Article

A Survey Data Approach for Determining the Probability Values of Vehicle-to-Grid Service Provision

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Abstract: One of the key aspects of vehicle-to-grid technology (V2G) is the analysis of uncertainty in electric vehicle user behavior. Correct estimation of the amount of available energy from electric vehicles that are expected to provide ancillary services to the electricity system operator or to secure the end user's demand is essential to design these services in an appropriate way. Therefore, it is necessary to analyze the probabilities of V2G service performance for different scenarios. This paper presents the author's approach to determining the values of V2G service provision probabilities using survey data. It was found that estimating these values using simulation and forecasting tools makes sense when the coefficients resulting from survey responses are used as initial data. Thus, the paper also presents the results of the surveys that were conducted. As the results from the simulations show, the values of the probabilities of V2G services are not high, which should induce future operators of V2G services to offer a beneficial product for the customer.

Keywords: vehicle-to-grid; vehicle-to-everything; electric vehicles; smart grids

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1. Introduction

In the 21st century, society is faced with the problem of excessive greenhouse gases emissions, which significantly affect climate change [1,2]. One of the largest emitters of carbon dioxide (CO₂) into the atmosphere is the transportation sector [3,4]. As a result, many government organizations are trying to influence the automotive sector through legislative changes in order to minimize CO₂ emissions into the atmosphere [5]. One of the factors that may influence such action is the promotion of electric vehicles (EVs) [6]. EVs can be divided into three main groups: battery electric vehicles (BEVs), which are vehicles that run solely on electricity from a battery pack, plug-in hybrid electric vehicles (PHEVs), which are hybrid vehicles that use electric motors and an internal combustion engine (ICE) but have the ability to charge the internal batteries from both the internal combustion engine and an electrical socket, and fuel cell electric vehicles (FCEVs), which are run by hydrogen [7]. Because electric vehicles have rechargeable batteries in their design, they can be treated as mobile electricity storage [8]. Therefore, their potential as an auxiliary source of electricity for additional demand should be exploited. These principles are the basis of vehicle-to-grid (V2G) technology or in general vehicle-to-everything (V2X) technology [9]. It involves voluntarily discharging the battery of an electric vehicle into the power grid or any other facility owned by the end-user, which can be called, in simple terms, a V2G service. It is worth mentioning here that in order to release the full potential of V2G technology, electric vehicles should be integrated with local power systems creating microgrids [10–12]. Through the development of renewable energy source (RES) technologies, local energy balancing solutions have become popular and there is certainly a place for electric vehicles in them [13]. It is possible to use EVs directly in covering the demand of the household (V2H—vehicle-to-home) or the commercial end user (V2L—vehicle-to-load) [9]. The idea of local energy balancing involves the efficient use of electricity produced from uncertain energy sources, such as photovoltaic plants (PVs) or wind turbines (WTs). This can be achieved by battery energy storage systems (BESS). Knowing that an

EV can be treated as a mobile energy storage, its use in accumulating energy from PVs and WTs and possibly discharging it in case of a lack of electricity production due to unfavorable weather conditions seems to be appropriate. Figure 1 shows an example concept for integrating an EV into a microgrid.

Figure 1. Integration of the EV in the local microgrid with possible V2X service provision.

With V2G technology also comes a number of economic aspects. Electric vehicles that would participate in V2G technology can also provide ancillary services to the power system operator. There are many references in the literature to such a use of electric vehicles [14–18]. In [14], the use of fuzzy linear programming in forecasting the provision of the most basic ancillary services such as capacity regulation is presented. In [15], the application of V2G technology in primary regulation is presented for a power system located on the island of Bornholm, while in [16] results of a simulation of V2G use in an industrial microgrid are presented. In [17], the capabilities of V2G technology in the context of large-scale power system balancing are presented. In [19,20], various algorithms needed to evaluate the performance of frequency control services are described. There are also mentions of the possibility of providing a supplementary energy source [21]. Electric vehicles are also a means to provide grid flexibility services [13,22,23]. In the literature it is also possible to find examples of creating business models, mainly based on aggregators, i.e., external companies grouping EVs with each other, e.g., from a given region [24]. V2G aggregator models were also presented in [25,26], where the settlement models are based on forecasting the service revenue for day-ahead markets. In [26], solutions similar to auction mechanisms have also been proposed, while in [14] the potential gains from providing system services are presented. In [27], an aggregator concept that can manage electric vehicles for V2H, V2G, and also vehicle-to-vehicle (V2V) technologies is presented. It was also pointed out that such an aggregator should communicate with the grid operator in order to inject energy into the power grid. Typical economic efficiency analyses of V2G service provision concepts have also been performed [28,29]. Following this, the literature also includes discussions on the quantification of revenue from the provision of V2G services. In [9], values of annual service revenue for different types of services are presented. The evaluation of EV battery degradation costs is also an important issue [21,30,31].

Nevertheless, one of the most important aspects regarding V2G technology is the social and legal aspect. In [32,33], the topic of the functioning of the technology in a legal framework was addressed. In [32,34], it is stated that the basic legal framework for the unrestricted functioning of V2G technology is missing. While analyzing the social aspects of introducing V2G technology into electricity markets, the opinion of future users should also be taken into account. In [33,35], the results of a social survey on V2G technology in the Nordic region are presented. Both the social point of view and potential legislative problems are presented. In [36], the authors present the results of a survey of Australian employers and employees on the use of V2G technology in company vehicles in an economic and operational context. In [37,38], survey results were presented that linked user behavior to proposed economic models of V2G service provision mechanisms. Nevertheless, one of the biggest issues that needs to be addressed relates to the uncertainty of performing V2G services due to the lifestyle of EV users. It should be emphasized that regardless of the energy merits of V2G services, it should be kept in mind that, as a priority, EV users will want to use them for their purposes. Therefore, several papers can be found in the literature on the analysis of travel patterns of EV users [39–41]. The literature also addresses the issue of how EV users' travel patterns affect charging profiles [42]. It is relevant because the times when the vehicle is being charged affect the length of the V2G service provision, as this is the moment when the vehicles are connected to the charging stations. All these aspects should encourage researchers to further expand their knowledge in the area of V2G technology.

This paper presents the consideration of EV user views in the process of calculating the probability of V2G service provision. This paper is also a continuation of the considerations presented in [34]. It should be mentioned that, according to [34], the provision of the V2G service depends not only on the available electric energy in EVs, but also on the probability of its provision. This means that the amount of energy available to the end user or operator will depend on how users behave. It is therefore proposed that surveys should be used to obtain an answer as to how much interest there would be in introducing V2G services into the market. The paper is organized as follows: V2G Program and V2G service are defined in Section 2. A mathematical notation of the provision of a V2G service is also presented. Section 3 presents the description of the survey, which are used to calculate the necessary probabilities later in the paper. Detailed results are depicted in Appendix A. Section 4 develops a methodology for calculating the probabilities of V2G service provision, and in Section 5, exemplary simulation results are presented.

2. Assumptions of V2G Program

2.1. Definitions

This paper is a follow-up to the discussion presented in [34]. Therefore, the most important definitions regarding the designed V2G Program mechanism should be referenced first. In this subsection, the concepts previously presented in [34] will be recalled, and some of them will be supplemented with additional information. The most important definitions are as follows [34]:

1. **V2G service** is a defined action, which is undertaken by the V2G Program participant, aimed at the improvement of the power system operation, or ensuring sufficient capacity for the end user.
2. **V2G Program participant (μ EV)** is the owner of an electric vehicle or fleet of electric vehicles, who provides services by offering battery capacity to end users or a distribution system operator.
3. **End user (EndUs)** is the energy consumer, who has decided to use electric vehicles for reserve power supply within the V2G Program.
4. **V2G Program** is understood as the activity of a power company involving the use of electric vehicles to improve the operation of the power grid or/and to improve the security (assurance) of supply.

5. **V2G service provider (V2Gsp)** is the party managing the V2G Program in a given area.
6. **Mandatory mode** is a V2G service mode in which the V2G Program participant (uEV) receives a fixed payment in exchange for remaining on standby and unconditionally providing service on demand from the V2G service provider. If the service is not provided, the uEV will incur fines that are proportional to their participation in the V2G Program.
7. **Optional mode** is a V2G service mode in which a V2G Program participant is paid only for the EV discharging action that is completed. The participant will not be remunerated for willingness to perform the service and remain on standby but will also not receive fines for not providing the service.

Analyzing the aforementioned definitions, it may be questioned why the terms are limited to vehicle-to-grid technology only and not to the overall service, i.e., vehicle-to-everything (V2X). In principle, there is not much difference in the flow of energy between a vehicle and the electric grid of a facility, household, or a point in the distribution grid. However, the choice of the word “grid” in the definitions is intentional and indicates that the services offered will be delivered to a larger number of customers or even to the power system. The usage of the terms associated with V2G technology is also intended to distinguish these services from the standard vehicle-to-home (V2H) or vehicle-to-building (V2B) technology framework. As included in [27], V2H technology is rather designed for a household’s self-consumption without the intervention of a third-party aggregator. On the other hand, in [34] and in this publication, assumptions are made for services that can also be provided in the household, but nonetheless at the order of a third-party operator—in this case a V2Gsp. Hence, it seems appropriate to use the term “grid”, which suggests third-party interference in the time and place of service provision. However, it is important to emphasize the difference between providing V2G service in one’s own household and providing service in other residential buildings. In the case where a particular uEV would provide the service in other households (e.g., neighbors), this should be considered as providing the service to the end user, to whom it should be moved, and the EndUs should provide a charging space. In [34] this type of service is named as “Emergency work for the energy consumer” and only this type of service will be analyzed in this paper (in Sections 4 and 5 referring to the V2GL). In case the uEV would provide a V2G service in their household for the purpose of a V2Gsp, it is necessary to refer to a different type of service. In [34], it is indicated that V2G services could be ordered to a V2Gsp by a DSO. Thus, discharging EVs for the household’s own purposes can be treated as a capacity constraint measure (later referred to as V2GH). Hence, it can be considered that this would be a type of grid flexibility services [23]. However, this material will be discussed in a separate paper.

Figure 2 shows the relations between the various members of the V2G Program during the provision of the V2G service. It should also be noted that it was indicated in [34] that it is practically impossible to perform services at the distribution system level and the operation of the V2G Program is limited for now to providing services directly to an EndUs. This is due to the lack of legal regulations regarding the provision of ancillary services by distribution system operators (DSOs).

Figure 2. Relations between the actors in the V2G Program—based on [34].

