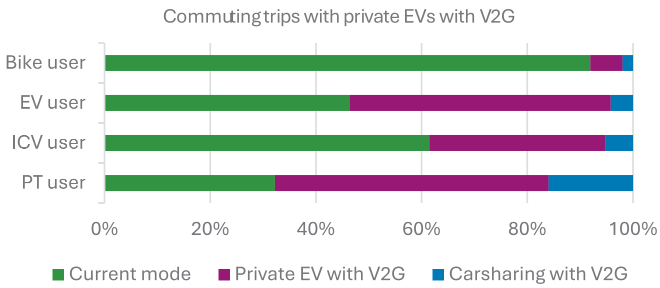
Because the recruited sample is not fully representative of the Dutch population, simple averaging of these person-level probabilities would yield biased aggregate shares. To correct for this, we apply iterative proportional fitting (raking) to construct per-respondent weights such that the weighted sample proportions match the population proportions for all characteristics listed in Table 2. The raking algorithm iteratively rescales the respondent weights until the weighted sample marginals simultaneously match the population marginals on all the dimensions. The resulting weight for respondent n reflects how much that respondent should count to make the sample representative of the population on these characteristics.

Aggregation is performed separately for each current-mode user group (PT, ICV, EV, and Bike users), so that the predicted adoption shares can be interpreted segment by segment. Within each group $\boldsymbol{g}$, the weighted average of person-level choice probabilities is computed as:

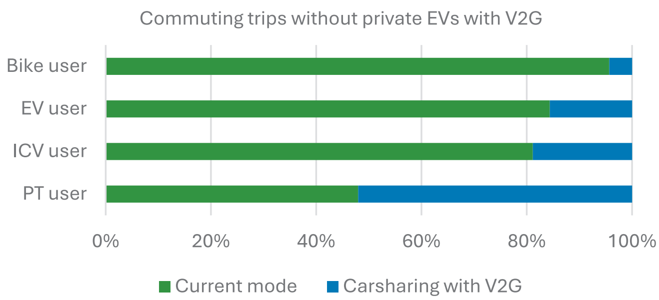
$$\overline{P}_j^{(g)} = \frac{\sum_{n\in g} w_n \cdot \overline{P}_{nj}}{\sum_{n\in g} w_n}$$

where $\overline{P}_{nj}$ is respondent n's mean simulated probability of choosing alternative j, averaged across the choice tasks t, and w_n is the raking weight.

These weighted aggregated shares can be interpreted as follows: if the overall socio-demographic composition of our sample matched that of the Dutch population in terms of gender, age, education, and presence of children, the predicted share of choices for each alternative within each current-mode user group would be as reported. The raking weights are constructed once on the full sample and then applied within each current-mode group during aggregation; this corrects for socio-demographic misrepresentation but does



(a)



(b)

Fig. 5. Predicted mode choice shares for commuting trips: (a) with private EVs equipped with V2G; (b) without private EVs equipped with V2G.

not adjust for the relative size of the four current-mode groups in the population. The reported shares therefore, refer to choice probabilities conditional on the current mode rather than to a single national market share. Two limitations should be noted. First, the shares are derived from stated rather than revealed preferences and may therefore be subject to hypothetical bias. We mitigate this risk by anchoring the choice tasks in respondents' own travel context: travel distances, times, and costs were customised to match each respondent's typical commuting and non-commuting trips (see Section 3.1), so that the trade-offs presented were concrete rather than abstract. Moreover, as V2G charging is not yet available on the Dutch market, stated preference remains the only feasible source of evidence at this stage. Second, the raking corrects for observable socio-demographic misrepresentation only and cannot account for unobserved selection.

Figs. 5 and 6 present the predicted mode choice shares for commuting and non-commuting trips, with and without access to a private EV equipped with V2G. The two figures exhibit similar patterns and share the following key observations.

