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Willingness to Participate in Vehicle-to-Everything (V2X) in Sweden, 2022—Using an Electric Vehicle's Battery for More Than Transport

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Abstract: Vehicle-to-everything (V2X) refers to the technology that enables electric vehicles (EVs) to push their battery energy back to the grid. The system's V2X integration includes key functions like V2G, V2H, V2B, etc. This paper explores the preferences of Swedish EV drivers in contributing to V2X programs through an online questionnaire. Respondents were asked to answer questions in three contexts: (1) claims related to their EV charging, (2) V2G application by EV, and (3) V2H application by EV. The respondents were questioned about the importance of control, pricing, energy sustainability and climate issues, impact on the battery, the acceptability of V2X, range anxiety, financial compensation, as well as how and where they prefer to charge the EV. The results of the survey indicate that Swedish EV drivers are more interested in the V2H application than in V2G. Additionally, they express more concern about range anxiety than battery degradation due to the V2X application.

Keywords: electric vehicle (EV); Swedish EV drivers' preference; vehicle-to-everything (V2X); online questionnaire

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1. Introduction

Light-duty vehicles account for half of the cars in the transportation sector which produce around 25% of carbon emissions related to global energy [1]. To decrease the carbon emissions from the transportation sector and reduce the dependency on fossil fuels, the electric vehicle (EV) market has been growing exponentially in the past decade. Nowadays, the weekly sales of EVs are more than the sales of EVs in the whole of 2012. Despite a 16% reduction in global car sales during the COVID-19 pandemic, EV registrations increased by 41% after 2019 [1]. The worldwide sales of EVs reached 10.5 million in 2022 (accounting for 14% of the global market), which was an increase by 60% from the year before [2]. Such a high increase in EV sales needs meticulous attention concerning the integration with the electricity network.

Typically, unidirectional inverters are used in onboard/offboard EV chargers for charging the EV's battery when the vehicle is plugged in. The EV's charging state acts as an electrical demand for the power grid to absorb electricity from the grid to the vehicle's battery. As the number of EVs increases, the need for electrical energy from the main grid increases. In addition, charging EVs at home would remarkably increase the electricity cost for the homeowner [3]. The installation of distributed renewable energy resources in the premises of one's home would reduce the electricity bill [4]. However, due to fewer installations of battery energy storage, it has a small influence on the peak power of the main grid. Hence, innovative solutions and strategies are required to smooth the impacts of EV charging on the power system.

With the new technology advancements in bidirectional inverters and chargers, the battery of EVs can be used for grid electrification rather than purely for traditional transport

and charging. Vehicle-to-everything (V2X) is the term that refers to using EV power and energy for grid support by sufficiently discharging the vehicles' batteries [5]. V2X can be used on different scales: (1) on the large scale of the power grid through the vehicle-to-grid (V2G) concept, (2) on a building or office scale through the vehicle-to-building (V2B) concept, (3) on a home or villa scale through the vehicle-to-home (V2H) concept, (4) on a vehicle scale by using the vehicle-to-vehicle (V2V) concept, and (5) on a small scale through vehicle-to-load (V2L) [6]. V2X integration improves flexibility in the electricity network. Thus, the implementation of V2X is an excellent opportunity to reach energy sustainability by integrating more renewable energy resources. The reliability and resiliency of the electricity network and residential homes can be significantly improved by V2X. More advantages of V2X implementation include the voltage control of distribution network, the frequency regulation of the power grid, energy arbitrage, load management, etc. [7]. Some new EV models like Kia EV6 [8] and Nissan Leaf [9] have enabled V2G technology which enables the car to not only receive power but also supply power back to the grid. However, the V2X technology is still in the early stage of development, and more studies should be carried out on its acceptability, benefits, barriers, and solutions. For example, there are big barriers like battery degradation and range anxiety for EV drivers to accept the V2X application.

Although the acceptability of V2X has not been directly investigated in previous studies, several works have been conducted on V2X-related topics like value streams [10], strategies and technologies [11], challenges [12], the battery degradation issue [13], benefits [14], app design [15], virtual power plant (VPP) development [16], and reducing transmission network requirements [17]. By investigating the value streams in [10], it was found that inadequate regulatory policies will constrain the complete economic and environmental benefits from V2X implementation. In [11], it was shown that broad software and hardware systems are required to equip parking lots and homes with bidirectional off-board chargers to enable V2X on a large-scale, and the technology still needs to be matured for such a seamless integration. Various obstacles for V2X implementation were investigated in [12]. It was emphasized by [13] that optimal energy management algorithms of V2X can prolong the lifetime of an EV's battery. The revenue opportunities for EV owners and cost savings for grid operators were emphasized as the main benefits of V2X [14]. In [15], a mobile app was designed to make recommendations to EV owners based on a charging station's location, range anxiety, electricity market data, and a route planner. It was mentioned that Polestar will develop a VPP using the V2G of EVs in the near future [16]. A new project in Italy will develop a high capacity V2G to reduce the transmission network expansion of fossil fuel power plants by 2027 [17].

In [18], the major benefits and potential barriers of V2X, as well as possible measures to overcome the barriers, were discussed. In [19], the preference of vehicle owners was compared on whether they wanted to have an EV with V2G or a gasoline vehicle. It was assumed that with V2G, a minimum guaranteed driving range should always be achieved. It was found that the V2G is acceptable if the grid operator makes a service payment or an advanced payment to the EV owners for participating in V2G. In [20], through 20 interviews, it was found that factors like transparent communication, financial compensation, and a reliable control system by the user has a positive impact on V2G acceptability in the Netherlands. In [21], based on interviews in Nordic countries, it was shown that while further awareness is required for technologies like V2G, further research is also required to examine this technology. In another study in Nordic countries [22], it was ascertained that recharging time and driving range are more important than other factors in V2G acceptability. The same results were found in a study based on choice experiment for vehicle users in Germany [23]. The impact of recharging technology on the preferences of EV owners in the Netherlands was examined using a context-dependent choice experiment [24]. A serious concern for the Dutch EV drivers was discharging cycles. It was shown in [25] that V2G is profitable for EV owners who charge their vehicles at home due to the sufficient time of the EV's grid connection. In [26], the authors showed

that the profitability of V2G depends on the EV charger's power rate, departure time, and the variations in the price of electricity. As mentioned above, all previous papers only considered V2G preferences in their studies. The importance of V2H for the consumers and its comparison with V2G were not examined for the acceptability of V2X.

The aim of this paper is to answer the following research questions: What are the end-users' views on V2G/V2H? What are the main drivers and barriers to participating in V2X schemes? The main contribution of this paper is to investigate the acceptability of V2X by Swedish EV drivers using an online questionnaire. V2X is considered and integrated into the questionnaire by taking into consideration both V2G and V2H applications for the EV owners. The respondents were required to answer questions in three contexts: (1) claims related to their EV charging, (2) V2G integration with the EV to support grid services, and (3) V2H application by the EV for reliability enhancement and bill reduction. Questions related to the importance of control, price, climate issues, impact on battery, the acceptability of V2X, range anxiety, financial compensation, as well as how and where they prefer to charge and discharge the EV were included. The questionnaire also included a general part where the respondents answered about their gender, accommodation type, whether they currently have an EV, and which parking/charging option they currently use. The comments of the respondents about each context of the questionnaire are included in this paper. The results from this study increase the understanding of end-users' perception of V2X and could support the development of V2X schemes.

2. Overview of Vehicle-to-Everything

V2X can be employed in various ways, with the primary mode of integration being V2G. In V2G, the battery capacity of EVs is gathered using aggregators to provide grid services to the distribution system operator (DSO) and transmission system operator (TSO). A large-scale aggregation of EVs is required to participate in the TSO's ancillary service markets while a more local but smaller EV fleet is required to provide services to the DSO. The main services provided on the TSO level by V2G are ancillary services and flexibility enhancement to integrate more renewable energy resources. The ancillary services by the EVs through V2G can be defined as frequency regulation, dispatching improvement, and spinning reserve [27]. On the DSO level, the aggregated discharging capacity of EVs can be used for different purposes like congestion management, voltage profile control, energy arbitrage, and peak shaving [28]. However, EV drivers are still not aware of the significance of V2G integration. V2H concerns the defined services through V2X technology for houses or villas. By V2H integration, homeowners can use the EV's battery to electrify their home loads. This makes it possible to increase the self-consumption of onsite installed solar photovoltaic (PV) systems. The electricity bill of the house can be reduced by V2H when the EV's battery is charged at a low electricity price and is discharged to supply the home loads at a high electricity price. Another important aspect of having V2H in the premises of one's home is to use the EV's battery as a back-up system during grid outages; e.g., when the electricity demand is not supplied by the main grid, the EV can be discharged through V2H to supply the loads.