2.2. Provision of V2G Service—Emergency Work for the Energy Consumer

In the analysis of the V2G service provision involving discharging an EV battery to the electricity grid or to a certain end user, the uncertainty associated with the actual service provision must be taken into account. In [34], it was proposed that the expected value of energy from the EV battery delivered to the end user should be equal to the multiplication of the probability of service provision and the quantity of energy from the required number of vehicles appropriately calculated (Equation (1)).

$$E_{V2G+,t} = P(A) \cdot \sum_{n=1}^{N_{EV}^{REQ}} e_{V2G+,n} \quad (1)$$

where:

E_d —the end user's electricity demand from V2G Program, in kWh;

$P(A)$ —the total probability of providing V2G service;

$e_{V2G+,n}$ —the energy flow injected by n -th electric vehicle;

N_{EV}^{REQ} —the required number of electric vehicles for provision of V2G service for an end user;

$E_{V2G+,t}$ —the expected energy delivered to the end user in time t .

Equation (1) shows the inputs that need to be calculated in order to determine the expected value of energy delivered to the end user at time t . Firstly, the idea of establishing a V2G service for an *EndUs* has to be considered. The primary goal of this service has to be covering the electricity demand of the *EndUs* in the time frame specified by the *EndUs*. In the literature, methods for determining demand profiles for non-residential users are mainly based on the usage of forecasting techniques [43,44]. That issue is not related to the main subject of this paper; hence, the analysis of method selection for power and energy demand calculation is omitted. However, it is necessary to focus on the calculation of the electrical energy delivered by a single EV. In the literature it is possible to find quite convergent mathematical models describing the charging and discharging processes. In [45], the dependence of the transmitted capacity from EV batteries to the power grid and

the efficiency of individual processes is indicated. On the other hand, in [46], the authors focused on modeling the discharging process in relation to the state-of-charge (SOC) and the efficiency of individual processes. Therefore, it is possible to write that the energy injected by an electric vehicle to the grid is equal to [34]:

$$e_{V2G+,n} = C \cdot \left(SOC_t - \left(SOC_f(1 + R) - SOC_0 \right) \right) \cdot \eta_d \quad (2)$$

where:

C —the battery capacity of the EV , in kWh;

SOC_t —the current state-of-charge (SOC) at the time of commencing V2G service provision, in %;

SOC_f —the state-of-charge required for the next journey, in %;

SOC_0 —the minimal state-of-charge limited by technical constraints, in %;

R —a reserve, which considers the possible lengthening of the route, e.g., to avoid congestion;

η_d —the efficiency of the discharging process.

It is worth noting that the moment when the vehicle records the SOC_t refers to the moment when the service provision commences. If the vehicle is not present at the place where the service is provided, the energy required to get it from the location where the service is accepted to the place where the service is provided must also be considered. This is denoted by Equation (3).

$$SOC_t = C \cdot \left(SOC_{act} - \frac{us_{EV} \cdot d}{C} \right) \quad (3)$$

where:

SOC_{act} —the state-of-charge at the time the service proposal is accepted by uEV , in %;

us_{EV} —the average electricity consumption of an electric vehicle, in kWh/km;

d —the distance between the uEV and the service provision point, in km.

Equations (2) and (3) were used to determine the energy injected into the power grid by the EV ; however, the transmission capacity of this process must also be considered. It is known that both the on-board charger and the charging station have their capacity limitations. Therefore, it can be written that

$$\begin{cases} p_{MIN}^{EVSE} \leq P_{V2G+} \leq p_{MAX}^{EVSE} \\ p_{MIN}^{CHARG} \leq P_{V2G+} \leq p_{MAX}^{CHARG} \end{cases} \quad (4)$$

where:

p_{MIN}^{EVSE} —the minimum capacity transmitted from the V2G charging station to the power grid, in kW;

p_{MAX}^{EVSE} —the maximum capacity transmitted from the V2G charging station to the power grid, in kW;

p_{MIN}^{CHARG} —the minimum capacity transmitted from the EV on-board charger to the power grid, in kW;

p_{MAX}^{CHARG} —the maximum capacity transmitted from the EV on-board charger to the power grid, in kW;

P_{V2G+} —the discharging capacity of the EV , in kW.

For each $EndUs$ facility, the maximum capacity resulting from the injection of energy in the V2G service can be equal to the sum of the $EVSE$ capacity (Equation (5)).

$$P_d \leq \sum_{i=1}^{n_{CS}} p_{MAX,i}^{EVSE} \quad (5)$$

where:

P_d —the maximum demand that can be covered by the V2G service, in kW;

n_{CS} —the number of bi-directional charging points owned by the *EndUs*;

Thus, the maximum electricity demand of the *EndUs* in a given time frame of service provision can be determined as follows:

$$E_d^{MAX} = \int_{\tau=1}^T P_{d,\tau} d\tau \quad (6)$$

where:

E_d^{MAX} —the maximum electricity demand of the *EndUs* in a given time frame of service provision;

τ —a single hour of V2G service provision;

T —the length of the time frame, in hours.

By analogy, the energy injected into the *EndUs* system can be determined considering the transmission capacity:

$$e_{V2G+,n} = \int_{\tau=1}^T P_{V2G+, \tau} d\tau \quad (7)$$

Due to the fact that the probability of service $P(A)$ cannot be greater than 1, it is necessary to find a sufficiently larger number of electric vehicles, N_{EV}^{EST} , which in a way covers this uncertainty. This can be represented by Equations (8)–(10) [34].

$$E'_{V2G+,t} \geq E_d \quad (8)$$

$$E'_{V2G+,t} = P(A) \cdot \sum_{n=1}^{N_{EV}^{EST}} e_{V2G+,n} \quad (9)$$

$$N_{EV}^{EST} = \frac{N_{EV}^{REQ}}{P(A)} \quad (10)$$

where:

N_{EV}^{EST} —the estimated number of electric vehicles expected to be involved in establishing V2G service, considering the probability of service provision;

$E'_{V2G+,t}$ —the expected energy delivered to the end user in time t , which covers the reserve resulting from the probability of service provision $P(A) < 1$.

Thus, it can be concluded that finding the probability of service $P(A)$ is crucial to correctly estimate the number of vehicles needed to provide the service and, consequently, it is necessary to secure the demand of the end user using electric vehicles for the emergency service. The algorithm for selecting the vehicles to provide the service is described in detail in [34]. Also in [34], the probability of service provision is defined. It depends on three simultaneous random events from three points of view:

- End user— $P(EndUs)$;
- V2G service provider— $P(V2Gsp)$;
- V2G Program participant— $P(uEV)$.

The probability of service provision $P(A)$ can be described by Equation (11) [34]:

$$P(A) = P(EndUs) \cdot P(V2Gsp) \cdot P(uEV) \quad (11)$$

Moreover, in [34], each of the random events was defined according to Formulas (12)–(14):

$$P(EndUs) = (1 - P(F_{EVSE})) \cdot P(D_{PL}) \quad (12)$$

$$P(V2Gsp) = 1 - P(F_S) \quad (13)$$

$$P(uEV) = P(EC) \cdot P(US_{EV}) \cdot (1 - P(INT)) \quad (14)$$

where:

$P(F_{EVSE})$ —the probability of failure of a bi-directional charging point; $P(D_{PL})$ —the probability of the availability of a V2G charging point at the place of service delivery.

$P(F_S)$ —the probability of failure of a metering and billing system.

$P(EC)$ —the probability of the user's reaction to providing the service at a given time, e.g., receiving an economic incentive or the willingness to perform a service due to the lifestyle of the uEV ;

$P(US_{EV})$ —the probability of electric vehicle availability due to its lack of use;

$P(INT)$ —the probability of service interruption.

A minor modification from the publication [34] should be highlighted at this point. Previously, $P(US_{EV})$ was described as the probability of using the vehicle. A minor adjustment had to be made here due to the fact that service provision will only be possible when the vehicle is not in use for its own uEV 's purposes, which will be superior to service provision.

2.3. Novelty

As pointed out in [34], there is a lack of widely available data to calculate the probability of V2G service delivery, mainly for the level related to participant decisions. This problem is also highlighted in [47], where the authors point out that the absence of an EV at the discharge location can be caused by a human decision. In [47], a single two-state model was used for the process of service interruption and the absence of an EV . In this paper, it was decided to separate these probabilities. The probability of service interruption will be determined according to the methodology presented in [47], while the concept of EV absence was decided to be redefined to depend on the vehicle usage at a given moment—the probability $P(US_{EV})$ described in Section 2.2. Furthermore, according to [34], the probability of service provision will also depend on the participant's decision. In order to determine these values, it was decided to use the public's voice to design metrics that will serve as starting data in the $V2Gsp$ business model. This approach seems to be appropriate since it will be the EV users who will ultimately use the V2G Program. The problem of a lack of social analysis in the technology area was also mentioned in [48]. As the authors note in [48], most research papers focus on the technical layer, and those that consider the social layer of the problem of implementing V2G technology are single percentages. In particular, they note that the description of user behavior was described in only 2.1% of the articles they analyzed [48]. The research survey exemplar papers use advanced statistical models, which most often illustrate the decision-making models that a V2G Program operator would need to make to ensure the viability of the service [36,38]. However, from the point of view of $V2Gsp$, both the statistical parameters on which the economic model will be built and, in the later real implementation stage, a tool to select the vehicles to provide these services need to be determined. In [34], such an algorithm is presented, for the operation of which the probabilities of events that make up the performance of the service should be used. These probabilities are described in detail in Section 2.2. It is therefore proposed to determine them experimentally based on results from surveys. Their purpose is to be used as starting values in the aforementioned algorithm [34]. In case of a real implementation, these indicators should be updated by the $V2Gsp$ in real-time with current user behavior. This paper also considers the author's approach to calculating probability values associated with the decisions made by V2G Program participants. It should be kept in mind that the fact of examining the available energy from a certain number of EVs does not mean that all this energy will be delivered to the grid or end user. By using a probabilistic approach in evaluating the provision of V2G services, EVs can be used more efficiently in their integration into the grid. Both the $V2Gsp$ and DSO will be offered an indicator to estimate the approximate real value of the energy distributed by EVs to the grid or for end users' own consumption. In addition to the mathematical description of the indicators determining the probability, a methodology for determining them for $V2Gsp$ will be proposed, and example calculations based on realized surveys will be presented.

In summary, this article includes the following novel contributions:

- The inclusion of the results of social surveys in the calculation process of the initial values of the V2G service provision probabilities and the calculation of the number of participants in Mandatory and optional mode (as assumed in Section 2.2).
- A proposed methodology for dealing with the calculation of the values of the probabilities of V2G service provision by V2Gsp.
- A proposed targeted methodology for calculating the probability values of the *uEV* reaction.
- The use of probabilistic methods to enhance the process of *EV* integration into the electricity grid within the scope of V2X technology.