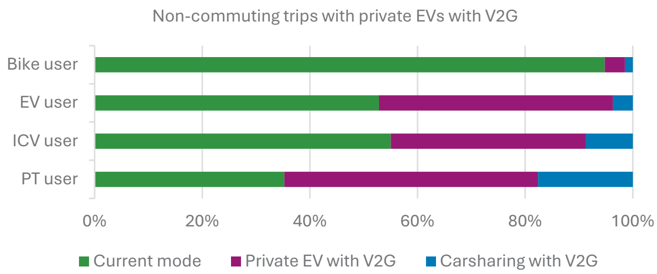
First, carsharing with V2G becomes much more attractive when private V2G with EVs are not available. Across all user groups, the absence of private V2G access results in higher shares of carsharing. However, the shift varies considerably by group. PT users show the largest increase in the choice of carsharing with V2G, whereas bike users show the least change. This heterogeneity suggests that shared V2G services would benefit from targeted strategies tailored to specific user segments, rather than a uniform approach. Second, bicycle users show the strongest tendency to retain their current mode, with very limited movement toward either private EVs or carsharing V2G options. This suggests a strong behavioural lock-in for this group. Third, across all user groups, a private EVs with V2G is generally preferred over a carsharing EV with V2G when the private option is available, reflecting a consistent preference for ownership-based solutions. The figure suggests that, if the policy goal is to promote overall V2G adoption, facilitating private V2G ownership is far more effective than relying on V2G carsharing alone.

6. Discussion and policy implications

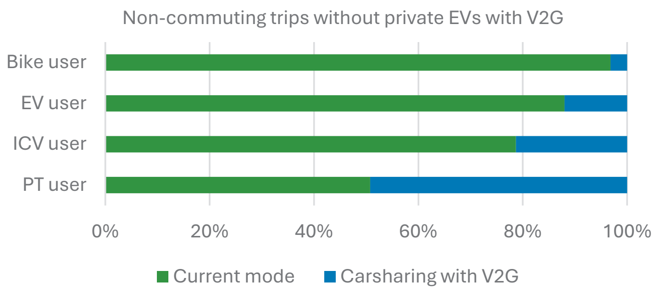
The results highlight that the potential of V2G adoption and the role of shared mobility vary substantially across user groups and trip purposes. Policies should therefore be differentiated, targeting specific behavioural barriers and motivations rather than promoting a uniform adoption strategy.

6.1. Group-targeted policy

People with different current modes of transport (public transport, ICVs, EVs, and bicycles) exhibit different behaviours and perceptions towards the two V2G-related modes. EV owners are the most promising early adopters of V2G. Their familiarity with EVs and established charging routines makes the transition to private V2G straightforward. However, they show a clear preference towards private EVs with V2G than carsharing options. This suggests that for this group, V2G is primarily perceived as an extension of existing private vehicle use rather than a shared mobility service. Policies aimed at EV users should therefore prioritise lowering the incremental costs of upgrading from conventional EV charging to V2G capability, rather than promoting shared V2G solutions to them.



(a)



(b)

Fig. 6. Predicted mode choice shares for non-commuting trips: (a) with private EVs equipped with V2G; (b) without private EVs equipped with V2G.

ICV users exhibit similar patterns, although their resistance to V2G is more context-dependent. While they show stronger rejection in commuting, their resistance weakens in non-commuting contexts, indicating greater flexibility outside routine travel. They represent a transitional group, that is, the potential future EV owners, whose adoption might be accelerated through visible, short-term economic benefits.

Both EV and ICV users exhibit clear sensitivity to travel costs when evaluating V2G-enabled alternatives. Given their strong preference for private ownership, financial benefits should primarily support private EVs with V2G, rather than relying on shared V2G solutions for these groups. In order to make the benefits more visible, clear communication of energy cost savings through V2G operation, and targeted information should be provided to increase the knowledge and trust towards V2G technology. For non-commuting trips, adoption can also be encouraged through parking-related incentives, such as free or discounted V2G-enabled parking at shopping and leisure destinations.

PT users exhibit lower unobserved disutility for the two V2G-related modes, suggesting that they are behaviourally open to considering V2G alternatives. At the same time, they exhibit strong sensitivity to the costs, travel time, waiting time, and walking time associated with public transport. Consequently, policies aimed at promoting V2G-based alternatives should ensure that these services are competitive with public transport in terms of pricing, minimise waiting times, and reduce walking distances between charging locations and final destinations. PT users are unlikely to be immediate adopters of privately owned V2G-capable vehicles, but they represent a potential adopter group in the longer term, particularly as they transition to EV ownership. In the short term, their engagement with V2G is more likely to occur through occasional use of shared mobility services, especially in contexts where public transport is less convenient or less reliable. From a policy perspective, improving real-time carsharing EVs availability information and providing booking guarantees can alleviate waiting and transfer burdens, which are important for PT users. Exposure to V2G through shared mobility services can further familiarise PT users with the technology, creating a gradual pathway towards private adoption. For non-commuting trips, V2G-enabled carsharing can be positioned as a convenient occasional-use option within integrated mobility platforms.