V2B is the extended and more complicated version of V2H, and it is defined as the services provided by the EVs to buildings like offices, campuses, apartments, and real estates. The vehicles participating in V2B can contribute to energy arbitrage to make profits. Since a higher number of vehicles are available in V2B compared to V2H, it gives more flexibility to the operator to use the energy of the vehicles. For example, greater energy is available as the back-up for the building. However, the energy management and coordination of vehicles in the building would be a challenge for the operator. The arrival and departure times as well as the travel distance of the vehicles in the building should be predicted. Then, based on the gathered data, the operator should make the best decision, and a business model for how to share the revenue from the V2B service needs to be developed. In buildings, the vehicles can share the energy of their EVs' batteries among each other. The next option of V2X integration is the V2V technology that makes it possible

to share energy between the vehicles themselves. This can also be used in camping areas where electricity from the grid is not available. V2L is another option in camping areas or any other places without grid connection where EV owners can use the energy of the vehicle's battery to supply essential loads or bicycles. It should be noted that this study focuses on V2G, V2H, and V2B as the main functionalities of V2X, and the definitions of V2L and V2V are only included for completeness.

3. Data Collection

EVs are considered as an effective and important technology to reduce carbon emissions from the transportation sector. In Sweden, the number of registered full-electric cars has drastically increased in recent years. Figure 1 shows the number of registered electric cars (divided into plug-in hybrids (PHEVs) and battery electric vehicles (BEVs)) in Sweden from 2010 to 2022 [29]. It is shown that since 2014, the number of registered BEVs and PHEVs has rapidly increased. The increase has continued and in 2023, 113,000 EVs and 62,000 PHEVs were registered. A survey in [30] found that Swedish electric car owners are satisfied with their EVs and most of them would consider to only use EVs. On the other hand, their willingness to participate in V2X has not been investigated in Sweden. Although several countries have started to investigate the barriers and willingness of EV owners to participate in the V2G program, e.g., [19–26], such studies are very limited in Sweden [31].

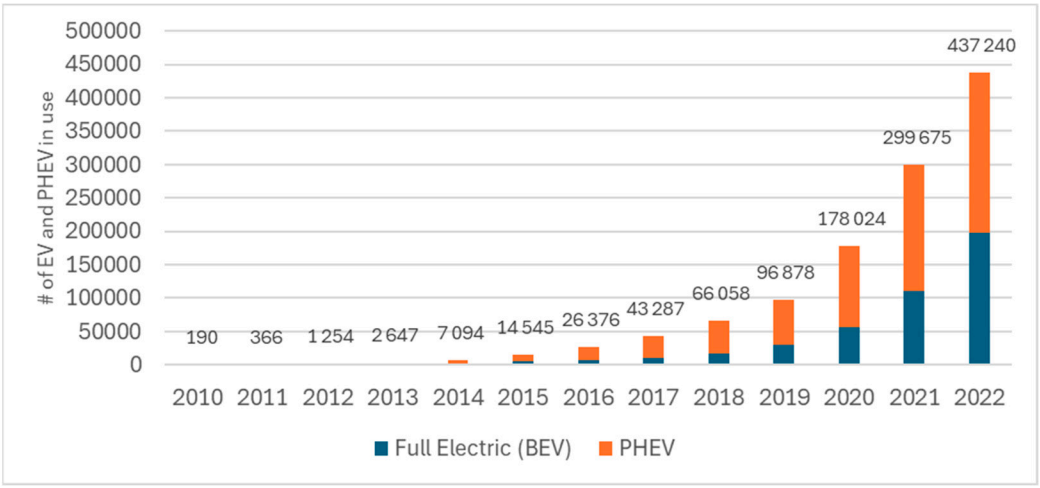

Figure 1. Registered full-electric cars in Sweden from 2010 to 2022 [29].

In order to explore Swedish EV owners' willingness surrounding V2X implementation, namely, V2G and V2H, in this study, the authors relied primarily on data collection through an online questionnaire. The aim of the questionnaire was to achieve a state-of-the-art overview of the expectations and challenges that the people involved in EV mobility have regarding V2X. In other words, the implementation of the online questionnaire allows the authors to reach flexibility and guidance, by asking a set of fixed questions, and create a conversational channel of information-gathering, allowing space for spontaneous responses that add depth and, in some instances, unforeseen narratives to the research.

Before answering the questionnaire "Vehicle to Everything-to use your electric car battery for more than transport?", the following description is provided for the respondents to familiarize them with the technology of V2X.

"This is a form where we try to map the driving forces and barriers that exist to use the battery in an electric car for other things than to drive the vehicle forward. There are different names for this, e.g., Vehicle to Grid (V2G), Vehicle to Home (V2H), Vehicle to Building (V2B) or Vehicle to Load (V2L). V2G means, unlike smart charging (V1G), that the battery can be discharged and thereby used to further reduce the owner's energy costs by reducing its power peaks, reducing electricity purchases when it is expensive (in the spot

market) or by selling other services to the electricity network operator (such as frequency control services, etc.). V2H is part of V2G but is usually defined as the ability to also use the car's battery to power the electrical system at home without being connected to the electricity grid (a so-called microgrid). If there is e.g., a power outage, the electric car could supply your home with electricity, or if you have a summer cottage without an electrical connection, you could use the electric car as a power source for the cottage."

After describing the V2X technology, the following description is provided to familiarize the participants with the questions in the questionnaire forms.

"The questions/statements below are divided into four groups; the first group is about some general background information about you. The second group is about your attitude towards electric car charging in general and about your attitude towards controlling the charge (so-called V1G). The third group of questions is about your attitude to also discharge the electric car's battery, i.e., V2G. The fourth group is about the benefit and value of using the car's energy storage in the event of a power failure, etc., i.e., V2H solutions. In most questions/statements, you must rate your answers on a scale of 1–10, where 10 corresponds to you fully agreeing and 1 corresponds to you not agreeing with the statement. If there is a question you cannot/do not want to answer, leave it blank. Your answers are anonymous, and we will not store any information that can be linked to you. The survey is part of the research project "Electric cars for everything (V2X-MAS)" in Sweden [32]".

Table 1 lists the main questions/statements in the questionnaire for V2X implementation. As shown in the table, the respondents are requested to answer the questions in four parts: (1) general background information, (2) claims related to their EV charging, (3) V2G integration with EV, and (4) V2H application by EV. The respondents were mainly asked about the importance of control, price, climate issues, impact on battery, the acceptability of V2X, range anxiety, financial compensation, as well as how and where they prefer to charge the EV. The questions were formulated to understand if barriers and drivers that were found important in earlier studies also were applicable to Swedish EV owners.

Table 1. The main questions/statements in the online choice experiment for V2X implementation in Sweden.

Context		Questions/Statements	Answer Alternatives
General background information	1	Gender?	Male/Female/Don't want to say
	2	Accommodation type?	Singel-family house/Town house, Apartment/Other
	3	Do you have an electric car today?	Yes/No, but I plan to buy one soon/No
	4	Parking/Charging option you use today?	Private/rented parking with charge possibility Private/rented parking without charge possibility Residential/street parking with charge possibility Residential/street parking without charge possibility Other

Table 1. *Cont.*

Context		Questions/Statements	Answer Alternatives
Claims related to their EV charging	1	Do you connect and charge your electric car as soon as you park at home?	1 (Don't agree)–10 (Fully agree)
	2	Do you plug in and charge your electric car at public charging stations if it's free?	1 (Don't agree)–10 (Fully agree)
	3	I control the charging of my electric car at night to avoid power peaks and/or lower electricity prices.	1 (Don't agree)–10 (Fully agree)
	4	I control the charging of my electric car at night to reduce the climate impact.	1 (Don't agree)–10 (Fully agree)
	5	I try to avoid charging my electric car in full to reduce the impact on the car's battery.	1 (Don't agree)–10 (Fully agree)
	6	Do you connect and charge your electric car at public charging stations if you need to pay for the electricity?	1 (Don't agree)–10 (Fully agree)
V2G integration with EV	1	I think V2G is an interesting concept.	1 (Don't agree)–10 (Fully agree)
	2	I'm worried that V2G will affect the life of my battery.	1 (Don't agree)–10 (Fully agree)
	3	I am worried that the V2G will affect the range of my electric car (i.e., the battery is not charged enough when I use the car).	1 (Don't agree)–10 (Fully agree)
	4	I am worried that V2G will affect the warranty of my electric car.	1 (Don't agree)–10 (Fully agree)
	5	For me, it is important that V2G leads to a lower electricity cost for me and/or that I receive financial compensation for using my electric car for V2G.	1 (Don't agree)–10 (Fully agree)
	6	I would consider using my electric car for V2G if it leads to a better environment.	1 (Don't agree)–10 (Fully agree)
	7	I would pay extra for an electric car with V2G functionality.	1 (Don't agree)–10 (Fully agree)
	8	I could use the following companies to control the charge and discharge.	• My electricity network operator (DSO) • My electricity retailer • My EV manufacturer • My charge station manufacturer • A third party aggregator • Doesn't matter as long as it does not affect me negatively • None, I want to control my charging/discharging myself • Other, please specify
	9	To allow V2G, I want the option to override the command and start charging if I need to.	1 (Don't agree)–10 (Fully agree)

Table 1. *Cont.*

Context		Questions/Statements	Answer Alternatives
V2H application by EV	1	I think V2H is an interesting concept.	1 (Don't agree)–10 (Fully agree)
	2	I'm more interested in V2H than in V2G (i.e., it's important to be able to use the electric car's battery to supply your home with electricity in case of power outages).	1 (Don't agree)–10 (Fully agree)
	3	To use the V2H, I want full control over when and how the electric car is charged.	1 (Don't agree)–10 (Fully agree)
	4	For me, it is important to be able to use the electric car's battery to supply my home with electricity in the event of a power failure.	1 (Don't agree)–10 (Fully agree)
	5	I would pay extra for an electric car with V2H functionality. Please specify below.	1 (Don't agree)–10 (Fully agree)

The questionnaire was conducted in Swedish to mainly receive the perspective from Swedish drivers and was distributed through online media channels such as LinkedIn and via the non-profit organisation "Elbil Sverige" and the non-profit organization "power circle's" newsletters. No pre-selection of the respondents was carried out to achieve a representative group of respondents. The main reason for this was to understand the willingness and interest of the early adopters and people with an interest in electrification and energy. Persons without an EV would likely have a low knowledge of the possibility of V2X, and their responses would be less valuable in a study like this. However, it is important to keep this in mind when assessing the results of the questionnaire.