3. Survey Research

Previous surveys have primarily relied on asking respondents what benefits the use of V2G technology might bring, what their concerns are, and what potential benefits they might be able to receive in exchange for discharging their vehicles. Another type of survey is the widely available survey on the use of electric vehicles and their charging strategies. The purpose of this survey is to combine the behaviors of *EV* and *ICE* users along with the assumptions of the V2G Program. Matching the right group of respondents is an essential issue. The peculiarity of the V2G technology, i.e., a relatively narrow group of consumers, which is additionally imposed by the Polish conditions of electromobility development, should make one think whether it is reasonable to carry out the survey on a representative group. Due to the aforementioned facts, it has been suggested that the survey should focus on people interested in electromobility, in particular the users of electric vehicles or people connected with the power sector. Due to the still limited possibilities of people-to-people communication caused by the COVID-19 pandemic, it was decided to use an online form of the survey using the Microsoft Forms tool. The suitable form was made available on electric vehicle user forums. The anonymous survey was conducted between 6 July 2021 and 19 July 2021 and consisted of 23 closed-ended single- or multiple-choice questions. The survey resulted in 130 responses. Additionally, to strengthen the tone of the survey, 5 responders were asked to elaborate on their feelings about the proposed V2G Program. Interviews were conducted in a manner that ensured anonymity. The selection process was based on their reaction to a request for contact after the survey was completed to clarify trip behaviors. It should be emphasized that survey research is not the main research problem of this paper. In fact, it is only a supplement to begin the discussion of determining service probability metrics. Table 1 provides background information on the survey.

Table 1. Basic information about the survey.

Duration of the Survey	6–19 July 2021
Form of the Survey	Internet—MS Forms
Number of Answers Received	130, including 5 interviews with <i>EV</i> users

A description of the survey results is included in Appendix A, due to the very extensive analysis of the responses.

4. Determination of the Parameters Needed to Provide the V2G Service

4.1. Method Based on a Two-State Model

This section of the paper is divided into three parts. In the first one, the probability values of some of the events described in Section 2.2 are calculated based on a two-state reliability model, which is commonly used in power system reliability analyses [49]. In the second part of this section, a novel method for calculating the initial probability values from the V2G Program participant perspective and the ratio of the number of vehicles in the mandatory mode to the number of vehicles in the optional mode are proposed. Finally, the last part of the section presents the author's approach to calculate the probability value

$P(EC)$ after the first month of V2G Program settlement, as it is one of the most difficult to estimate due to the random nature of user behavior. Also, the deliberations are summarized and a graphical diagram of the developed methodology is presented.

The first probability values determined concern events from the perspective of the end user (*EndUs*). As can be seen from Equation (12), the probability of V2G service from the *EndUs* perspective is determined by two separable events—charging station operation ($1 - P(F_{EVSE})$) and the charging station availability at the service location ($P(D_{PL})$). The values to calculate the first one can be found in [50]. The authors in [50] used a two-state model in their calculations. It should be noted that the transition intensities from state “0” to “1” and “1” to “0” are unique for each parameter analyzed and will be identified when discussing the individual probabilities. A “0” state may indicate a non-functioning charging station or supervisory system but may also indicate a lack of available space to discharge an EV or an interruption of V2G service. State “1” refers to events where the V2G service is provided in an uninterrupted and fault-free manner.

Using the two-state model, it can be assumed that the probability of charging station failure is determined according to Equation (15).

$$q_{EVSE} = \frac{\lambda_{EVSE}}{\lambda_{EVSE} + \mu_{EVSE}} \quad (15)$$

where:

μ_{EVSE} —the charging station restoration intensity (repair rate);

λ_{EVSE} —the charging station failure intensity (failure rate);

q_{EVSE} —the probability of the charging station being out of service.

Thus, it can be concluded that in order to calculate the probability of V2G service from the *EndUs* perspective, the opposite value will be needed, i.e., the probability of the charging station being in the operating state p_{EVSE} . It is determined by Equation (16).

$$p_{EVSE} = 1 - q_{EVSE} = \frac{\mu_{EVSE}}{\lambda_{EVSE} + \mu_{EVSE}} \quad (16)$$

The second event relates to the availability of the V2G charging station at the service location. Availability of a V2G charging station is understood as unrestricted access to this station provided to the particular *uEV* by the V2Gsp or *EndUs*. In other words, no other vehicle that is not a member of the V2G Program may be parked at the station or no maintenance work may be taking place at the station. Regardless of the reason, such an event should be treated as the absence of an electric vehicle at the service location. Accordingly, the methodology for calculating the values of restoration and failure stream parameters can be adopted as in [47]. Analogously to Equation (16), the probability value of charging station availability was determined, which is presented in Equation (17).

$$p_{DPL} = \frac{\mu_{DPL}}{\lambda_{DPL} + \mu_{DPL}} \quad (17)$$

where:

μ_{DPL} —the intensity of V2G charging station availability comeback;

λ_{DPL} —the intensity of the V2G charging station transition into an occupied state;

p_{DPL} —the probability of V2G charging station availability.

By introducing Equations (16) and (17) into Equation (12), a formula for calculating the probability of service from the *EndUs* side is obtained, which is shown in Equation (18).

$$P(EndUs) = p_{EVSE} \cdot p_{DPL} = \frac{\mu_{EVSE}}{\lambda_{EVSE} + \mu_{EVSE}} \cdot \frac{\mu_{DPL}}{\lambda_{DPL} + \mu_{DPL}} \quad (18)$$

The second probability value ($P(V2Gsp)$) that needs to be calculated relates to the V2G Program operator, i.e., the V2Gsp. In this case, the research reported in [47] was also

referenced. The authors in [47] presented the role of the *V2Gsp* as an aggregator and created a two-state model for such an actor. Thus, it is possible to bring the unavailability of the aggregator to the unavailability of the *V2Gsp*, which will occur if the supervisory control system fails. Then, the *V2Gsp* will not be able to execute its tasks. In further research, the reliability model of the *V2Gsp* can be extended to consider the reliability of individual components of the system architecture. Using Equation (19), a relation that allows to calculate the probability of V2G service from *V2Gsp* perspective is presented.

$$P(V2Gsp) = 1 - P(F_S) = 1 - q_S = 1 - \frac{\lambda_S}{\lambda_S + \mu_S} \quad (19)$$

where:

λ_S —the intensity of failures in the *V2Gsp* supervisory control system;
 μ_S —the intensity of repairs of the *V2Gsp* supervisory control system;
 q_S —the probability of the *V2Gsp* supervisory control system failure.

The third probability value needed to calculate the total service probability relates to the V2G Program participant (*uEV*). As shown in Equation (14), it is determined by three components:

- $P(EC)$ —the probability of the user's reaction to providing the service at a given time, e.g., receiving an economic incentive or the willingness to perform a service due to the lifestyle of the *uEV*;
- $P(US_{EV})$ —the probability of electric vehicle availability because of its lack of usage;
- $1 - P(INT)$ —the probability of service not being interrupted.

Of these three probabilities, only one can be determined easily by using a two-state model, and that is the probability $1 - P(INT)$. The probability of service interruption can be calculated similarly to the probability of V2G charging station availability. The reason for that is that in [47] the authors do not specify what EV absence is. They even mentioned that it can refer to hardware failure or human action. Due to the lack of other available sources that could confirm other values than assumed, it was decided to use the aforementioned approximation. The calculation of the $1 - P(INT)$ component is shown by Formula (20).

$$1 - P(INT) = 1 - q_{INT} = 1 - \frac{\lambda_{INT}}{\lambda_{INT} + \mu_{INT}} \quad (20)$$

where:

λ_{INT} —the intensity of transition to the state of interruption of V2G service;
 μ_{INT} —the intensity of restoration from interruption of V2G service;
 q_{INT} —the probability of V2G service interruption.

4.2. Method for Determining Initial Probability Values of V2G Service Provision Based on Survey Data

The other two event types related to V2G Program participants are strongly dependent on the behavior of potential users. The novelty of this paper is to try to use the collected survey data to estimate “initial” values for these events' probabilities. The first of these events is the reaction of a V2G Program participant to a proposed V2G service offer. The probability of this event will vary depending on the time of day, as the economic conditions of such a service are different at night and during the day. Additionally, during the course of the research, the opinions of users who expressed a high willingness to provide EV discharging services at a V2G home charging station were taken into account (V2GH). However, due to the different types of service provided (as described in Section 2), probability values for this case will be calculated in future studies. Therefore, the probability values of $P(EC)$ for providing the service at the location of another end user secured by the V2G Program $P(EC)_t^{V2GL}$ were distinguished. In order to determine the parameter $P(EC)_t^{V2GL}$, the V2G Program operator must first conduct surveys, which require the questions described in Appendix A, and in particular those shown in Figures A9–A11.

Once the questions are answered, the indicator can be determined from Equation (21). It is recommended to obtain a sample of at least 100 respondents, but it should be emphasized that this does not have to be a representative sample as mentioned in Section 3.

$$P(EC)_t^{V2GL} = \frac{N_{uEV}^{V2GL}(t)}{R_{YES}^{V2GL} + R_{DK}^{V2GL}} \quad (21)$$

where:

$P(EC)_t^{V2GL}$ the probability of V2G Program participant reaction on the provision of the V2G service at the *EndUs* location at time t ;

$N_{uEV}^{V2GL}(t)$ the number of respondents willing to provide V2G service at the *EndUs* location at time t ;

R_{YES}^{V2GL} the total number of “Yes” responses in the survey question regarding the willingness to provide V2G service at the *EndUs* location;

R_{DK}^{V2GL} the total number of “Don’t know” responses in the survey question regarding the willingness to provide V2G service at the *EndUs* location.

Based on the collected survey data, it can be assumed that the condition of providing the service at time t would be to find out how many respondents would like to provide the service during that period. In addition, those respondents who did not know whether such services would be provided were also included. This is an intentional measure that can help in the risk analysis of the uncertainty of V2G service delivery.