Bike users are the most loyal to their current mode of transport and exhibit the strongest rejection of both V2G options in commuting and non-commuting contexts. Compared with other user groups, they are particularly sensitive to the costs associated with using V2G-enabled EVs, likely because cycling entails no additional daily monetary costs. To encourage cyclists to consider V2G-based modes, targeted financial incentives may be required, for example, entry incentives or for occasional use. In non-commuting scenarios, parking searching time also plays a significant role in discouraging bike users from switching to V2G-based modes. Ensuring sufficient parking availability and minimising effort, the effort required to search for parking is therefore an important policy lever. This can be achieved, for instance, by reserving dedicated parking spaces for V2G users or by siting charging stations near parking facility entrances.

Given the high attractiveness of cycling for both commuting and non-commuting trips, V2G alternatives are unlikely to be competitive for this group; adoption is therefore expected to occur only in exceptional situations, such as long-distance travel or adverse weather conditions. Overall, large-scale V2G adoption among cyclists appears unlikely, suggesting that policy efforts may be more efficiently directed towards user groups with higher uptake potential.

Across all user groups, regardless of their current travel mode, walking time from the charging location to the final destination is consistently perceived as a negative influence in both commuting and non-commuting contexts. This indicates that V2G adoption is highly sensitive to access-related inconvenience. Policies that minimise additional walking effort relative to users' existing travel arrangements can therefore support V2G uptake without requiring fundamental changes in routine mobility behaviour. For example, this can be achieved through the optimal siting of charging stations near key destinations or activity centres, the integration of charging facilities into existing parking infrastructure, and the provision of on-street charging in high-demand areas.

6.2. Socio-demographic targeting

Policy strategies should be tailored to individuals with different sociodemographic backgrounds. Existing conventional EV owners should be prioritised as a primary target group to boost V2G usage in both private EVs with V2G and carsharing EVs with V2G, as V2G represents a relatively low-cost and intuitive extension of their current vehicle. For this group, policies should focus on facilitating V2G adoption by offering clear, direct financial incentives, simplified enrolment procedures, and transparent information on economic benefits. For non-EV users, initial exposure to V2G through carsharing services may lower entry barriers and encourage trial use, allowing them to gain experience with EVs and thereby facilitating subsequent adoption.

Households with children, who tend to be less willing to adopt V2G-based options, may be encouraged through strong assurances of service reliability and vehicle availability. For this group, policies should prioritise guaranteed access, reservation certainty, and sufficient vehicle supply during peak demand periods. Emphasising reliability and convenience, rather than cost savings alone, can help address their greater sensitivity to time constraints and schedule inflexibility.

Carsharing services with V2G-enabled EVs can be promoted as an affordable and flexible option for younger users and lower-income groups, for whom the upfront costs of vehicle ownership may be prohibitively high. By lowering financial and commitment barriers, shared V2G services can increase access to vehicle electrification and flexibility services without requiring private ownership. Policy measures to boost the attractiveness of carsharing services with V2G could include subsidised memberships, discounted usage during off-peak periods, or integration with public transportation subscriptions. Such approaches help ensure that the benefits of mobility electrification are distributed more equitably, rather than being concentrated among higher-income groups.

6.3. Trip purpose discussion

Trip purpose plays a critical role in shaping adoption barriers. Commuting trips require high levels of stability and reliability, leading travellers to rely more strongly on their habitual modes of transport and to exhibit greater resistance to switching. By contrast, non-commuting trips are associated with weaker attachment to existing modes and may therefore serve as more feasible entry points for early adoption of V2G-based options.

For commuting trips, users place greater emphasis on cost, travel time, and walking time, underscoring the importance of reliability and efficiency in daily travel. Policy measures targeting V2G adoption in commuting contexts should therefore prioritise competitive pricing, minimised access time, and seamless integration with existing travel routines. In non-commuting contexts, these factors become less dominant, whereas parking costs and parking search time become more important, highlighting the role of destination-side convenience. Accordingly, policies aimed at promoting V2G participation for leisure and shopping trips should focus on ensuring parking availability, reducing search effort through reserved or guaranteed parking, and strategically siting charging facilities near key destinations.