4. Results of the Questionnaire

A total number of 189 responses were received from Swedish respondents for the online questionnaire. As shown in Figure 1, the total number of registered EVs (i.e., population size) in Sweden was around 197,000 by the end of 2022 [29], giving a response rate of approximately 0.1% of the EV owners. As noted in the previous section, the questionnaire was organized in four parts. The results of each part are discussed in this section.

First, the participants were asked questions about general background information. Tables 2–5 illustrate the results of the questionnaire about the general background information of the respondents. As indicated in the tables, around 88.1% of the respondents were men and the other 11.9% were women. Most of the respondents (~91.3%) owned an EV and around 6.5% intended to purchase EV in the near future. The remaining respondents had previously owned an EV, owned a PHEV, or had access to an EV through their job. Although the number of EVs is not representative for Sweden, it is persons with an EV who would participate in V2X programs, hence their opinion is more relevant. The respondents were mostly (~77.3%) living in single-family houses, some (~14.6%) were living in apartments (multi-family houses), and a small portion (~7%) in town houses. In Sweden, about 50% of the population lives in single-family houses or town houses [31], hence these persons are over-represented in this study. Around 77.3% of the respondents charged their EVs in their own private or rented parking with individual chargers. Swedish EV owners also used accommodation/street parking with EV chargers to charge their EVs; this option worked for about 11.4% of the respondents. The other respondents may not yet have an EV charger at their accommodation, and they use the public chargers in shopping malls, in workplaces, or in charging stations.

Table 2. Answers to the question "Gender?".

Male	Female	Other/Don't Want to Say
165	22	2

Table 3. Answers to the question "Accommodation type?".

Apartment	Singel-Family House	Town House	Other
28	145	13	3

Table 4. Answers to the question "Do you have an electric car today?".

Yes	No, but I Plan to Buy One	No	Other
171	12	4	2

Table 5. Answers to the question "Parking/Charging option you use today?".

Private/Rented Parking with Charger	Private/Rented Parking without Charger	Street Parking with Charger	Street Parking without Charger	Other
145	11	22	4	6

In the second part, the respondents answered the claims related to their EV charging. Figure 2 presents the results of the responses for all questions/statements in part 2 of the questionnaire. As can be seen, the participants had very different habits for charging their EVs. Around 12.6% of the EV owners charged their car as soon as they arrived home, while about 10.9% of the participants never charged the EV immediately after arrival. For the remaining respondents, the charge time varied for different days (this will be thoroughly discussed in Section 5). Furthermore, about 17% of the participants were wholly interested in free public charging if available, while only 8% always connected when they needed to pay for the charging. These are primarily the respondents that do not have a private charger. It can also be seen that 36% of EV owners tried to control the charging of their electric car at night to avoid power peaks and/or lower electricity prices, while around 21% said that they did not control the charging of their EV at night. The economic reasons for scheduling the charging were found to be higher compared to the environmental aspects, which were a very important aspect for about 20% of the respondents while 24% did not consider it important at all. It is important to note that there is a very large difference between the respondents on whether they control the charging or not, where almost half of the respondents selected either 1 (do not agree) or 10 (completely agree). The importance of charging in order to enhance battery health was less of a driving factor than economical aspects but higher than environmental ones.

By investigating the difference between male and female respondents, a small difference can be seen when it comes to charging behaviour, as shown in Figures 3 and 4. It was found that female respondents were more interested in environmental aspects than economical aspects, which is in line with previous research in this field. Analysing the difference between those who had a private charger and those who did not, the results showed that those with a private charger were more prone to control the charging at night (about 70% responded 6 or above) while they were not as willing to pay for the charging at public locations (60% answered 5 or below). The opposite holds for the respondents without their own charger, which was expected since these respondents depend more on the public charge infrastructure.

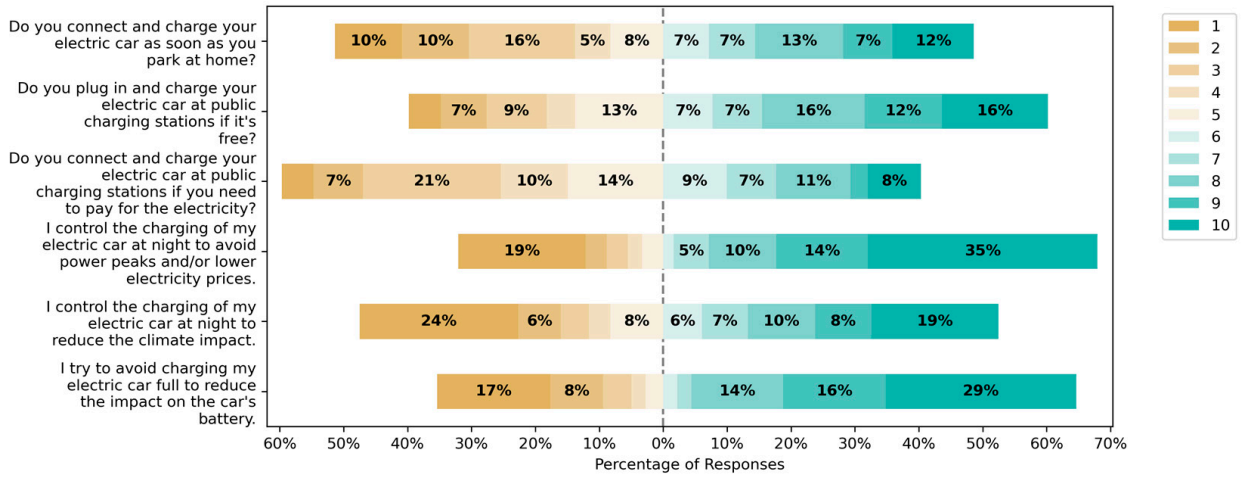

Figure 2. Results of questions/statements about claims related to the respondents' EV charging in part 2 of the questionnaire; all respondents (N = 181).

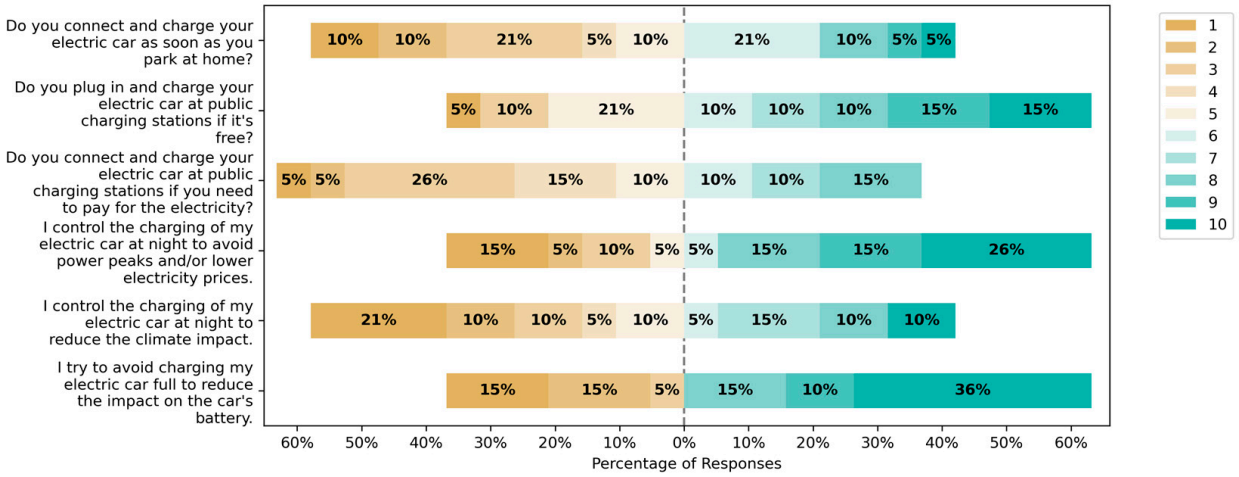

Figure 3. Results of questions/statements about claims related to the respondents' EV charging in part 2 of the questionnaire (1 = don't agree, 10 = completely agree); female respondents only (N = 19).