The second indicator needed to calculate the probability $P(uEV)$ is the probability of electric vehicle availability related to the lack of use at a given point in time $P(US_{EV})$. In order to quantify this value, it is first necessary to refer to the survey data. The vehicle usage profile shown in Figure A4 will be helpful. The proposed survey examined 3-h intervals due to a willingness toward simplifying the questionnaire. However, the target version of the survey prepared by the V2Gsp should reduce the time frame to 1-h intervals. This will allow for a more accurate estimation of initial probability values of $P(US_{EV})$. However, the methodology for calculating the specific probability value will also be broadened to include other components in relation to the EV usage profile. Namely, the calculation method also includes respondents who answered that they own an ICE vehicle and are considering purchasing an electric vehicle within 5 years. This procedure is intended to increase the accuracy of calculating the probability of $P(US_{EV})$, assuming that current users of ICE vehicles will maintain their travel patterns, i.e., travel at similar times. The methodology for calculating $P(US_{EV})$ is presented by Equations (22) and (23).

$$P_1(US_{EV})_t = \frac{N_{US}^{EV}(t) + N_{US}^{ICE}(t)}{R_{EV} + R_{ICE}} \quad (22)$$

$$P(US_{EV})_t = 1 - P_1(US_{EV})_t \quad (23)$$

where:

$N_{US}^{EV}(t)$ the number of respondents that indicated they are using an EV in time (t);

$N_{US}^{ICE}(t)$ the number of respondents who intend to purchase an EV in 5 years of having used an ICE vehicle in time (t);

R_{EV} —the total number of EV users;

R_{ICE} —the total number of ICE users who intend to purchase an EV in 5 years of having used an ICE vehicle in time (t);

$P_1(US_{EV})_t$ —the probability of vehicle usage in time (t);

$P(US_{EV})_t$ —the probability of electric vehicle availability because of its lack of usage in time (t).

It is assumed that the final solution should include the ability for V2Gsp to collect location data from the on-board computers of individual *uEVs*, and then this data would be used to build short-term prediction models. Unfortunately, this solution requires a large invasion of user privacy, which may be a problem for V2G Program implementation [51].

The last value that will be determined using the survey data is a factor that determines the ratio of mandatory to optional mode vehicles—the *MOD* coefficient. This ratio will be based solely on survey responses in the first phase and will be updated on the last workday of the month in a later phase of the V2G Program implementation. Ultimately, it should count customers who are assigned to mandatory or optional mode, according to Formulas (24) and (25).

$$MOD_{MAN}^{V2GL} = \frac{N_{uEV_{V2GL}}^{MAN}}{N_{uEV_{V2GL}}} \quad (24)$$

$$MOD_{OPT}^{V2GL} = \frac{N_{uEV_{V2GL}}^{OPT}}{N_{uEV_{V2GL}}} \quad (25)$$

where:

$N_{uEV_{V2GL}}^{MAN}$ —the number of V2G Program participants in mandatory mode for a given type of V2G service;

$N_{uEV_{V2GL}}^{OPT}$ —the number of V2G Program participants in optional mode for a given type of V2G service;

$N_{uEV_{V2GL}}$ —the total number of V2G Program participants for a given type of V2G service.

The *MOD* coefficient should be based on the results of social surveys to determine the initial values. However, in order to accurately determine the values of the coefficients for the aforementioned conditions, it is necessary to analyze more closely the results of the questionnaires for the participants who would be interested in a given mode of service provision—the *SUR* coefficient. This is deduced from answering the questions described in Tables A10 and A11. Then, one must subtract those who answered “No” to both of the questions in Tables A10 and A11, so that the result obtained will be the denominator of the *SUR* coefficient. Thus, the following methodology is proposed:

1. Examine the number of respondents who declared “Yes” to the question presented in Table A9 and then answered “Yes” and “Yes but with additional benefits” to the question: “In exchange for a fixed monthly remuneration, would you be willing to stand by to discharge an electric vehicle during the hours set by the V2G Program operator, being aware of potential fines for not providing the service?” and answered “No” in the question: “In exchange for a financial benefit for a single discharging action, would you be able to provide discharging services without incurring fines for not providing the service?”. Thus, the number of V2G Program participants for a given service provision location in mandatory only mode can be calculated.
2. Examine the number of respondents who declared “Yes” to the question presented in Table A9 and then answered “No” to the question: “In exchange for a fixed monthly remuneration, would you be willing to standby to discharge an electric vehicle during the hours set by the V2G Program operator, being aware of potential fines for not providing the service?” and answered “Yes” to the question: “In exchange for a financial benefit for a single discharging action, would you be able to provide discharging services without incurring fines for not providing the service?”. Thus, the number of V2G Program participants for a given service location in optional mode only can be calculated.
3. Examine the number of participants who declared “Yes” to the question presented on Table A9 and then answer “Yes” and “Yes but with additional benefits” to the question: “In exchange for a fixed monthly remuneration, would you be willing to standby to discharge an electric vehicle during the hours set by the V2G Program operator, being aware of potential fines for not providing the service?” and answered “Yes” to the question: “In exchange for a financial benefit for a single discharging action, would you be able to provide discharging services without incurring fines for not providing the service?”. Thus, the number of V2G Program participants for a given service location who said they were willing to participate in both modes can be calculated. Due to the aforementioned fact, these V2G Program participants are eligible for the mandatory mode first.

The mathematical notation of the aforementioned methodology is shown by Equations (26)–(28).

$$SUR_{MAN}^{V2GL} = \frac{N_{MANONLY}^{V2GL} + N_{MANOPT}^{V2GL}}{N_{uEV}^{V2GL} - N_{NOTINTL}} \quad (26)$$

$$SUR_{OPT}^{V2GL} = \frac{N_{OPTONLY}^{V2GL}}{N_{uEV}^{V2GL} - N_{NOTINTL}} \quad (27)$$

where:

SUR_{MAN}^{V2GL} the coefficient of respondents willing to participate in the V2G Program at the *EndUs* location in mandatory mode;

SUR_{OPT}^{V2GL} the coefficient of respondents willing to participate in the V2G Program at the *EndUs* location in optional mode;

$N_{MANONLY}^{V2GL}$ the number of respondents interested in the V2G Program at the *EndUs* location only in mandatory mode;

$N_{OPTONLY}^{V2GL}$ the number of respondents interested in the V2G Program at the *EndUs* location only in optional mode;

N_{MANOPT}^{V2GL} the number of respondents interested in the V2G Program at the *EndUs* location in mandatory and optional mode;

$N_{NOTINTL}$ the number of respondents, who would like to discharge their vehicle at an *EndUs* location but are not interested in the V2G Program in mandatory and optional modes.

Thus, it can be concluded that

$$SUR_{MAN}^{V2GL} + SUR_{OPT}^{V2GL} = 1 \quad (28)$$

Considering all the coefficients, the initial parameters of the V2G Program model can be calculated from the perspective of a *V2Gsp*. A graphical summary of the aforementioned deliberations is shown in Figure 3.

Figure 3. Methodology for calculating the probability of V2G service provision from a V2Gsp perspective.

The last phase of the methodology, the validation phase, deserves special emphasis. In the *uEV* path, it was pointed out that parameters need to be recalculated after the first month of V2G Program operation. This is crucial to maintain the relative accuracy of the model calculations. A detailed description of this step is described in Section 4.3.

4.3. Method for Calculating the Probability Value $P(EC)$ after the First Month of V2G Program Settlement

The user reaction probability $P(EC)$ is extremely difficult to estimate due to the stochastic decision-making process of users. It is also one of the more sensitive factors affecting the V2G Program model operation. In order to calculate the probability $P(EC)_t^{V2GL}$ after the first settlement month of the V2G Program, it is proposed to use the author's algorithm, which in its assumptions will take into account the mobility of *uEVs* in the area of operation of a *V2Gsp*. Therefore, the description of the area of operation of the *V2Gsp* should be introduced first. It will be defined similarly to the one in [34]. Therefore, let G denote the area of operation of the *V2Gsp* in which each vehicle can be located at a point g described by the following relation [34]:

$$g(x_G, y_G) \in G \quad (29)$$

where x_G and y_G are the geometric coordinates of the selected point g .

Subsequently, a square grid with a side length of 1 km must be created in area G . Therefore, the grid will consist of NG squares, which can be described as follows:

$$G_i = [(x_G, y_G); (x_G, y_{G'}); (x_{G'}, y_G); (x_{G'}, y_{G'})] \quad (30)$$

Knowing that

$$x_{G'} - x_G = 1 \text{ km} \wedge y_{G'} - y_G = 1 \text{ km} \quad (31)$$

and

$$x_G \leq x_{G_{max}} \wedge y_G \leq y_{G_{max}} \quad (32)$$

where $x_{G_{max}}$ and $y_{G_{max}}$ are the boundary values of the area.

With the *V2Gsp* operating area divided into squares, one needs to assign the number of V2G Program participants to each square at a given hour τ on day D_d . It is important to keep in mind that particular *uEVs* are constantly travelling, so it is necessary to average this number to indicate a single value. Therefore, it is proposed to use a solution borrowed from the analysis of electricity demand, i.e., to use an hourly averaging based on 15-min measurements. This is represented by Formula (33):

$$N_{G_i, \tau, D_d}^{uEV} = \frac{\sum_{t_{15}=1}^4 N_{G_i, t_{15}, D_d}^{uEV}}{4} \quad (33)$$

where:

N_{G_i, τ, D_d}^{uEV} the number of *uEVs* in a given square G_i of the *V2Gsp* operation area on day D_d at hour τ ;

$N_{G_i, t_{15}, D_d}^{uEV}$ the number of *uEVs* in a given square G_i of the *V2Gsp* operation area on day D_d at each quarter of hour τ ;

It is worth noting that, by including a given *uEV* in the number of vehicles, $N_{G_i, t_{15}, D_d}^{uEV}$ is understood as finding this *uEV* in the area of the square G_i in the selected quarter of the hour τ on day D_d , i.e., the vehicle monitoring system should record the x_g and y_g

coordinates of the given uEV defined for the given square G_i . Thus, the state of the number of vehicles at hour τ on day D_d can be presented by the following matrix:

$$N_{G_i, \tau, D_d}^{uEV} = \begin{bmatrix} N_{G_1, \tau, D_d}^{uEV} & N_{G_2, \tau, D_d}^{uEV} & N_{G_3, \tau, D_d}^{uEV} & \cdots & N_{G_n, \tau, D_d}^{uEV} \\ N_{G_{n+1}, \tau, D_d}^{uEV} & \cdots & \cdots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \cdots & \cdots & \cdots & \cdots & N_{G_{NG}, \tau, D_d}^{uEV} \end{bmatrix} \quad (34)$$

where:

i the successive squares of area G ;

NG the maximum number of squares in area G .