7. Conclusion and research outlook

This paper investigates how the availability of V2G technology in both private and shared mobility influences individuals' mode choice behaviour, with particular focus on transitions from current travel modes to privately owned V2G-capable EVs and V2G-enabled carsharing EVs. This perspective provides direct insights for future mobility policy but has been largely overlooked in the existing literature. To capture behavioural differences across the population, the analysis examines taste heterogeneity and the effects of socio-demographic characteristics and current travel modes across different trip purposes. A stated choice experiment was conducted, and the resulting data were analysed using a Random Parameters Rank-Ordered Logit (RPROL) model. The findings offer valuable insights into mode substitution patterns and inform policy strategies for promoting large-scale V2G adoption and equitable access to electrified mobility.

Taste heterogeneity is captured by introducing two random error terms for the V2G options and a shared error term to account for their unobserved correlation. The standard deviations are statistically significant in both commuting and non-commuting contexts, indicating that preferences are diverse and that people tend to perceive the two V2G alternatives similarly.

Across all model specifications, the statistically significant ASCs for the V2G alternatives are negative relative to the SQ, indicating lower residual utility after accounting for the included attributes and a strong underlying preference for retaining the current mode. Comparing the two V2G options, the carsharing alternative is often associated with a more negative and significant constant than the privately owned V2G-capable EV alternative, suggesting that ownership and control factors may play an important role in respondents' willingness to consider V2G participation. Nevertheless, V2G-enabled carsharing can play a complementary role by providing access to electrified mobility for individuals who lack the motivation or financial capacity to own a vehicle. To be effective, such services require high operational reliability and strong visibility to overcome trust and convenience barriers. Across all contexts, cost savings emerge as a key driver of V2G adoption, while long walking time and parking searching time could deter people from using V2G services. Interestingly, the minimum guaranteed battery range after V2G participation has limited influence on mode choice behaviour, provided it remains sufficient to cover the intended trip distance.

Behavioural patterns vary considerably across user groups. Current EV owners emerge as the most promising early adopters of V2G, reflecting their openness to technological upgrades. Users of ICVs exhibit behavioural patterns similar to those of EV owners. For both groups, preferences vary by trip purpose. For commuting trips, cost and walking time are important; for non-commuting trips, parking costs also play a significant role. Public transport users exhibit lower unobserved disutility toward V2G options, indicating greater openness to adoption; however, they remain highly sensitive to cost, travel time, waiting time, and walking time. As such, they represent potential switchers whose adoption depends on V2G services offering affordability and reliability comparable to public transport. Cyclists are the most strongly oriented towards the SQ, reflecting the habitual and structural attractiveness of cycling, which makes them a less relevant target group for V2G promotion. The findings also show that carsharing with V2G is more attractive to younger and lower-income users, while families with children are less inclined to use these options, likely due to concerns about reliability.

Future research can extend this study in several directions. First, incorporating attitudinal questions would help capture psychological factors, such as environmental concern, privacy, and social influence, that may affect mode choice. Second, the current survey included only four main user groups: PT, ICV, EV, and bike users, due to sample size constraints. Including a broader range of modes could improve the generalisability of the results. Third, the carsharing alternative could be refined by distinguishing between service types such as round-trip and free-floating systems, or by accounting for uncertainty in vehicle availability. Finally, as mode choice represents only one dimension of travel behaviour and does not fully capture the activity-travel patterns that shape V2G preferences, future research could examine travellers' willingness to adjust their activity schedules and vehicle-use patterns to maximise the benefits of V2G participation in private and shared mobility contexts.

CRediT authorship contribution statement

Qiaochu Fan: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Kuldeep Kavta:** Writing – review & editing, Validation, Supervision, Conceptualization. **Shadi Sharif Azadeh:** Writing – review & editing, Validation, Supervision, Conceptualization.

Gonçalo H.A. Correia: .

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. . Survey Introduction to V2G Technology

What is Vehicle-to-Grid (V2G)?

V2G technology allows an electric vehicle (EV) to do more than just drive. This EV can charge its battery from the power grid, but it can also send power back when it's needed. Think of this car like a "battery on wheels," storing energy when there's lots of it (like on sunny or windy days) and sharing it back when everyone needs more power.

A smart system manages all of this for the car owner. It picks the best times to charge the EV with cheap electricity and the best times to sell electricity back to the grid, so car owners save money and help keep the lights on for everyone. However, the car has to be plugged into special chargers.

Fig. A1. Illustration of V2G integration. Adapted from "Vehicle-to-Grid: Delivering the Future of Energy," Signature Electric, 2018. Retrieved from https://signatureelectric.ca/blog/vehicle-to-grid-delivering-the-future-of-energy/.