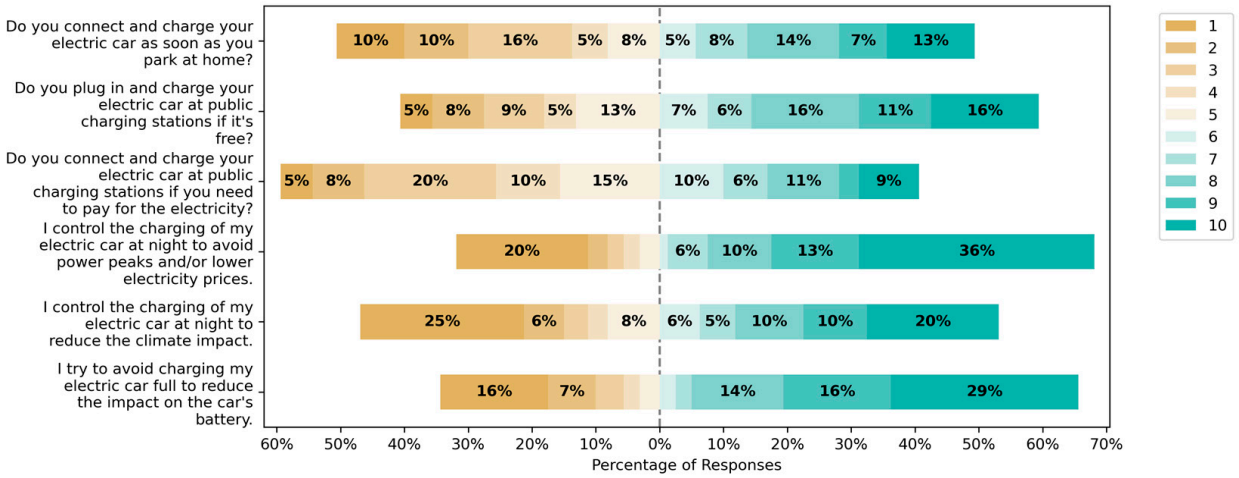

Figure 4. Results of questions/statements about claims related to the respondents' EV charging in part 2 of the questionnaire (1 = don't agree, 10 = completely agree); male respondents only (N = 160).

In the third part, the respondents were asked about V2G integration with EV. Figure 5 illustrates the results of the responses for all questions/statements in part 3 of the questionnaire. More than 68% of the participants totally agreed that V2G is an interesting concept. The effect of V2G on the battery lifetime was an issue for some of the EV owners; however, the respondents seemed to be less concerned compared to other studies, e.g., [33]. As shown in Figure 5, the number of participants worried about the V2G impact on battery life was lower than the number of participants who were not worried about battery degradation. This could be due to the reason that the respondents are not currently using V2G and hence they do not know how V2G would affect battery aging. Another concern raised by previous studies of V2G is the range anxiety of the EV owners. The result indicates that the participants mostly disagreed that V2G will affect the range of their electric car (~61% answered 5 or below). The participants were also less worried that V2G will affect the warranty of their electric car. Most respondents answered that it is important that V2G leads to a lower electricity cost and/or that they receive financial compensation for using their electric car for V2G. Hence, financial compensation in terms of incentives, remunerations, and discounts is very important for the implementation of V2G. Similarly, most participants were willing to use their electric car for V2G if it leads to a better environment. Compared to the questions about smart charging, a larger share were willing to use the EV for V2G services, which was unexpected. A possible reason for that could be that the respondents believe that the value of V2G is higher than just doing smart charging. Furthermore, the result showed that a vast majority of the respondents would require the possibility to abort the V2G operation and start charging. Almost 65% agreed to pay extra for an electric car with V2G functionality, which was lower than the number of respondents who thought it was an interesting concept. Comparing female and male respondents, as seen in Figures 6 and 7, the results indicate that men were more concerned about battery degradation, range, and warranty than women, and they were also more prone to pay extra for V2G functionality. On the other hand, female respondents were more willing to use the V2G both for economic and environmental reasons.

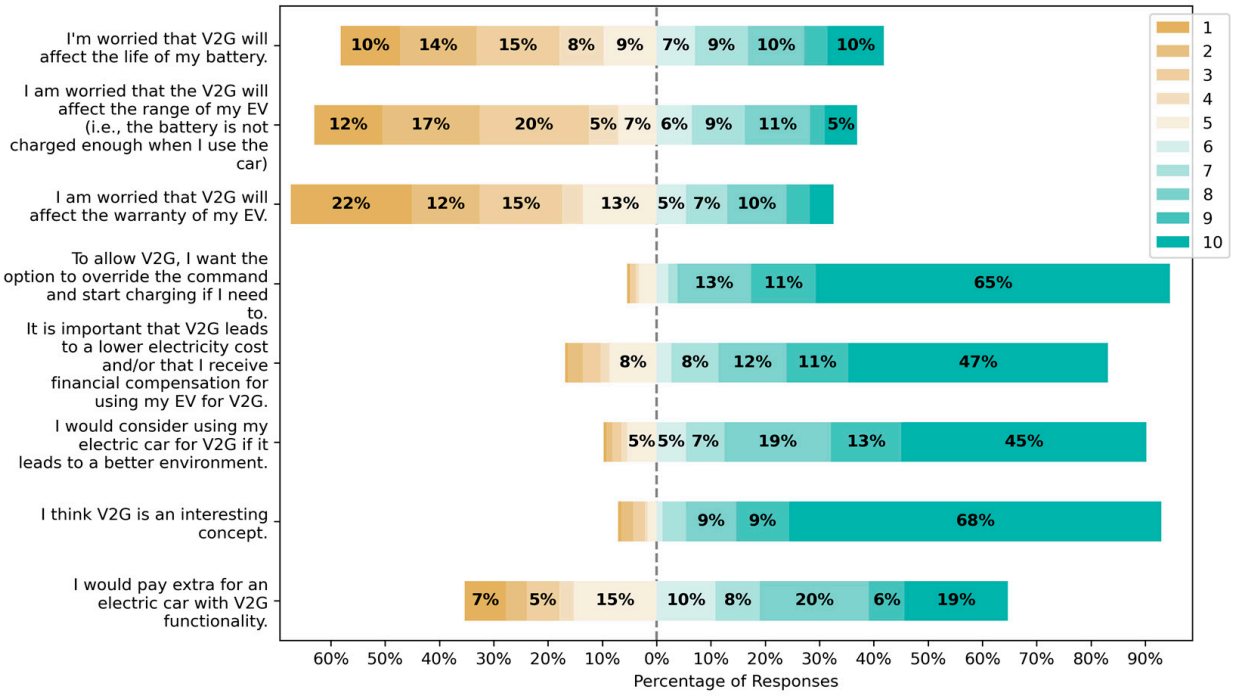

Figure 5. Results of questions/statements about V2G integration with EV in part 3 of the questionnaire; all respondents (N = 184).

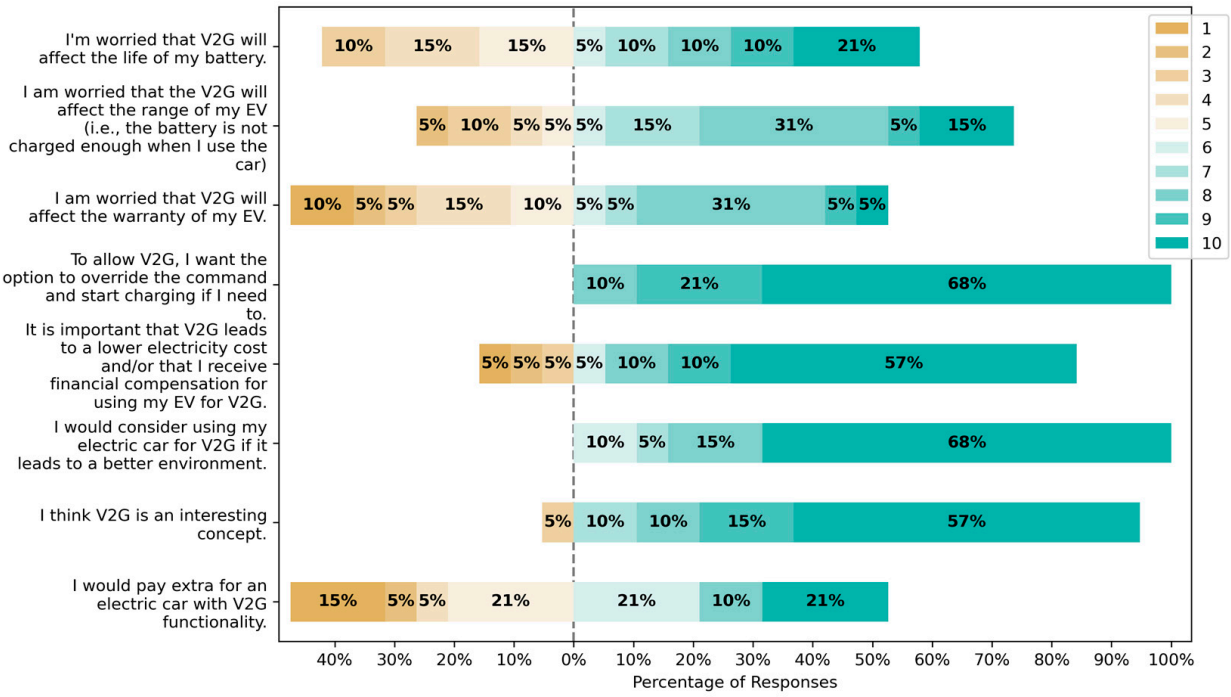

Figure 6. Results of questions/statements about V2G integration with EV in part 3 of the questionnaire; female respondents only (N = 19).