Then, knowing the number of vehicles in the given squares, one can proceed to calculate the probability $P(EC)$, which relates to the area of the operation of the $V2G_{sp}$. The first step in this process is to collect data on the number of reactions in hour τ on day D_d , resulting in acceptance of $V2G$ service provision $ACPT_{\tau, D_d}$ and data on all correctly received reactions on that day NS_{τ, D_d} , i.e., those that were delivered to the uEV and either accepted or rejected. Due to the necessity of predicting the probability value $P(EC)$, it is then necessary to group the data by each day of the week. Thus, for a selected day of the week (e.g., Monday), this can be expressed in the form of a matrix:

$$ACPT_{\tau, D_d} = \begin{bmatrix} ACPT_{1, D_1} & ACPT_{2, D_1} & ACPT_{3, D_1} & \cdots & ACPT_{24, D_1} \\ ACPT_{1, D_2} & ACPT_{2, D_2} & ACPT_{3, D_2} & \cdots & ACPT_{24, D_2} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ ACPT_{1, D_d} & ACPT_{2, D_d} & ACPT_{3, D_d} & \cdots & ACPT_{24, D_d} \end{bmatrix} \quad (35)$$

where:

$ACPT_{\tau, D_d}$ the number of reactions in hour τ on day D_d , ending with acceptance of $V2G$ service provision;

τ each hour of the day D_d ;

d the same days of the week consecutively in a month (e.g., Mondays).

Similarly, for other days of the week, matrices would be determined as in Equation (35). In a similar manner, the matrix for the number of all calls and requests for $V2G$ service provided to users should be determined:

$$NS_{\tau, D_d} = \begin{bmatrix} NS_{1, D_1} & NS_{2, D_1} & NS_{3, D_1} & \cdots & NS_{24, D_1} \\ NS_{1, D_2} & NS_{2, D_2} & NS_{3, D_2} & \cdots & NS_{24, D_2} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ NS_{1, D_d} & NS_{2, D_d} & NS_{3, D_d} & \cdots & NS_{24, D_d} \end{bmatrix} \quad (36)$$

Then, the probability of user reaction can be calculated for the whole $V2G_{sp}$ operating area—hereafter called the system probability $P^{SYS}(EC)_{\tau, D_d}$. This process is presented in Equations (37) and (38).

$$P^{SYS}(EC)_{\tau, D_d} = \frac{ACPT_{\tau, D_d}}{NS_{\tau, D_d}} \quad (37)$$

$$P^{SYS}(EC)_{\tau, D_d} = \begin{bmatrix} P^{SYS}(EC)_{1, D_1} & P^{SYS}(EC)_{2, D_1} & P^{SYS}(EC)_{3, D_1} & \cdots & P^{SYS}(EC)_{24, D_1} \\ P^{SYS}(EC)_{1, D_2} & P^{SYS}(EC)_{2, D_2} & P^{SYS}(EC)_{3, D_2} & \cdots & P^{SYS}(EC)_{24, D_2} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ P^{SYS}(EC)_{1, D_d} & P^{SYS}(EC)_{2, D_d} & P^{SYS}(EC)_{3, D_d} & \cdots & P^{SYS}(EC)_{24, D_d} \end{bmatrix} \quad (38)$$

where:

NS_{τ, D_d} all correctly received reactions at each hour τ of the day D_d ;

$ACPT_{\tau, D_d}$ the number of reactions in hour τ on day D_d , ending with acceptance of V2G service provision.

Then, over the settlement month for a given τ hour, the average value of the system probabilities for successive groups of days of the week should be determined:

$$P^{SYS}(EC)_{\tau, avg} = \frac{\sum_{d=1}^{N_D} P^{SYS}(EC)_{\tau, D_d}}{N_D} \quad (39)$$

where:

d —the same days of the week consecutively in a month (e.g., Mondays);

ND —the number of the same days of the week in a month (e.g., the number of all Mondays in a given month).

Then, the probability value $P^{SYS}(EC)_{\tau, avg}$ should be dependent on the number of $uEVs$ that are located in each square of the operation area of the $V2Gsp$. It is assumed that the probability of service for the $EndUs$ located in a square with a higher number of $uEVs$ will be higher than in the case of an area less densely covered with $uEVs$. Therefore, for each square of the area G , determine the ratio of the average number of $uEVs$ located in the area of that square in each hour τ for the same weekdays in a month, to the average of the sums of all $uEVs$ in the area G for each hour τ for the same weekdays in a month. This is represented by Equations (40)–(44):

$$N_{G_i, \tau, D_d}^{avg} = \frac{\sum_{d=1}^{N_D} N_{G_i, \tau, D_d}^{uEV}}{N_D} \quad (40)$$

$$N_{G_i, \tau, D_d}^{SUM} = \sum_{i=1}^{N_G} N_{G_i, \tau, D_d}^{uEV} \quad (41)$$

$$N_{G_i, \tau, D_d}^{SUMavg} = \frac{\sum_{d=1}^{N_D} N_{G_i, \tau, D_d}^{SUM}}{N_D} \quad (42)$$

$$W_{G_i, \tau, D_d} = \frac{N_{G_i, \tau, D_d}^{avg}}{N_{G_i, \tau, D_d}^{SUMavg}} \quad (43)$$

$$W_{Gi \tau, D_d} = \begin{bmatrix} W_{G_1, \tau, D_d} & W_{G_2, \tau, D_d} & W_{G_3, \tau, D_d} & \cdots & W_{G_n, \tau, D_d} \\ W_{G_{n+1}, \tau, D_d} & \cdots & \cdots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \cdots & \cdots & \cdots & \cdots & W_{G_{NG}, \tau, D_d} \end{bmatrix} \quad (44)$$

where:

N_{G_i, τ, D_d}^{avg} —the average number of $uEVs$ located in the area of that square in each hour τ for the same weekdays in a month;

N_{G_i, τ, D_d}^{SUM} —the sum of all $uEVs$ in the area G for each hour τ for the same weekdays in a month;

$N_{G_i, \tau, D_d}^{SUMavg}$ —the average value of the N_{G_i, τ, D_d}^{SUM} in the area G for each τ hour for the same weekdays in a month;

ND —the number of the same days of the week in a month (e.g., the number of all Mondays in a given month);

NG —the maximum number of squares in area G ;

W_{G_i, τ, D_d} —the ratio between N_{G_i, τ, D_d}^{avg} to $N_{G_i, \tau, D_d}^{SUMavg}$.

Then, it is necessary to determine the average value from every value of matrix (44)— W_{G_i, τ, D_d}^{avg} :

$$W_{G_i, \tau, D_d}^{avg} = \frac{\sum_{i=1}^{NG} W_{G_i, \tau, D_d}}{NG} \quad (45)$$

Based on the obtained calculations, the system probability value can be decomposed as a function of the number of uEV s in a given square at a given hour τ for selected days of the week in the settlement month. This process is represented by Equations (46) and (47):

$$P^{G_i}(EC)_{\tau, D_d} = P^{SYS}(EC)_{\tau, avg} + (W_{G_i, \tau, D_d} - W_{G_i, \tau, D_d}^{avg}) \quad (46)$$

$$P^{G_i}(EC)_{\tau, D_d} = \begin{bmatrix} P^{G_1}(EC)_{\tau, D_d} & P^{G_2}(EC)_{\tau, D_d} & P^{G_3}(EC)_{\tau, D_d} & \cdots & P^{G_n}(EC)_{\tau, D_d} \\ P^{G_{n+1}}(EC)_{\tau, D_d} & \cdots & \cdots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \cdots & \cdots & \cdots & \cdots & P^{G_{NG}}(EC)_{\tau, D_d} \end{bmatrix} \quad (47)$$

where $P^{G_i}(EC)_{\tau, D_d}$ is the probability of the user's reaction of V2G service provision in the square G_i at a given hour τ for selected days of the week D_d in the settlement month.

Obtained from Equation (46), the probability of the user's reaction of V2G service provision in the square G_i $P^{G_i}(EC)_{\tau, D_d}$ refers to the settlement month M . However, for the purpose of forecasting the probability value $P(EC)$ in month $M+1$, the trend of changes from month M and $M-1$ should also be considered. Hence,

$$P_{M+1}^{G_i}(EC)_{\tau, D_d} = P_M^{G_i}(EC)_{\tau, D_d} + \Delta P \quad (48)$$

$$\Delta P = P_M^{G_i}(EC)_{\tau, D_d} - P_{M-1}^{G_i}(EC)_{\tau, D_d} \quad (49)$$

5. Results and Discussion

In order to validate the methodology presented in Sections 4.1 and 4.2, exemplary calculations were performed that will determine the initial parameters for calculating the total probability of V2G service, as well as simulation on targeted $P(EC)$ values. At the end of this section, the results from the calculations and the values assumed in [34] will be compared.

The first probability that will be evaluated concerns *EndUs*. It should be calculated according to Formula (18). As mentioned in the previous section, the methodology and values needed to calculate it will be taken from the literature. First, the probability that the charging station will operate normally should be calculated using Equation (16). The values presented in [50] were used. It was assumed that $\mu_{EVSE} = 20,000$ per 1 million hours and $\lambda_{EVSE} = 11.3266$ per 1 million hours [50]. The value of λ_{EVSE} was determined for the non-repairable two-phase interleaved topology. Thus, having the aforementioned data, the probability of operation of the charging station can be calculated according to Equation (16):

$$p_{EVSE} = \frac{\mu_{EVSE}}{\lambda_{EVSE} + \mu_{EVSE}} = \frac{20,000}{20,000 + 11.3266} = 0.99943 \quad (50)$$

Then, according to Equation (11), the probability of V2G charging station availability for a V2G Program participant should be calculated. In [47], an approach was presented in which, regardless of the factor (hardware or human activity) affecting the absence of an *EV* at a charging location, such an event should be treated equally. Therefore, the values from [47] were adopted and are as follows: $\mu_{DPL} = 1 \times 10^{-2}$ per hour and $\lambda_{DPL} = 5 \times 10^{-4}$ per hour. The probability of charging station availability is thus equal to

$$p_{DPL} = \frac{\mu_{DPL}}{\lambda_{DPL} + \mu_{DPL}} = \frac{1 \times 10^{-2}}{1 \times 10^{-2} + 5 \times 10^{-4}} = 0.9524 \quad (51)$$

Therefore, the probability $P(EndUs)$ is equal to

$$P(EndUs) = p_{EVSE} \cdot p_{DPL} = 0.99943 \cdot 0.9524 = 0.9518 \quad (52)$$

Another probability to be evaluated concerns the $V2G_{sp}$. Once again, the data presented in [47] was used, and $P(V2G_{sp})$ was calculated assuming that

$$\begin{aligned} \lambda_S &= 1 \text{ per year} \\ \mu_S &= 99 \text{ per year} \\ P(V2G_{sp}) &= 1 - P(F_S) = 1 - q_S = 1 - \frac{\lambda_S}{\lambda_S + \mu_S} = 1 - \frac{1}{99+1} = 0.99 \end{aligned} \quad (53)$$

Then, the probability of service provision by the $V2G$ Program participant uEV was calculated. The first event concerns the operation of the $V2G$ charging station due to the uninterrupted service by the uEV —component $1 - P(INT)$. Analogous considerations for the probability of charging station availability from Equation (51) should be used [47]. Given these considerations, it can be assumed that

$$\begin{aligned} \mu_{INT} &= 1 \times 10^{-2} \text{ per hour} \\ \lambda_{INT} &= 5 \times 10^{-4} \text{ per hour} \\ 1 - P(INT) &= 1 - \frac{\lambda_{INT}}{\lambda_{INT} + \mu_{INT}} = 1 - \frac{5 \times 10^{-4}}{1 \times 10^{-2} + 5 \times 10^{-4}} = 0.95 \end{aligned} \quad (54)$$

The next calculation will be based on the survey results presented in Appendix A. The first probability to be calculated will be the reaction probability of the $V2G$ Program participant. As mentioned in Section 4, the first calculated parameter will be the probability of user reaction $P(EC)$. It is worth noting that in the conducted survey time frames were used. Ultimately, the values of the aforementioned probabilities should be variable for each hour of the day, but in order to simplify the survey form, time frames were used. In the process of calculating the probability $P(EC)_t^{V2GL}$, the distribution of answers to question (13) was used. The crucial values are presented in Table A9. In Table 2, the answers from Figure A10 are extracted and according to Equation (21) the probability $P(EC)_t^{V2GL}$ is calculated.