Opportunities and Challenges of the Technology

Save Money: Your car charges up when electricity is cheap and sells it back when prices are high.

Balance the Grid: V2G helps balance energy by storing extra renewable power and supplying it to the grid when it's needed.

Impact on the Environment: V2G makes it easier to use clean, renewable energy like solar and wind, cutting down on fossil fuels and lowering carbon emissions.

Battery Life: Charging and discharging may gradually affect your car's battery over time, similar to what happens with a phone battery.

Automatic Control: The system decides when to charge and discharge your car, so you won't control it yourself.

Data Privacy: V2G systems might collect information about how you use energy and charge your car. It's important that this data is kept safe and follows privacy rules.

Appendix B. . Scenario without private EVs equipped with V2G

B.1 Estimation results for commuting Trips

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Table B1
Estimated parameters and model summary for the commuting scenario with two alternatives.

Parameters	Value	Std err	p-value
Alternative specific constants (reference is the status quo)			
V2G_CS: ASC (current PT users)	−1.36	1.10	0.22
V2G_CS: ASC (current ICV users)	**−2.63**	0.67	0.00
V2G_CS: ASC (current EV users)	**−3.24**	0.95	0.00
V2G_CS: ASC (current Bike users)	**−5.17**	1.04	0.00
V2G_CS: standard deviation	**3.43**	0.31	0.00
Mode attributes for the status quo alternative (β_k^X)			
SQ: travel cost (all respondents)	**−0.10**	0.05	0.03
SQ: travel time (current PT users)	**−0.08**	0.02	0.00
SQ: travel time (current Bike users)	0.03	0.08	0.71
SQ: waiting time (current PT users)	**−0.25**	0.10	0.02
SQ: parking cost (current ICV and EV users)	0.02	0.08	0.81
SQ: parking search time (current ICV, EV, and Bike users)	0.04	0.12	0.73
SQ: walking time (all respondents)	**−0.05**	0.02	0.03
SQ: SOC (current EV users)	**0.02**	0.01	0.03
Mode Attributes for the V2G alternatives (β_{jk}^X)			
V2G_CS: travel cost (current PT users)	**−0.22**	0.09	0.01
V2G_CS: travel cost (current ICV and EV users)	**−0.20**	0.06	0.00
V2G_CS: travel cost (current Bike users)	−0.98	0.67	0.14
V2G_CS: travel time (current PT users)	**−0.13**	0.02	0.00
V2G_CS: travel time (current Bike users)	0.00	0.20	0.99
V2G_CS: walking time (all respondents)	**−0.08**	0.02	0.00
V2G_CS: minimum guaranteed battery range (all respondents)	−0.01	0.01	0.33
Socio-demographic variables (β_j^S)			
V2G_CS: owning EVs	**1.64**	0.50	0.00
V2G_CS: monthly household income ≤ 3000 euros	**0.92**	0.42	0.03
Model summary	Value		
Nbr of parameters	22		
Sample size	730		
Null log likelihood	−1517.99		
Final log likelihood	−810.69		
Likelihood ratio test (null)	1414.61		
Rho square (null)	0.47		
Rho bar square (null)	0.45		
Akaike Information Criterion	1665.38		
Bayesian Information Criterion	1766.42		

Note:
Estimates in bold are significant at $p < 0.05$. Estimates in italic are significant at $p < 0.10$.
SQ refers to the status quo alternative (respondent's current mode).
V2G_CS denote the carsharing EV with V2G.

Table B2
Estimated parameters and model summary for the non-commuting scenario with two alternatives.

Parameters	Value	Std err	p-value
Alternative specific constants (reference is the status quo)			
V2G_CS: ASC (current PT users)	*−3.05*	1.69	0.07
V2G_CS: ASC (current ICV users)	**−2.66**	1.00	0.01
V2G_CS: ASC (current EV users)	**−3.76**	1.02	0.00
V2G_CS: ASC (current Bike users)	**−7.27**	1.21	0.00

(continued on next page)

Table B2 (*continued*)