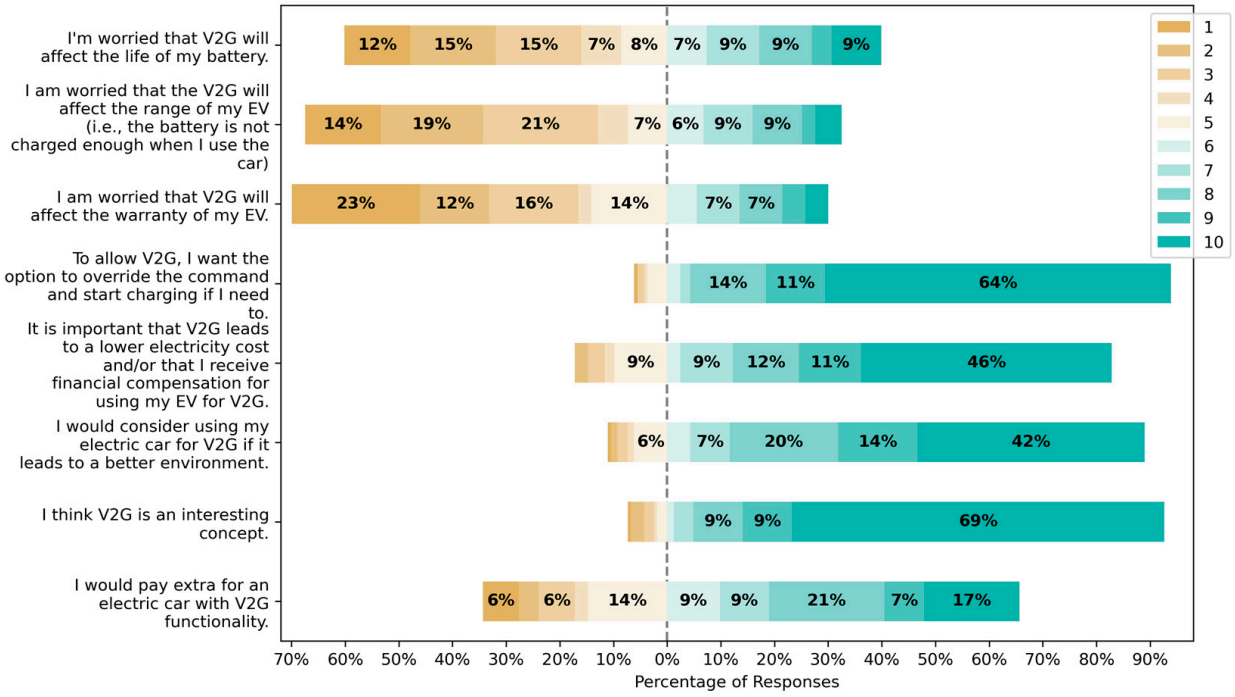

Figure 7. Results of questions/statements about V2G integration with EV in part 3 of the questionnaire; male respondents only (N = 163).

The possible provider of the V2G services seems to be a less important question for the respondents as long as the service does not affect the user negatively, although third a party aggregator would be more preferred over OEMs, as shown in Figure 8.

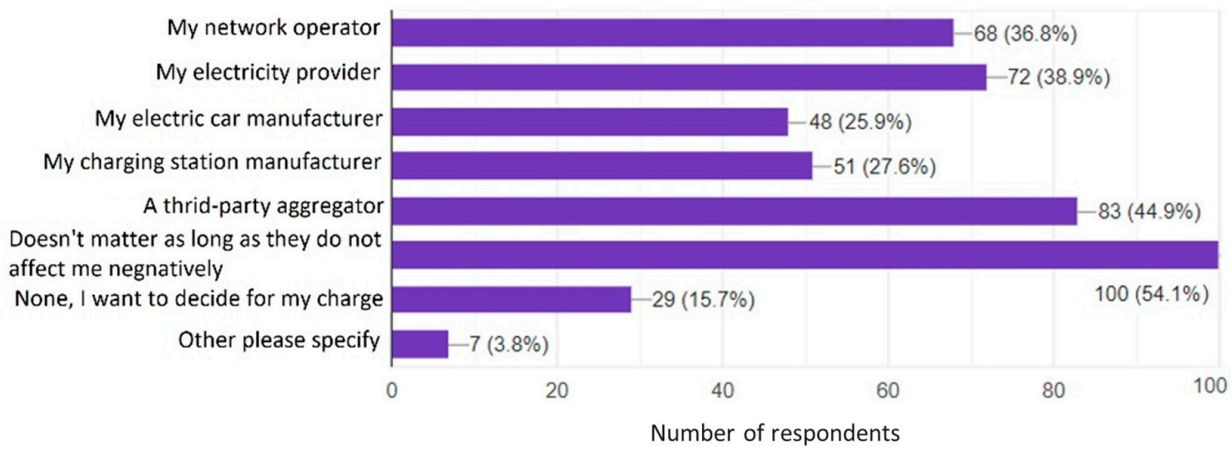

Figure 8. Results of the question/statement "I could use the following companies to control the charge and discharge.".

In the fourth part, the respondents provided their answers about V2H application by EV. Figure 9 shows the results of the responses for all questions/statements in part 4 of the questionnaire. More than 73% of the participants thought that V2H is an interesting concept, and the respondents were more interested in V2H than in V2G (i.e., it is important to be able to use the electric car's battery to supply the home's load with electricity in case of power outages). As for V2G, most of the respondents wanted full control of V2H over when and how the electric car is charged. This could be linked to the importance of being able to override the V2G operation. More than 70% of the respondents indicated that it is important (answered < 6) to be able to use the electric car's battery to supply their home with electricity in the event of a power failure. Compared to V2G, a few more respondents (69%) showed interest in paying extra for an electric car with V2H functionality.

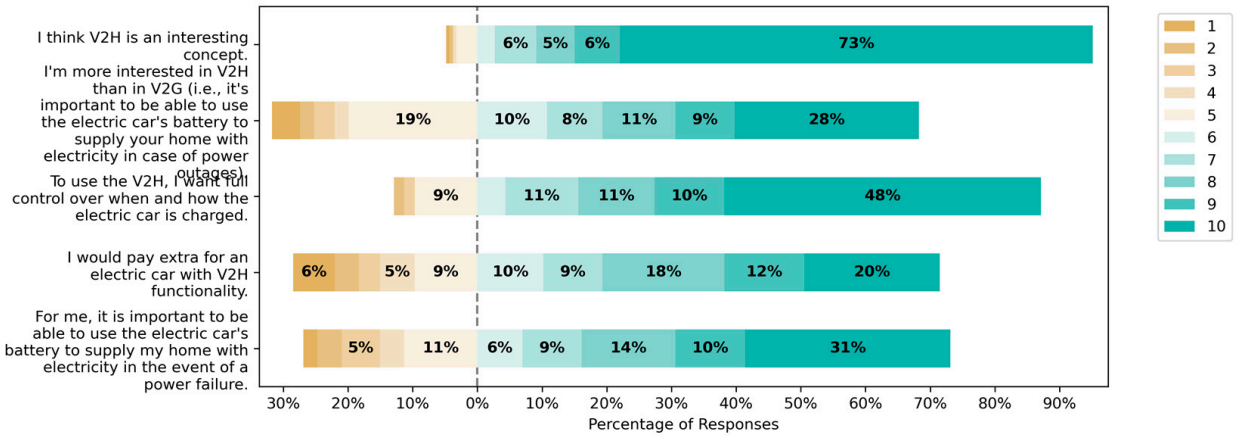

Figure 9. Results of questions/statements about V2H application by EV in part 4 of the questionnaire; all respondents (N = 186).

Female respondents seemed to be more interested in V2H compared to male respondents, as shown in Figures 10 and 11. As for V2G, female respondents also required more control of the charging.