Table 2. Distribution of responses to the question regarding the hours of potential $V2G$ service provision location of $EndUs$ and calculated probability $P(EC)_t^{V2GL}$ values.

Question:	(14) During What Hours Would You be able to Provide an Electric Vehicle Discharging Service at the Point of Service (e.g., Industrial Facility)?	$P(EC)_t^{V2GL}$
00:00–06:00	12	0.21
06:01–09:00	10	0.18
09:01–12:00	21	0.38
12:01–15:00	23	0.41
15:01–18:00	9	0.16
18:01–21:00	17	0.30
21:01–23:59	23	0.41

Exemplary calculations are shown by Equation (55).

$$P(EC)_{12:01-15:00}^{V2GL} = \frac{N_{uEV}^{V2GL}(t)}{\sum_{k=1}^{R_{YES}^{V2GL}} N_k + \sum_{l=1}^{R_{DK}^{V2GL}} N_l} = \frac{23}{30 + 26} = 0.41 \quad (55)$$

The final component needed to calculate the probability $P(A)$ is the probability of electric vehicle availability related to lack of use at a given point in time $P(US_{EV})$. As with $P(EC)$, the calculation will be done based on the surveys and within the defined time frames. During the surveys, 51 respondents indicated that they own a BEV or $PHEV$, and after a further analysis of the responses, 22 respondents indicated that they currently own an ICE vehicle and plan to purchase an EV within the next 5 years. It should be noted that the number of respondents who plan to purchase a vehicle within 5 years and are users of an ICE vehicle is from post-processing of the survey data. According to Equation (22), the sum of these indices will be the set of all users to be considered when calculating the

initial probability value $P_1(US_{EV})$. Each respondent could select multiple responses, i.e., multiple hourly intervals. Table 3 shows the distribution of responses to the question regarding the hours of movement of users and calculates the probabilities $P(US_{EV})$. It is also worth mentioning that in order to calculate the probability $P(US_{EV})$, one must first calculate the value $P_1(US_{EV})$, i.e., the actual value indicating the share of active vehicles in traffic, according to Formula (23).

Table 3. Calculation of probability values $P(US_{EV})$.

Question:	What Hours Do You Use Your Car Most Often?		Probability of Using Vehicle	Probability of Electric Vehicle Availability Related to the Lack of Use $P(US_{EV})$
Hours:	BEV and PHEV Owners	ICE Owners, Who Intend to Buy an EV within 5 Years	$P_1(US_{EV})$	
00:00–06:00	2	1	0.04	0.96
06:01–09:00	30	12	0.58	0.42
09:01–12:00	28	4	0.44	0.56
12:01–15:00	29	4	0.45	0.55
15:01–18:00	36	15	0.70	0.30
18:01–21:00	22	6	0.38	0.62
21:01–23:59	5	4	0.12	0.88

Exemplary calculations are shown by Equations (56) and (57).

$$P_1(US_{EV})_{12:01-15:00} = \frac{N_{US}^{EV}(t) + N_{US}^{ICE}(t)}{\sum_{m=1}^{R_{EV}} N_m + \sum_{n=1}^{R_{ICE}} N_n} = \frac{29 + 4}{51 + 22} = 0.45 \quad (56)$$

$$P(US_{EV})_{12:01-15:00} = 1 - P_1(US_{EV})_t = 1 - 0.4521 = 0.55 \quad (57)$$

Knowing that $P(uEV)$ is defined by Equation (14), its value for each time frame can be calculated. Table 4 shows the calculated uEV probability values, whereas the total probability of V2G service provision is the product of three separable events: $P(EndUs)$, $P(V2Gsp)$, and $P(uEV)$, defined by Equation (5). Table 5 shows the calculated probability values $P(A)$ for the selected time frames.

Table 4. Calculation of probability values $P(uEV)$.

Hours:	Probability of Service Not being Interrupted $1-P(INT)$	Probability of Electric Vehicle Availability Related to the Lack of Use $P(US_{EV})$	Probability of uEV Reaction on the Provision of the V2G Service at the $EndUs$ Location $P(EC)_t^{V2GL}$	Probability Relates to the V2G Service Provision at an $EndUs$ Location from a uEV Perspective $P(uEV)_{V2GL}$
00:00–06:00	0.95	0.96	0.21	0.20
06:01–09:00		0.42	0.18	0.07
09:01–12:00		0.56	0.38	0.20
12:01–15:00		0.55	0.41	0.21
15:01–18:00		0.30	0.16	0.05
18:01–21:00		0.62	0.30	0.18
21:01–23:59		0.88	0.41	0.34

Knowing the values of the probabilities $P(A)$ calculated according to the methodology presented in this publication, it is possible to compare them with the previously assumed values of the probabilities in [34]. It turns out that only for $P(V2Gsp)$ was the correct value assumed. The biggest differences are in the results of $P(uEV)$. Such low $P(uEV)$ values imply that the search area mentioned in [34] should be much larger and may not meet the users' expectations for the distances traveled between their current location and the location where the service is provided.

Table 5. Calculation of probability values $P(A)$.

Hours:	Probability Relates to the V2G Service Provision at an <i>EndUs</i> Location from a <i>uEV</i> Perspective $P(uEV)_{V2GL}$	Probability Relates to the V2G Service Provision from a V2Gsp Perspective $P(V2Gsp)$	Probability Relates to the V2G Service Provision from an <i>EndUs</i> ¹ Perspective $P(EndUs)$	Total Probability of V2G Service Provision at an <i>EndUs</i> Location $P(A)_{V2GL}$
00:00–06:00	0.20			0.18
06:01–09:00	0.07			0.07
09:01–12:00	0.20			0.19
12:01–15:00	0.21	0.99	0.9518	0.20
15:01–18:00	0.05			0.04
18:01–21:00	0.18			0.17
21:01–23:59	0.34			0.32

¹ In this case, *EndUs* is the secured customer of the V2G Program. This could be a household or other industrial facility.

It should also be emphasized that using the survey data approach to calculate the initial probabilities of V2G service provision requires the aforementioned surveys to be carried out in the most accurate manner. It should be kept in mind that the accuracy of the calculations will be affected not only by the number of respondents, but also by the way the questions are asked. Therefore, the future V2Gsp should conduct these surveys with the help of specialists in social research. Considering the fact that initial values will be needed to establish boundary conditions in the first months of V2G Program implementation, it is necessary to use advanced forecasting tools in the future to verify the calculations performed.

The coefficients determining the proportion of users in mandatory and optional mode for both types of services, i.e., at home and at the *EndUs* location, were also calculated. The results are presented in Equations (58) and (59) and Table 6 shows the parameters needed to calculate the aforementioned coefficients.

$$SUR_{MAN}^{V2GL} = \frac{N_{MANONLY}^{V2GL} + N_{MANOPT}^{V2GL}}{N_{uEV}^{V2GL} - N_{NOTINTL}} = 0.7586 \quad (58)$$

$$SUR_{OPT}^{V2GL} = \frac{N_{OPTONLY}^{V2GL}}{N_{uEV}^{V2GL} - N_{NOTINTL}} = 0.2414 \quad (59)$$

Table 6. Parameters required to calculate SUR coefficients.

Parameter	Value
N_{uEV}^{V2GL}	30
$N_{MANONLY}^{V2GL}$	1
N_{MANOPT}^{V2GL}	21
$N_{OPTONLY}^{V2GL}$	7
$N_{NOTINTL}$	1

Analyzing the results presented in Equations (58) and (59) and comparing them to the assumed values in [34], it can be concluded that the willingness of declared mandatory users is well above expectations. Nevertheless, it should be mentioned that the SUR coefficients consider only committed participants, which can also be misleading in observing the assumptions of the V2G Program.

In order to perform calculations for the target solution while calculating the probability $P(EC)$, a number of simulations must be performed on random data. It should be emphasized that the indicated values do not represent the real state of the *uEV* distribution in the real location. The following simulation conditions were established:

- The number of days for analysis: $d = 4$;

- Analysis for one-hour τ ;
- The number of service acceptances and all successful reactions determined randomly;
- The operating area of a $V2Gsp$ (G) is $6 \text{ km} \times 6 \text{ km}$;
- In each square G_i , a random number of vehicles was assigned according to $N_{G_i, \tau, D_d}^{uEV} \in (0, 3000)$

The matrices describing the number of vehicles at a given hour τ on days $d = 1, d = 2, d = 3$, and $d = 4$ are shown in Equations (60)–(63), according to Relation (34).