Parameters	Value	Std err	p-value
V2G_CS: ASC (shopping)	−0.37	0.65	0.58
V2G_CS: standard deviation	**4.07**	0.40	0.00
Mode attributes for the status quo alternative (β_k^X)			
SQ: travel cost (all respondents)	0.05	0.09	0.61
SQ: travel time (current PT users)	−0.05	0.08	0.54
SQ: travel time (current Bike users)	−0.06	0.07	0.40
SQ: waiting time (current PT users)	**−0.43**	0.14	0.00
SQ: parking cost (current ICV and EV users)	**−0.19**	0.09	0.03
SQ: parking search time (current ICV and EV users)	−0.01	0.15	0.94
SQ: parking search time (current Bike users)	**−0.77**	0.29	0.01
SQ: walking time (all respondents)	*−0.11*	0.06	0.07
SQ: SOC (current EV users)	0.01	0.01	0.26
Mode Attributes for the V2G alternatives (β_{jk}^X)			
V2G_CS: travel cost (current PT users)	**−0.36**	0.15	0.02
V2G_CS: travel cost (current ICV and EV users)	−0.10	0.08	0.20
V2G_CS: travel cost (current Bike users)	**−3.02**	0.89	0.00
V2G_CS: travel time (current PT and Bike users)	−0.02	0.04	0.62
V2G_CS: walking time (all respondents)	**−0.08**	0.02	0.00
V2G_CS: minimum guaranteed battery range (all respondents)	0.00	0.01	0.92
Model summary	**Value**		
Nbr of parameters	21		
Sample size	716		
Null log likelihood	−1488.88		
Final log likelihood	−656.3105		
Likelihood ratio test (null)	1665.139		
Rho square (null)	0.559		
Rho bar square (null)	0.545		
Akaike Information Criterion	1354.621		
Bayesian Information Criterion	1450.668		

Note:
Estimates in bold are significant at $p < 0.05$. Estimates in italic are significant at $p < 0.10$.
SQ refers to the status quo alternative (respondent's current mode).
V2G_CS denote the carsharing EV with V2G.

Data availability

The authors do not have permission to share data.

References

Bailey, J., Axsen, J., 2015. Anticipating PEV buyers' acceptance of utility controlled charging. Transp. Res. Part Policy Pract. 82, 29–46. https://doi.org/10.1016/j.tra.2015.09.004.

Bakhuis, J., Barbour, N., Molin, E., Chappin, É.J.L., 2025. Understanding user preferences regarding vehicle-to-grid (V2G): a latent class choice analysis. Transp. Res. Part Policy Pract. 199, 104610. https://doi.org/10.1016/j.tra.2025.104610.

Bierlaire, M., 2020. A short introduction to PandasBiogeme (No. TRANSP-OR 200605). Transport and Mobility Laboratory.

Ceccato, R., Chicco, A., Diana, M., 2021. Evaluating car-sharing switching rates from traditional transport means through logit models and Random Forest classifiers. Transp. Plan. Technol. 44, 160–175. https://doi.org/10.1080/03081060.2020.1868084.

Centraal Bureau voor de Statistiek, 2025. Mobiliteit; per persoon, vervoerwijzen, motieven, regio's.

Chorus, C.G., Kroesen, M., 2014. On the (im-)possibility of deriving transport policy implications from hybrid choice models. Transp. Policy 36, 217–222. https://doi.org/10.1016/j.tranpol.2014.09.001.

Christidis, P., Focas, C., 2019. Factors affecting the uptake of hybrid and electric vehicles in the European Union. Energies 12, 3414. https://doi.org/10.3390/en12183414.

Cornet, Y., Lugano, G., Georgouli, C., Milakis, D., 2022. Worthwhile travel time: a conceptual framework of the perceived value of enjoyment, productivity and fitness while travelling. Transp. Rev. 42, 580–603. https://doi.org/10.1080/01441647.2021.1983067.

De Luca, S., Di Pace, R., 2015. Modelling users' behaviour in inter-urban carsharing program: a stated preference approach. Transp. Res. Part Policy Pract. 71, 59–76. https://doi.org/10.1016/j.tra.2014.11.001.

Fan, Q., Kavta, K., Azadeh, S.S., Correia, G.H.A., 2026. Understanding drivers' willingness to incorporate V2G technology into their mobility routines. Transp. Res. Part C Emerg. Technol. 188, 105667. https://doi.org/10.1016/j.trc.2026.105667.

Geske, J., Schumann, D., 2018. Willing to participate in vehicle-to-grid (V2G)? Why not! Energy Policy 120, 392–401. https://doi.org/10.1016/j.enpol.2018.05.004.