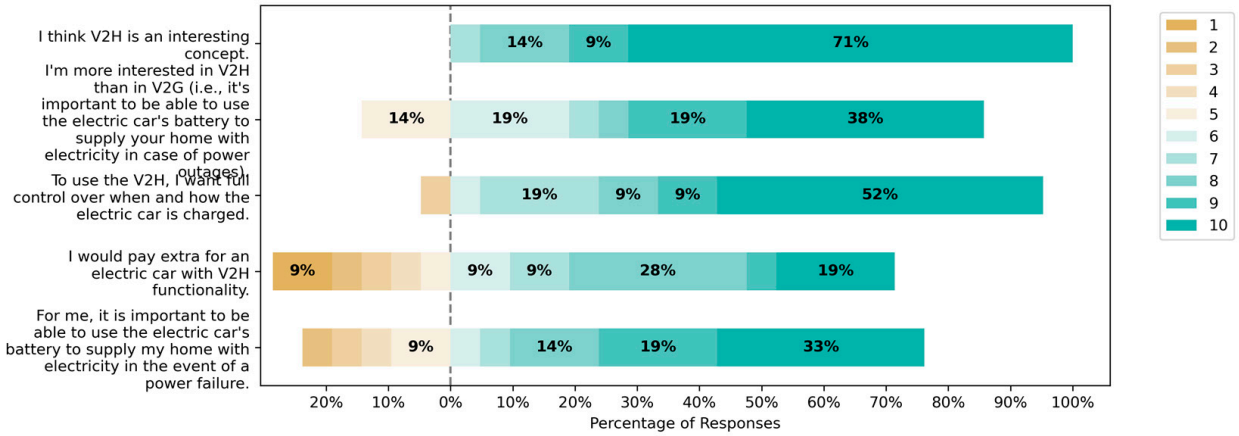

Figure 10. Results of questions/statements about V2H application by EV in part 4 of the questionnaire; female respondents only (N = 21).

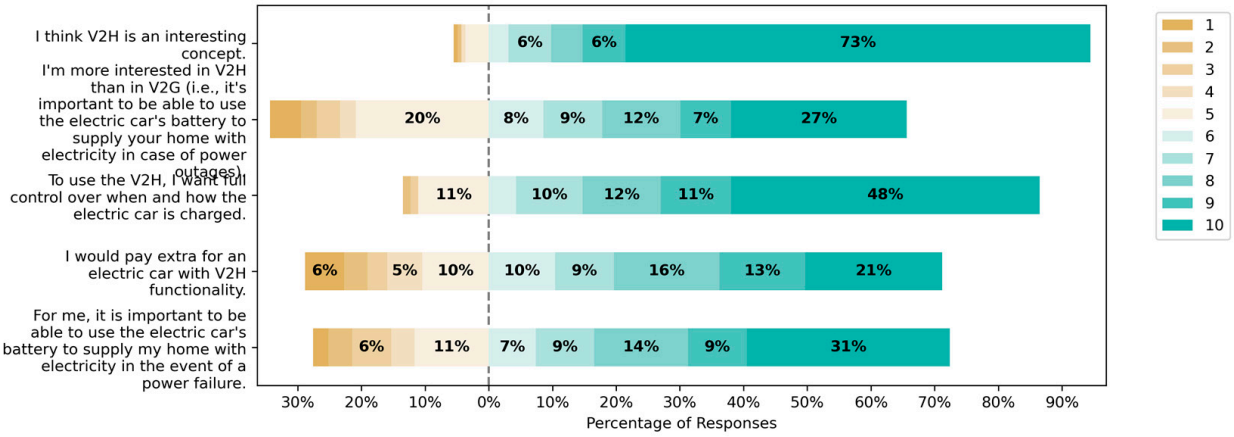

Figure 11. Results of questions/statements about V2H application by EV in part 4 of the questionnaire; male respondents only (N = 163).

5. Comments and Discussions

At the end of each part of the questionnaire, the respondents were asked to add their comments. This section discusses the comments by the respondents in the online questionnaire.

After part 1 finished, the respondents were asked to add their comments in general about that part. They made comments in three different aspects: (i) charging option, (ii) V2X benefits, and (iii) charging with PV. First, they discussed their charging option, i.e., where they normally charge their EVs. Table 6 presents the comments made by the respondents regarding their charging options. It is notable that some of the responses are not shown in the table because of repetition.

The respondents also made comments regarding the V2X benefits for their EVs. Although a respondent felt good about V2X with the comment "*Looking forward to when the electric car can be seen as an asset in the grid instead of a load!*", others had concerns about it. For example, a respondent made a comment that "*Another thought I have is whether the V2X actually gives such great advantages over just smart charging (i.e., avoid high bills and power peaks)?*". As raised in the comment, the respondent is still not sure whether V2X is beneficial for them or not. Another concern was raised in the following comment: "*V2G is a natural development, with the "political risk" as usual the big problem. Making decisions that affect your finances for maybe 20 years. At the same time that politicians can change everything with a 30-s decision is absurd. If this is to be done, the rules of the game must NOT be changed without at least two parliamentary elections between them.*". Another concern was raised regarding the battery

warranty of the EV: "*Would love to use the car's battery to balance the house's consumption, so-called peak shaving or load-shift. I don't see any technical obstacles really, but how the car's warranties regarding the battery limit.*".

Table 6. Comments made by the respondents regarding their charging options after part 1 of the questionnaire.

Context	Comments/Statements Made by the Respondents
Charging options	*"Villa with its own garage, charging possibilities both in the garage and in the garage driveway"* *"Country place for me or siblings with charging for two cars 11 kW and 3.6 kW"* *"We live in the countryside and charging possibilities in addition to our own charging box at home are limited."* *"Has car with 220 V socket 16 A and the possibility to charge another electric car"* *"Charging at work mainly. Secondly, malls and other public chargers"* *"Has the possibility of charging in a holiday home"* *"Access to parking with charging at my workplace within walking distance of home."* *"Summer cottage with charging box"* *"Probably 95% at home."* *"Living in the country has charger for family's 2 electric cars + guest charging point"*

Some of the respondents raised concerns regarding their solar PVs at home and their role in their EV charging. For example, it was mentioned that "*Lives in the country. Have a Zoe that lasts over 30 miles summer and 22 miles winter. Ideal. solar cells that charge cheaply in the summer*". Other respondents also made comments regarding smart charging with dynamic load control and the prioritization of solar electricity for EV charging. It is inevitable that having rooftop PV can add to the benefits of V2X by charging the EV using PV electricity and discharging the EV at peak times when there is no PV power.

After part 2 of the questionnaire, the respondents were asked to explain their EV charging by answering the following questions: "Describe how you charge your electric car today? Do you control the charging on time, or do you charge immediately after parking? If you control the charging, do you control it manually or automatically? How much would you need to save per month for it to be relevant to control your charging? Or if you have any other comments about your charging behaviour."

Figure 12 demonstrates the different ways of EV charging mentioned by the respondents. Most respondents start charging immediately when they park their EVs after the end of the working day. Some of them charge their EV manually. However, most of them charge their EV automatically, using smart chargers which decide for charging based on the time of day. Some respondents stated that they can control the charging using an app. The other respondents said that they use the scheduling program of the car for charging.

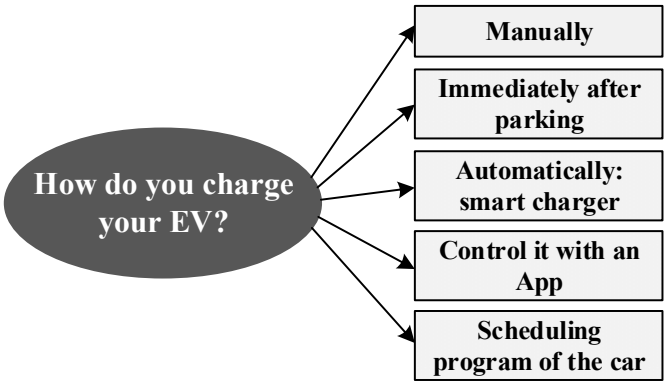

Figure 12. Ways of EV charging mentioned by the respondents.

Table 7 presents some of the comments and statements of the respondents on their electric car charging. Some of the respondents start charging automatically at 23.00 because

the network is less loaded then. The respondents mostly said that they only need to charge once or twice a week. Based on the received comments, they usually charge in single-phase sockets, but in some cases, they also charge via a three-phase fast charger. Some respondents noted that they use the charging box at the apartment that cannot (unfortunately) be controlled; hence, they always charge when they plug in. As shown in Table 7, the respondents use different strategies to reduce the charge cost of EV. Some try to charge their EV at noon using the generated power of solar PV. Charging at midnight is also mentioned by the respondents. Some follow the market electricity price to charge their EV at low prices manually or automatically.

Table 7. Detailed comments by the respondents regarding how they charge their EV after part 2 of the questionnaire.