$$N_{G_i, \tau, D_1}^{uEV} = \begin{bmatrix} 625 & 399 & 64 & 394 & 747 & 92 \\ 628 & 577 & 513 & 605 & 27 & 553 \\ 618 & 13 & 406 & 760 & 557 & 105 \\ 307 & 122 & 566 & 267 & 405 & 495 \\ 662 & 421 & 622 & 287 & 448 & 381 \\ 473 & 652 & 228 & 122 & 295 & 51 \end{bmatrix} \quad (60)$$

$$N_{G_i, \tau, D_2}^{uEV} = \begin{bmatrix} 245 & 489 & 550 & 425 & 550 & 659 \\ 410 & 277 & 520 & 588 & 506 & 228 \\ 403 & 282 & 199 & 315 & 349 & 249 \\ 553 & 356 & 340 & 266 & 498 & 109 \\ 457 & 330 & 263 & 284 & 5637 & 545 \\ 446 & 313 & 137 & 335 & 618 & 455 \end{bmatrix} \quad (61)$$

$$N_{G_i, \tau, D_3}^{uEV} = \begin{bmatrix} 254 & 515 & 708 & 883 & 986 & 389 \\ 19 & 153 & 413 & 766 & 942 & 746 \\ 225 & 582 & 653 & 258 & 424 & 241 \\ 127 & 1004 & 316 & 314 & 651 & 164 \\ 674 & 333 & 938 & 18 & 8 & 829 \\ 679 & 781 & 820 & 625 & 1009 & 406 \end{bmatrix} \quad (62)$$

$$N_{G_i, \tau, D_4}^{uEV} = \begin{bmatrix} 299 & 1404 & 424 & 2200 & 1210 & 2520 \\ 935 & 810 & 553 & 1353 & 1039 & 1698 \\ 977 & 145 & 920 & 293 & 1131 & 2505 \\ 351 & 1354 & 148 & 718 & 2438 & 1971 \\ 253 & 424 & 2147 & 374 & 1777 & 2535 \\ 779 & 1423 & 2179 & 881 & 997 & 855 \end{bmatrix} \quad (63)$$

Then, it is necessary to note the matrices that represent the number of acceptances of the $V2G$ service $ACPT_{\tau, D_d}$ and the number of all successful uEV reactions NS_{τ, D_d} , i.e., all accepted and rejected requests and demands. According to Formulas (35) and (36) for the selected simulation cases, these will be vectors with four rows and one column, as one hour of the day for the selected group of weekdays in a month was analyzed (no. of days in the analysis is $d = 4$). Thus,

$$ACPT_{\tau, D_d} = \begin{bmatrix} 644 \\ 456 \\ 583 \\ 700 \end{bmatrix} \quad (64)$$

$$NS_{\tau, D_d} = \begin{bmatrix} 1400 \\ 901 \\ 1800 \\ 2421 \end{bmatrix} \quad (65)$$

Therefore, the system probability for each day can be determined according to Equation (37), and then the matrix for days $d = 4$ can be determined according to Equation (38):

$$P^{SYS}(EC)_{\tau, D_d} = \begin{bmatrix} 0.460 \\ 0.506 \\ 0.324 \\ 0.289 \end{bmatrix} \quad (66)$$

The average system probability value $P^{SYS}(EC)_{\tau, avg}$ was then determined according to Equation (39):

$$P^{SYS}(EC)_{\tau, avg} = \frac{0.460 + 0.506 + 0.324 + 0.289}{4} = 0.395 \quad (67)$$

In the following steps, the four-day average of the number of uEV s in a given square was determined. In the exemplary results, the calculation for square G_1 is shown. Knowing that area G consists of a 6×6 km grid, it can be deduced that the number of NG squares is equal to 36, i.e., there are 36 G_i squares in area G . After calculating the sum of uEV s in the area for each day d according to Equation (41), the average of the sums for the four days was then obtained.

$$N_{G_i, \tau, D_d}^{avg} = \frac{625 + 245 + 254 + 299}{4} = 356 \quad (68)$$

$$N_{G_i, \tau, D_d}^{SUMavg} = \frac{14,487 + 14,116 + 18,853 + 42,020}{4} = 22,369 \quad (69)$$

By having the aforementioned values, the ratios $W_{G_i \tau, D_d}$ can be calculated according to Equation (43). Formula (70) shows the matrix of ratios $W_{G_i \tau, D_d}$. Then, the average value from the values of the matrix of ratios $W_{G_i \tau, D_d}$ was calculated according to Equation (45).

$$W_{G_i \tau, D_d} = \begin{bmatrix} 0.016 & 0.031 & 0.020 & 0.044 & 0.039 & 0.041 \\ 0.022 & 0.020 & 0.022 & 0.037 & 0.028 & 0.036 \\ 0.025 & 0.011 & 0.024 & 0.018 & 0.028 & 0.035 \\ 0.015 & 0.032 & 0.015 & 0.017 & 0.045 & 0.031 \\ 0.023 & 0.017 & 0.044 & 0.011 & 0.031 & 0.048 \\ 0.027 & 0.035 & 0.038 & 0.022 & 0.033 & 0.020 \end{bmatrix} \quad (70)$$

$$W_{G_i, \tau, D_d}^{avg} = \frac{1}{36} = 0.0278 \quad (71)$$

In the last step, it is necessary to calculate the modified system probability considering the uEV density in a given square $P^{G_i}(EC)_{\tau, D_d}$. An example calculation for square G_1 is presented in Equation (72), based on Equation (46). The matrix of probabilities $P^{G_i}(EC)_{\tau, D_d}$ is then presented in Equation (73). It should be emphasized that the trend of changes in the values of the probabilities was not evaluated in this case study, due to its purely illustrative nature.

$$P^{G_1}(EC)_{\tau, D_d} = 0.395 + (0.016 - 0.0278) = 0.383 \quad (72)$$

$$P^{G_i}(EC)_{\tau, D_d} = \begin{bmatrix} 0.383 & 0.398 & 0.387 & 0.411 & 0.406 & 0.408 \\ 0.389 & 0.387 & 0.389 & 0.404 & 0.395 & 0.403 \\ 0.392 & 0.378 & 0.391 & 0.385 & 0.395 & 0.402 \\ 0.382 & 0.399 & 0.382 & 0.384 & 0.412 & 0.398 \\ 0.390 & 0.384 & 0.411 & 0.378 & 0.398 & 0.415 \\ 0.394 & 0.402 & 0.405 & 0.389 & 0.400 & 0.387 \end{bmatrix} \quad (73)$$

Thus, it was verified that the methodology for calculating values of probability $P^{G_i}(EC)_{\tau, D_d}$ allows us to determine them from the number of uEV s in a given grid square of the $V2G_{sp}$ operating area.

6. Conclusions

This paper presented an original methodology for calculating the values of initial V2G service probabilities needed to estimate the number of electric vehicles (V2G Program participants) providing discharging services in a given area. In addition, the results of a survey on the willingness to participate in the V2G Program were presented.

The survey section of the article presented the results of this survey. The survey took place between 6 July 6 and 19 July 2021, during which 130 forms were collected. Additionally, five follow-up interviews were conducted in which current EV users evaluated the assumptions of the V2G Program based on their experience of driving an electric vehicle. From the survey results, it can be deduced that there is public interest in V2G technology. However, potential users are mainly interested in providing V2G services in their own households. At this point, it is worth noting that during the interviews and in the additional comments to the survey, a large number of respondents indicated that they would like to use the electric vehicle as an additional, backup energy source exclusively for their own household needs. This would be in contrast to the V2G Program's intent, in which a regional operator would manage the energy in available EVs. Nevertheless, it does set some direction for potential operators to take while offering an interesting household business case. Furthermore, it can be read from the surveys that respondents are not very keen on moving between locations to provide V2G services. This highlights a problem that is mentioned in almost every publication on the impact of V2G on user behavior, which is the mobility behavior of V2G Program participants. There is another interesting finding from the surveys regarding electric vehicle charging locations. One of the questions asked current EV owners to indicate where they most often charge their vehicles, and respondents who do not have such a vehicle were asked to indicate the place where they would like to charge it. Interestingly, the responses for the two groups of respondents were consistent for charging at home, while there were big differences for charging in public places. It can be presumed that current EV owners have verified the possibility and chances of charging in public places.

The second part of the paper presented the original methodology for calculating the probability values based on the collected survey data. It was assumed that the survey results can be used as initial parameters in the business model of the V2G service provider. However, it should be emphasized that in the real conditions of V2G Program implementation, these parameters should be updated using advanced forecasting tools. This is due to the fact that, in the proposed V2G Program model, the service probability values are extremely important as they affect the number of vehicles that will be called to provide the service. There may be some doubt about the value of the calculated probabilities from the perspective of the V2G Program operation. During hours of peak power demand in the power system or in industrial plants, the availability of users providing the service is very low, as it does not exceed 20%. This result should encourage potential V2G Program operators to thoroughly analyze the business risks of this venture. In addition, the article presented a method for calculating the share of participants in mandatory and optional mode. In its assumptions, the mandatory mode involves a fixed revenue that would be received for the availability of V2G services, but also potential fines for not providing the service. During the simulation tests, there was a high percentage of participants willing to participate in the mandatory mode, with a significant number declaring their willingness to participate in both modes. This is important as it may guarantee a high-quality service, as perhaps a small proportion of all those willing would take part in active service provision, but those committed would be determined to provide the service reliably. The values of μ_{EV} participation in mandatory and optional modes as well as the values of probabilities should be updated on an ongoing basis during the operation of the V2G Program. A target methodology for calculating the probability of V2G Program participant reactions was also presented. From the perspective of V2G service provision, this is the most sensitive element that may affect the correct or incorrect estimation of the total probability of service provision, due to the impossibility of predicting human behavior. Therefore, it is

necessary to predict the value of this probability based on historical data obtained during the operation of the V2G Program. This only underlines the fact that determining initial probability values based on survey data will be necessary to begin operation of the entire V2G Program.

In summary, the selection of initial parameters is crucial for the continued smooth operation of the V2G Program. An extremely important element is to conduct social research that will help to properly select V2G products and services in a given area of operation. Future research work in the area of the proposed V2G Program mechanism will focus on developing settlement models for individual parties and on enhancing survey questions that would even more adequately describe *EV* users' behavior.

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Appendix A. Description of Survey Results

In this Appendix, 15 of the 23 questions posed during the survey were selected for detailed analysis in order to determine probability values for V2G service provision. Table A1 shows all the questions asked in the survey and those that are analyzed later in the article are outlined. The responses to the selected questions are presented numerically and graphically in tables and figures.

Table A1. Questions posed in the survey.

No.	Question	Total Number of Responders	Single- or Multiple-Choice	Remarks
(1)	Are you interested in electromobility and its related technologies?	130	Single	
(2)	Is there an electric vehicle charging station at your place of residence?	130	Single	
(3)	Is there an electric vehicle charging station at your workplace?	130	Single	
(4)	Do you currently own a private internal combustion engine (ICE) passenger car?	130	Single	
(5)	What hours do you use your ICE car most often?	86	Multiple	Only those who answered "Yes" to question (4)
(6)	Do you currently own a battery electric vehicle (BEV) or plug-in hybrid (PHEV)?	130	Single	
(7)	What hours do you use your EV car most often?	51	Multiple	Only those who indicated that they own an EV in question (6)
(8)	If you own an electric vehicle, please indicate where you would be most likely to charge it.	79	Multiple	Only those who indicated that they do not own an EV in question (6)
(9)	Please indicate the charging location where you are most likely to do it.	51	Multiple	Only those who indicated that they own an EV in question (6)
(10)	Are you familiar with vehicle-to-grid (V2G) or vehicle-to-everything (V2X) technology?	130	Single	
(11)	If you owned an electric car, would you join a V2G program, which involves plugging your car into a home charging station at the order of a third-party operator and then discharging the battery to a specified level in exchange for financial benefits?	130	Single	

Table A1. Cont.