Ghotge, R., Nijssen, K.P., Annema, J.A., Lukszo, Z., 2022. Use before you choose: what do EV drivers think about v2g after experiencing it? Energies 15, 4907. https://doi.org/10.3390/en15134907.

Government of the Netherlands, 2024. Road Traffic Signs and Regulations in the Netherlands. Government of the Netherlands.

Gschwendtner, C., Krauss, K., 2022. Coupling transport and electricity: how can vehicle-to-grid boost the attractiveness of carsharing? Transp. Res. Part Transp. Environ. 106, 103261. https://doi.org/10.1016/j.trd.2022.103261.

Hess, S., Daly, A., Bliemer, M., Guevara, A., Daziano, R., Dekker, T., 2025. Statistical significance in choice modelling: computation, usage and reporting. Doi: 10.48550/arXiv.2506.05996.

Hidrue, M.K., Parsons, G.R., 2015. Is there a near-term market for vehicle-to-grid electric vehicles? Appl. Energy 151, 67–76. https://doi.org/10.1016/j.apenergy.2015.04.051.

Huang, B., Meijssen, A.G., Annema, J.A., Lukszo, Z., 2021. Are electric vehicle drivers willing to participate in vehicle-to-grid contracts? A context-dependent stated choice experiment. Energy Policy 156, 112410. https://doi.org/10.1016/j.enpol.2021.112410.

Kempton, W., Tomić, J., 2005. Vehicle-to-grid power implementation: from stabilizing the grid to supporting large-scale renewable energy. J. Power Sources 144, 280–294. https://doi.org/10.1016/j.jpowsour.2004.12.022.

Kester, J., Zarazua de Rubens, G., Sovacool, B.K., Noel, L., 2019. Public perceptions of electric vehicles and vehicle-to-grid (V2G): insights from a Nordic focus group study. Transp. Res. Part Transp. Environ. 74, 277–293. https://doi.org/10.1016/j.trd.2019.08.006.

Kubli, M., 2022. EV drivers' willingness to accept smart charging: measuring preferences of potential adopters. Transp. Res. Part Transp. Environ. 109, 103396. https://doi.org/10.1016/j.trd.2022.103396.

Letcher, M., Britton, D.J., Hoggett, R., 2026. Charged with potential: Lessons from Utrecht Energized vehicle-to-grid project.

Liao, F., Vleugel, J., Bösehans, G., Dissanayake, D., Thorpe, N., Bell, M., Van Arem, B., De Almeida, H., Correia, G., 2024. Mode substitution induced by electric mobility hubs: results from Amsterdam. Transp. Res. Part Transp. Environ. 129, 104118. https://doi.org/10.1016/j.trd.2024.104118.

Maeng, K., Ko, S., Shin, J., Cho, Y., 2020. How Much electricity sharing will electric vehicle owners allow from their battery? Incorporating vehicle-to-grid technology and electricity generation Mix. Energies 13, 4248. https://doi.org/10.3390/en13164248.

Mo, B., Wang, Q.Y., Moody, J., Shen, Y., Zhao, J., 2021. Impacts of subjective evaluations and inertia from existing travel modes on adoption of autonomous mobility-on-demand. Transp. Res. Part C Emerg. Technol. 130, 103281. https://doi.org/10.1016/j.trc.2021.103281.

Mondal, A., Bhat, C.R., 2022. A spatial rank-ordered probit model with an application to travel mode choice. Transp. Res. Part B Methodol. 155, 374–393. https://doi.org/10.1016/j.trb.2021.12.008.

Noel, L., Papu Carrone, A., Jensen, A.F., Zarazua de Rubens, G., Kester, J., Sovacool, B.K., 2019. Willingness to pay for electric vehicles and vehicle-to-grid applications: a Nordic choice experiment. Energy Econ. 78, 525–534. https://doi.org/10.1016/j.eneco.2018.12.014.

Pan, X., Rasouli, S., Timmermans, H., 2019. Modeling social influence using sequential stated adaptation experiments: a study of city trip itinerary choice. Transp. Res. Part Policy Pract. 130, 652–672. https://doi.org/10.1016/j.tra.2019.10.007.

Parsons, G.R., Hidrue, M.K., Kempton, W., Gardner, M.P., 2014. Willingness to pay for vehicle-to-grid (V2G) electric vehicles and their contract terms. Energy Econ. 42, 313–324. https://doi.org/10.1016/j.eneco.2013.12.018.