Context	Comments/Statements Made by the Respondents
How do you charge your EV?	*"Have solar cells on the roof so charge when the sun shines the most and I get the most power, usually after 12 o'clock on a sunny day. In winter, I charge in the evening after 9 pm if I don't need the car at the time and the battery is uncharged (for planned trip)."* *"I have an Easee charger that my electricity supplier supports (Tibber) which makes charging smart. It shows how many percent I want charged to and when I'm going away in the morning. Based on this, it looks at the price of electricity and when it is most advantageous to charge."* *"Control the charging with the car's scheduling so that it charges to 80 percent at night and is heated when it's time to leave in the morning. On weekends, it is allowed to charge 100 percent, in case there is a longer excursion planned."* *"I charge just over 1800 kWh per month. The price is not very important. What is required is intelligence in the car and the charger, i.e., that you can set up "rules" how it should work."* *"I plug in the car at home but don't charge until the night. What public charging stations? There is a big difference between destination charging and fast charging, you have to distinguish between that. I never use public destination charging, I just do it at home. I only use public fast chargers and I do that when I make longer trips. At home, I charge slowly, 8 A single phase, at night."* *"Control manually. In the summer months mainly during the daytime to utilize power from own solar cells. In the winter months mainly evening/weekend. Only fully loaded for long journeys, otherwise to 80% SOC."* *"We charge at home when needed. But usually overnight and that the charging is ready until about 05:00 as we control through the car's built-in schedule, this to help with the balancing of the electricity grid, we have fixed electricity subscription for three more years, so we don't really have to care. The car and box we have is one that can receive and deliver 22 kW, but we have only secured up to 25 A, so we do not get the maximum speed at home. Before, we had about 17 miles of round-trip commuting, hence a little more important for us with fast AC charging. Our house is heated with a waterborne electric boiler so having an hourly rate on the electricity is not an option for us until we change the heating system."* *"Try to charge during the day in the summer with our own solar cells on the roof. In December with record electricity price, I cancelled night charging so I would say I have to save at least 500 SEK to control my charging."* *"Charging to 80%, if necessary, thus does not charge after each drive, if there is a need for longer mileage charging to 100%, no steering against time or price, today has regular fuse subscription, so the only thing that limits is the main fuse, so usually the car is charged with about half the maximum charging current"* *"I have a variable monthly price, so when in the day I charge does not affect the cost. However, for fun, I have in recent months manually controlled the charging to times when an intended hourly charge has been low. So, it is not primarily the savings, but being able to influence the load on the mains, that makes me adjust the charging. Charging to 70% and to full of preheating of the car when I'm going far."* *"In addition to electricity price control, I myself have implemented a power control that controls the charging power in such a way that the total hourly power output from the grid does not exceed a present level, due to the power tariff. Charging at night saves me in the order of SEK 100/month and optimizing the charging power against the power tariff saves me about 250 SEK/month."*

After part 3 (V2G integration) of the questionnaire, the participators asked to note their comments regarding the following questions: Are there other aspects that affect whether you would use your electric car to deliver V2G services? How much would you need to save/earn per month for it to be relevant to use your electric car for V2G? Or would you like to clarify the answer above?

Several respondents noted that the value of V2G for the environment is high and hence they do not care about the financial compensation. They noted that it is important

that the electric car manufacturer has guarantees that the battery can withstand many discharges. On the other hand, the respondents noted that it should be visually clear what they are saving/earning: both in terms of money and the environment. Different ranges of remuneration (financial compensation), from SEK 100/month to SEK 1000/month, were reported by the respondents. Table 8 presents the details of some comments and statements of the respondents regarding V2G integration.

Table 8. Detailed comments by the respondents regarding V2G integration after part 3 of the questionnaire.

Context	Comments/Statements Made by the Respondents
Are there other aspects that affect whether you would use your electric car to deliver V2G services? How much would you need to save/earn per month for it to be relevant to use your electric car for V2G? Or would you like to clarify the answer above?	*"But the kickback has to be hefty for me to be interested. Kind of free charging. My potential marginal cost must be lower than the electricity company's margin gain. So, selling the electricity three times my purchase price (including taxes, fees and network charges) is the absolute lowest. Five times would be reasonable, and ten times would be a no-brainer."* *"It would have been nice if you could save the equivalent of a higher price for the electric car in about 5 years, but it is not a requirement, I mostly want to participate in the technology development."* *"The financial incentive must be significant. Alternatively, the car manufacturer includes an extended battery warranty as long as you offer your battery to the V2X."* *"Depends on negative impact on the car's economy/warranties/battery life. Sees primarily the possibility of V2V as interesting rather than V2G (although V2V also facilitates for G because the house consumption is evened out)."* *"The compensation must at least correspond to "wear and tear"/depreciation. The key question is which manufacturers allow V2G and under what forms. There is a clear conflict between the interest and priority of the owner and the manufacturer."* *"I believe in selling flexibility services. Want to be sure that there is at least 70–80% charging when I need it (I can specify the time in advance). Economics is not unimportant (fair compensation) but climate and system benefits even more important."* *"The most important thing is that the car is sufficiently charged when I need it and that any cost of wear and tear/impact on the car is weighed up by some kind of compensation for the electricity one contributed."* *"The question is, after all, whether it is worth it to pay more for a charging box and electric car that enables the V2X in the end, and who profits the most? Is it worth it for me as a prosumer (i.e., do I get compensation for the service)? Is it network crew that feels it (i.e., it frees up power cache - but then they probably need to pay compensation to V2G customers). What is the net effect on society?"* *"I would love to use the car as a power bearing for the hours of the day when the electricity is at its most expensive, and then charge it when it is at its cheapest. However, there are no technical conditions for it today where I live - in rental housing. I would love to earn something, but it doesn't have to be much as long as the investment is not so big. I need to buy a car anyway, unlike solar cells which are a big cost and take a relatively long time to earn."*

After part 4 (V2H application) of the questionnaire, the participators asked to note their comments regarding the following questions: Are there other aspects that affect whether you would use your car for V2H services? Or would you like to clarify the answer above?

Some of the respondents noted that they want to have V2H to reduce electricity consumption from the grid at high electricity prices (electricity price optimization). It was also noted that V2H is interesting for the summer cottage, where there is no electricity at all. Some of the respondents stated that they would like to pay for a stationary battery rather than V2H. Some stated that they do not see a huge need for V2H; it would be good to have it sometimes, but they do not want to pay a large amount of money for it. There was a conflict in the comments about using V2H as a back-up for power outages. While some respondents showed a great interest in becoming independent of the main grid because they foresee more power outages in the future, others stated that working off-grid is not an advantage because, given the quality of supply of the electricity networks where they live, they have only experienced a couple of short power outages in the past 10 years. Table 9 presents the details of some comments and statements by the respondents regarding V2G integration.

Table 9. Detailed comments by the respondents regarding V2G integration after part 4 of the questionnaire.

Context	Comments/Statements Made by the Respondents
Are there other aspects that affect whether you would use your car for V2H services? Or would you like to clarify the answer above?	*"A little doubtful if the V2H is worth it from an economic perspective as it would probably require a lot of other "smart gadgets" to control it (maybe even a separate DC network or similar to avoid losses etc.)."* *"The question is, does the network owner allow it? Have battery for the solar cells today and it must have power to work, i.e., if the power goes, I have no use of the battery. Off-grid solutions only work if they are always completely off the grid."* *"The use of the car for V2H requires some investment in the property's electricity network so as not to risk trying to supply the entire electricity grid in the event of an outage, this is a factor to take into account."* *"I think you have to think V2G and V2H together. Only if you get both can it get so interesting that I want to pay for it. And it must be able to be connected to the existing solar cell system."* *"I am prepared to pay 10 thousand SEK extra or even more to get V2H support in the car. I don't have to buy an extra battery for the house. However, the system must of course be able to cope with island operation otherwise it is not interesting."* *"My electrical installation must be built for V2H for it to be usable. The installation must be approved by the network owner for the necessary security for network owner personnel."* *"Automated V2G I think is more interesting than V2H. Power outages are so rare that if a well-developed V2G is in place, the arguments for V2H decrease in my opinion. V2L, on the other hand, could be more interesting in that case. But the most important thing is that all cars in the future support the V2X in some form."* *"How easy it is for me as a user to control. A good electricity trading agreement where I can save money and see the climate benefits of using the car battery as stock."*

6. Conclusions and Policy Implications

The main purpose of this research was to examine the willingness of Swedish EV owners to participate in vehicle-to-everything (V2X) implementation. This aim was investigated using an online questionnaire. The respondents of the questionnaire were requested to answer the questions in three important contexts: (1) claims related to their EV charging, (2) V2G integration with EV, and (3) V2H application by EV. The respondents were also able to make a comment after each part of the questionnaire. The results could be used to better understand if there is an interest for V2X solution among EV owners in Sweden and what motivates an EV owner to participate. A total of 191 persons responded to the questionnaire, mostly men, living in a single-family house with an EV. The main findings obtained from the results of this questionnaire can be summarized as follows:

- As an important finding through the questionnaire, it was emphasized that Swedish EV owners are more interested in V2H than V2G for the V2X implementation. They think having the electric car as a back-up power at home is more important, and a majority were willing to pay extra for an electric car with V2H functionality.
- The participants in this study were less concerned about battery degradation, range anxiety, and EV warranty, compared to other studies. One reason for this could be that a majority of the respondents were male, who were less concerned about these aspects compared to the female respondents.
- The participants showed a high interest in having full control over when and how the electric car is charged/discharged. They would like to have the option to over-ride the V2G operation and start charging directly.
- Regarding financial compensation, the respondents mostly noted in their comments that it should cover the battery wear cost. Since the extra cycles by V2X reduce the battery lifetime, the car manufacturer or other stakeholders should compensate the cost of battery degradation for EV owners.
- It was found that EV owners would like to care about sustainability as much as they would like financial compensation by the V2X implementation. Economic compensation is not unimportant (fair compensation) but sustainability and system benefits are also important.
- For respondents without their own charger, it was a bit more important to have control of the charging. They were also worried whether they can have a clear view of the V2X

implementation in terms of contribution through the apartment buildings' chargers which are controlled by the real estate owner or other actors.

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References

1. International Energy Agency. Global EV Outlook 2023. Available online: https://www.iea.org/reports/global-ev-outlook-2023 (accessed on 5 January 2024).
2. World Economic Forum. Electric Car Sales Have Surged in Europe—So Why is Adoption Still Slow? Available online: https://www.weforum.org/agenda/2023/11/electric-car-sales-europe-barriers-ev-adoption/ (accessed on 5 January 2024).
3. Khezri, R.; Mahmoudi, A.; Haque, M.H. Impact of Optimal Sizing of Wind Turbine and Battery Energy Storage for a Grid-Connected Household with/without an Electric Vehicle. *IEEE Trans. Ind. Inform.* **2022**, *18*, 5838–5848. [CrossRef]
4. Khezri, R.; Mahmoudi, A.; Aki, H. Optimal planning of solar photovoltaic and battery storage systems for grid-connected residential sector: Review, challenges and new perspectives. *Renew. Sustain. Energy Rev.* **2022**, *153*, 111763. [CrossRef]
5. Šolić, A.J.; Jakus, D.; Vasilj, J.; Jolevski, D. Electric Vehicle Charging Station Power Supply Optimization with V2X Capabilities Based on Mixed-Integer Linear Programming. *Sustainability* **2023**, *15*, 16073. [CrossRef]
6. Islam, S.; Iqbal, A.; Marzband, M.; Khan, I.; Al-Wahedi, A.M. State-of-the-art vehicle-to-everything mode of operation of electric vehicles and its future perspectives. *Renew. Sustain. Energy Rev.* **2022**, *166*, 112574. [CrossRef]
7. Emodi, N.V.; Dwyer, S.; Nagrath, K.; Alabi, J. Electromobility in Australia: Tariff design structure and consumer preferences for mobile distributed energy storage. *Sustainability* **2023**, *14*, 6631. [CrossRef]
8. Vehicle-to-Grid (V2G) Technology in Kia EV6. 2023. Available online: https://www.turnerkia.com/blogs/3300/uncategorized/the-future-of-driving-exploring-the-technology-behind-the-kiaev6/#:~:text=The%20Kia%20EV6%20is%20equipped,to%20the%20grid%20when%20needed (accessed on 25 December 2023).
9. Vehicle-to-Grid Tech Impowers EV Owners. 2023. Available online: https://www.nissan-global.com/EN/STORIES/RELEASES/v2g-tech-empowers-ev-owners/#:~:text=The%20V2G%20technology%20in%20the,to%20stabilize%20the%20power%20grid (accessed on 20 September 2023).
10. Thompson, A.W.; Perez, Y. Vehicle-to-Everything (V2X) energy services, value streams, and regulatory policy implications. *Energy Policy* **2020**, *137*, 111136. [CrossRef]
11. Pearre, N.S.; Ribberink, H. Review of research on V2X technologies, strategies, and operations. *Renew. Sustain. Energy Rev.* **2019**, *105*, 61–70. [CrossRef]
12. Gschwendtner, C.; Sinsel, S.R.; Stephan, A. Vehicle-to-X (V2X) implementation: An overview of predominate trial configurations and technical, social and regulatory challenges. *Renew. Sustain. Energy Rev.* **2021**, *145*, 110977. [CrossRef]
13. Thompson, A.W. Economic implications of lithium-ion battery degradation for Vehicle-to-Grid (V2X) services. *J. Power Sources* **2018**, *396*, 691–709. [CrossRef]
14. Corchero, C.; Sanmarti, M. Vehicle- to- Everything (V2X): Benefits and Barriers. In Proceedings of the 2018 15th International Conference on the European Energy Market (EEM), Lodz, Poland, 27–29 June 2018; pp. 1–4.
15. Ferreira, J.C.; Monteiro, V.; Afonso, J.L. Vehicle-to-Anything Application (V2Anything App) for Electric Vehicles. *IEEE Trans. Ind. Inform.* **2014**, *10*, 1927–1937. [CrossRef]
16. Polestar Initiates V2G Project. 2023. Available online: https://media.polestar.com/global/en/media/pressreleases/675426/polestar-initiates-v2g-projects-and-develops-virtual-power-plant-to-support-large-scale-energy-trans (accessed on 28 November 2023).
17. The DrossOne V2G Parking Project. 2023. Available online: https://www.esolutions.free2move.com/company/drossone-project/ (accessed on 25 December 2023).
18. Khezri, R.; Steen, D.; Tuan, L.A. A Review on Implementation of Vehicle to Everything (V2X): Benefits, Barriers and Measures. In Proceedings of the 2022 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe), Novi Sad, Serbia, 10–12 October 2022; pp. 1–6.

19. Parsons, G.R.; Hidrue, M.K.; Kempton, W.; Gardner, M.P. Willingness to pay for vehicle-to-grid (V2G) electric vehicles and their contract terms. *Energy Econ.* **2014**, *42*, 313–324. [CrossRef]
20. van Heuveln, K.; Ghotge, R.; Annema, J.A.; van Bergen, E.; van Wee, B.; Pesch, U. Factors influencing consumer acceptance of vehicle-to-grid by electric vehicle drivers in the Netherlands. *Travel Behav. Soc.* **2021**, *24*, 34–45. [CrossRef]
21. Kester, J.; Noel, L.; de Rubens, G.Z.; Sovacool, B.K. Promoting Vehicle to Grid (V2G) in the Nordic region: Expert advice on policy mechanisms for accelerated diffusion. *Energy Policy* **2018**, *116*, 422–432. [CrossRef]
22. Noel, L.; Carrone, A.P.; Jensen, A.F.; de Rubens, G.Z.; Kester, J.; Sovacool, B.K. Willingness to pay for electric vehicles and vehicle-to-grid applications: A Nordic choice experiment. *Energy Econ.* **2019**, *78*, 525–534. [CrossRef]
23. Geske, J.; Schumann, D. Willing to participate in vehicle-to-grid (V2G)? Why not! *Energy Policy* **2018**, *120*, 392–401. [CrossRef]
24. Huang, B.; Meijssen, A.G.; Annema, J.A.; Lukszo, Z. Are electric vehicle drivers willing to participate in vehicle-to-grid contracts? A context-dependent stated choice experiment. *Energy Policy* **2021**, *156*, 112410. [CrossRef]
25. Zheng, Y.; Shao, Z.; Shang, Y.; Jian, L. Modeling the temporal and economic feasibility of electric vehicles providing vehicle-to-grid services in the electricity market under different charging scenarios. *J. Energy Storage* **2023**, *68*, 107579. [CrossRef]
26. Hao, X.; Chen, Y.; Wang, H.; Wang, H.; Meng, Y.; Gu, Q. A V2G-oriented reinforcement learning framework and empirical study for heterogeneous electric vehicle charging management. *Sustain. Cities Soc.* **2023**, *89*, 104345. [CrossRef]
27. Kim, J.; Kim, J.; Jeong, H. Key Parameters for Economic Valuation of V2G Applied to Ancillary Service: Data-Driven Approach. *Energies* **2022**, *15*, 8815. [CrossRef]
28. Gowda, S.N.; Nazaripouya, H.; Gadh, R. Congestion Relief Services by Vehicle-to-Grid Enabled Electric Vehicles Considering Battery Degradation. *Sustainability* **2023**, *15*, 16733. [CrossRef]
29. Statistics Sweden. Dwelling Stock. Available online: https://www.scb.se/bo0104-en (accessed on 5 January 2024).
30. Vassileva, I.; Campillo, J. Adoption barriers for electric vehicles: Experiences from early adopters in Sweden. *Energy* **2017**, *120*, 632–641. [CrossRef]
31. Andersen, P.B.; Toghroljerdi, S.H.; Sørensen, T.M.; Christensen, B.E.; Ho, J.C.M.L.; Zecchino, A. *The Parker Project: Final Report*; Technical University of Denmark: Lyngby, Denmark, 2019. Available online: https://parker-project.com/wpcontent/uploads/2019/03/Parker_Final-report_v1.1_2019.pdf (accessed on 5 January 2019).
32. Research Chalmers. Electric Cars for Everything—Mobility with Additional Services (V2X-MAS). Available online: https://research.chalmers.se/en/project/?id=10258 (accessed on 24 October 2022).
33. Sovacool, B.K.; Noel, L.; Axsen, L.; Kempton, W. The neglected social dimensions to a vehicle-to-grid (V2G) transition: A critical and systematic review. *Environ. Res. Lett.* **2018**, *13*, 013001. [CrossRef]