Philip, T., Whitehead, J., Prato, C.G., 2023. Adoption of electric vehicles in a laggard, car-dependent nation: investigating the potential influence of V2G and broader energy benefits on adoption. Transp. Res. Part Policy Pract. 167, 103555. https://doi.org/10.1016/j.tra.2022.11.015.

Prencipe, L.P., Theresia Van Essen, J., Caggiani, L., Ottomanelli, M., De Almeida, H., Correia, G., 2022. A mathematical programming model for optimal fleet management of electric car-sharing systems with Vehicle-to-Grid operations. J. Clean. Prod. 368, 133147. https://doi.org/10.1016/j.jclepro.2022.133147.

Qualtrics, 2026. Qualtrics XM Platform. Qualtrics. URL https://www.qualtrics.com (accessed 2.17.26).

Reck, D.J., Haitao, H., Guidon, S., Axhausen, K.W., 2021. Explaining shared micromobility usage, competition and mode choice by modelling empirical data from Zurich, Switzerland. Transp. Res. Part C Emerg. Technol. 124, 102947. https://doi.org/10.1016/j.trc.2020.102947.

Shahadat Hossain, M., Rahman Fatmi, M., 2022. Modeling individuals' preferences towards different levels of vehicle autonomy: a random parameter rank-ordered logit model. Transp. Res. Part Policy Pract. 163, 88–99. https://doi.org/10.1016/j.tra.2022.06.010.

Sovacool, B.K., Kester, J., Noel, L., De Rubens, G.Z., 2018. The demographics of decarbonizing transport: the influence of gender, education, occupation, age, and household size on electric mobility preferences in the Nordic region. Glob. Environ. Change 52, 86–100. https://doi.org/10.1016/j.gloenvcha.2018.06.008.

Srinivasan, S., Bhat, C.R., Holguin-Veras, J., 2006. Empirical analysis of the impact of security perception on intercity mode choice: a panel rank-ordered mixed logit model. Transp. Res. Rec. 1942, 9–15. https://doi.org/10.1177/0361198106194200102.

Sturmberg, B.C.P., Hapuarachchi, L., Jones, L., Lucas-Healey, K., Van Biljon, J., 2024. Vehicle-to-grid response to a frequency contingency in a national grid. Npj Sustain. Mobil. Transp. 1, 7. https://doi.org/10.1038/s44333-024-00010-8.

Suel, E., Xin, Y., Wiedemann, N., Nespoli, L., Medici, V., Danalet, A., Raubal, M., 2024. Vehicle-to-grid and car sharing: willingness for flexibility in reservation times in Switzerland. Transp. Res. Part Transp. Environ. 126, 104014. https://doi.org/10.1016/j.trd.2023.104014.

Van Heuveln, K., Ghotge, R., Annema, J.A., Van Bergen, E., Van Wee, B., Pesch, U., 2021. Factors influencing consumer acceptance of vehicle-to-grid by electric vehicle drivers in the Netherlands. Travel Behav. Soc. 24, 34–45. https://doi.org/10.1016/j.tbs.2020.12.008.

Walker, J.L., Wang, Y., Thorhauge, M., Ben-Akiva, M., 2018. D-efficient or deficient? A robustness analysis of stated choice experimental designs. Theory Decis. 84, 215–238. https://doi.org/10.1007/s11238-017-9647-3.

Wang, N., Tang, L., Pan, H., 2017. Effectiveness of policy incentives on electric vehicle acceptance in China: a discrete choice analysis. Transp. Res. Part Policy Pract. 105, 210–218. https://doi.org/10.1016/j.tra.2017.08.009.

Wei, Y., Yao, Y., Pang, K., Xu, C., Han, X., Lu, L., Li, Y., Qin, Y., Zheng, Y., Wang, H., Ouyang, M., 2022. A comprehensive study of degradation characteristics and mechanisms of commercial Li(NiMnCo)O2 EV batteries under vehicle-to-grid (V2G) services. Batteries 8, 188. https://doi.org/10.3390/batteries8100188.

Yan, X., Levine, J., Zhao, X., 2019. Integrating ridesourcing services with public transit: an evaluation of traveler responses combining revealed and stated preference data. Transp. Res. Part C Emerg. Technol. 105, 683–696. https://doi.org/10.1016/j.trc.2018.07.029.

Yun, S., Woo, J., Kwak, K., 2025. Unlocking peak shaving: how EV driver heterogeneity shapes V2G potential. Energy 329, 136773. https://doi.org/10.1016/j.energy.2025.136773.