No.	Question	Total Number of Responders	Single- or Multiple-Choice	Remarks
(12)	During what hours would you be able to provide an electric vehicle discharging service at a home charging station?	106	Multiple	Only those who indicated a "Yes" or "Don't know" answer in question (11)
(13)	If you owned an electric car, would you join a V2G program which involves traveling to a point of service (e.g., an industrial facility), plugging your car into a charging station at the order of a third-party operator, and then discharging the battery to a specified level in exchange for financial benefits?	130	Single	
(14)	During what hours would you be able to provide an electric vehicle discharging service at the point of service (e.g., industrial facility)?	56	Multiple	Only those who indicated a "Yes" or "Don't know" answer in question (13)
(15)	What distance would you be able to travel to reach the point of service?	56	Multiple	Only those who indicated a "Yes" or "Don't know" answer in question (13)
(16)	What type of benefit would be your main incentive to join a V2G program?	130	Multiple	8 responders did not answer
(17)	In exchange for a fixed monthly remuneration, would you be willing to standby to discharge an electric vehicle during the hours set by the V2G Program operator, being aware of potential fines for not providing the service?	130	Single	1 responder did not answer
(18)	In exchange for a financial benefit for a single discharging action, would you be able to provide discharging services without incurring fines for not providing the service?	130	Single	2 responders did not answer
(19)	What economic incentive would make you decide to discharge your electric vehicle?	130	Multiple	12 responders did not answer
(20)	Would you be able to perform actions in a critical situation for the operation of the National Power System, i.e., the risk of a system blackout, involving arriving at an agreed location and offering the available energy stored in the battery in order to rescue the power system?	130	Single	
(21)	Which of the following requirements should be met in order for you to join a V2G program?	130	Multiple	7 responders did not answer
(22)	What population range represents a place where you stay most of the year (min. 180 days per year)?	130	Single	
(23)	What gross salary range represents your current monthly earnings?	130	Single	

The first question in the survey presented in the paper concerns interest in electromobility and related technologies (Table A2 and Figure A1). The purpose of this question is to verify whether the pre-determined points of access to the questionnaires actually allow for aiming at the target group, i.e., persons with a keen interest in electromobility. Based on Table A2 and Figure A1, it can be concluded that the vast majority of respondents are interested in electromobility or have some knowledge on the topic. This breakdown of the results allows us to conclude that the survey was addressed to the proper group of people.

Table A2. Detailed responses to question (1).

Question:	<i>Are you Interested in Electromobility and Its Related Technologies?</i>
Yes	98
No	11
Difficult to say	21
Total number of respondents	130

Figure A1. Responses to question (1).

Considering that people interested in electromobility may not exclusively own an electric vehicle, the next questions concerned the type of car currently owned. Each respondent who answered that he or she owns a particular type of passenger vehicle was asked to indicate the hours in which they drive it. The responses are shown in Tables A3 and A4 and also in Figures A2 and A3. This information helped to design a vehicle usage profile that allowed for the calculation of initial values for the probability of the service provision. Interestingly, 27 respondents indicated that they owned both a combustion and electric vehicle. This issue was also asked about during the supplementary interviews, as two of the interviewees indicated this option. Both stated that their electric vehicle is used for getting around town, while they use ICE vehicles for longer trips. The survey found that almost 40% of the respondents own an electric vehicle or a plug-in hybrid. A good forecast for the development of electromobility is the fact that as many as 20% of respondents are considering the purchase of an electric vehicle within 5 years. At this point, it is worth noting that 4 respondents out of 130 indicated that they do not currently own an ICE vehicle but are considering purchasing EVs in the next 5 years. It should also be emphasized that among these four respondents there could be individuals who already own an EV and are planning to purchase a second one. Nevertheless, after analyzing the detailed responses of the interviewees, none of them suggested such an option in the comment box at the end of the survey. It should also be emphasized that this group of users are potentially interested in the V2G Program. This is due to the possibility of looking for additional benefits of EV ownership.

Table A3. Detailed responses to question (4).

Question:	<i>Do you Currently Own a Private Internal Combustion Engine (ICE) Passenger Car?</i>
Yes	86
No	44
Total number of respondents	130

Figure A2. Responses to question (4).

Table A4. Detailed responses to question (6).

Question:	Do You Currently Own a Battery Electric Vehicle (BEV) or Plug-in Hybrid (PHEV)?
Yes—BEV	48
Yes—PHEV	3
Considering purchasing an electric vehicle within 5 years	26
No	53
Total number of respondents	130

Figure A3. Responses to question (6).

The next questions asked *ICE* and *EV* users during which hours they use their vehicles. The results are presented in Table A5 and Figure A4. It is important to note that in this question, respondents were able to select several options. Based on these results, the profiles of *ICE* and *EV* users are fairly similar. The biggest differences appear between the hours of 9:00 and 15:00. In this time frame, more than 50% of *EV* owner respondents indicated that they use an *EV*, while only 30% of *ICE* vehicle users did so. However, given the fact that the profiles tend to coincide for most of the day, it can be concluded that the use of the data set in further deliberations is appropriate and can certainly be used to determine the probability value defined by Equation (8).

Table A5. Detailed responses to questions (5) and (7)—multiple-choice.

Question:	(5) What Hours Do You Use Your ICE Car Most Often?	(7) What Hours Do You Use Your EV Car Most Often?
00:00–06:00	3	2
06:01–09:00	51	30
09:01–12:00	26	28
12:01–15:00	23	29
15:01–18:00	62	36
18:01–21:00	35	22
21:01–23:59	13	5
No answer	1	-
Total number of respondents	86	51

Figure A4. Responses to questions (5) and (7) expressed as a percentage of responders.

The next questions asked about current or potential *EV* charging locations. Respondents who indicated ownership of an electric vehicle were asked to indicate where they most often charge their vehicles. Conversely, respondents who answered “No” or “*Considering purchasing an electric vehicle within 5 years*” to this question (Table A4) were asked to indicate the locations where they would do such charging. The set of charging locations was intentionally limited by excluding publicly available municipal charging stations. This is due to some restrictions that could be imposed on the V2G Program’s operation in the future. According to Polish law (Act on Electromobility and Alternative Fuels), *EV* charging services at publicly available charging stations must be provided on equal, non-discriminatory terms [52]. The use of V2X technology, on the other hand, requires the reservation of a place to provide such a service. It is assumed that those who would use the V2G Program described in Chapter 2 would be able to provide service at locations that potentially also serve as charging sites—e.g., with a several hour parking period, discharging could occur in the first few hours and state-of-charge (SOC) renewal in subsequent hours after emergency energy delivery is complete. Table A6 and Figure A5 show the results from the survey respondents for *EV* charging locations.

Table A6. Detailed responses to questions (8) and (9)—multiple-choice.

Question:	(8) If you Own an Electric Vehicle, Please Indicate Where You Would Be Most Likely to Charge It.	(9) Please Indicate the Charging Location Where You Are Most Likely to Do It. (EV Owners)
House or parking lot in front of the building	68	44
Workplace	44	15
Petrol station	14	3
Shopping mall	14	6
Sports and recreation centers	4	0
Total number of respondents	79	51

Figure A5. Responses to questions (8) and (9) expressed as a percentage of responders.

The vast majority of *EV* users as well as potential users charge or would like to charge their vehicle in their own home. Interesting differences can be observed in the case of workplace charging. Analyzing the responses presented in Table A6, it can be concluded that there is quite a big difference between the two surveyed groups (*EV* users and those who do not have them). As many as 55% of the respondents who do not have an *EV* would like to charge their vehicle at the workplace, but only 29% of current *EV* users said they do so. The difference may be due to the confrontation between future *EV* users' expectations for daily vehicle use and the reality that current *EV* users face. Potential problems may be caused by lack of charging infrastructure or lack of employer permission to charge vehicles in the parking lot. As such, employers should rethink plans to build infrastructure in their staff parking lots. A similar situation applies to petrol stations and shopping malls. However, it should be considered whether current *EV* users do not charge their vehicles in public places due to the already reviewed availability of infrastructure in public places and the power of these chargers, which also results in charging time.

Understanding the potential charging hours and its locations, a series of questions about participation in the V2G Program were subsequently asked. First, respondents were asked if they were familiar with the concepts of V2G or V2X technology. Table A7 and Figure A6 show the responses to this question.

Table A7. Detailed responses to question (10).

Question:	Are You Familiar with Vehicle-to-Grid (V2G) or Vehicle-to-Everything (V2X) Technology?
Yes	74
No	33
I have partial knowledge	23
Total number of respondents	130

Based on Table A7, it can be concluded that most of the respondents were familiar with the concept of V2G or V2X. It is interesting to note that, when analyzing the detailed responses of individual respondents, 41 out of 51 *EV* users stated they were familiar with V2X technology. This could mean that *EV* owners not only want to lead green lives or see economic savings in *EV* use but are also aware of the technology surrounding electromobility. Further analysis of the data revealed that 12 respondents indicated in question (1) that they are interested in electromobility, while in question (10) they gave the answer that they are not familiar with V2G technology. This is a good sign, suggesting that the knowledge about V2X technology is reaching a wider and wider group of people interested in electromobility.

Figure A6. Responses to question (10).

In the next questions, the respondents were asked whether they would join the V2G Program, in which they would discharge their vehicle at the order of a third-party operator in a home charging station. If the respondent selected “Yes” or “I don’t know” they were asked to indicate the hours during which they would do so (multiple choices possible). Table A8 alongside Figures A7 and A8 show the results of the responses to questions (11) and (12), respectively.

Table A8. Detailed responses to question (11).

Question:	<i>If you Owned an Electric Car, would you Join a V2G Program, which Involves Plugging Your Car into a Home Charging Station at the Order of a Third-Party Operator and then Discharging the Battery to a Specified Level in Exchange for Financial Benefits?</i>
Yes	72
No	24
Don't know	34
Total number of respondents	130

Figure A7. Responses to the question (11).

Figure A8. Responses to question (12).

The responses to the questions presented in Table A8 address the situation where the provision of discharging services is similar in concept to *V2H* technology. Based on the survey results, it can be concluded that most respondents would be willing to discharge vehicles at their home. At this point, it is important to see how many of the respondents would make the decision to join the *V2G* Program in their own home without any knowledge of *V2G* technology, based only on the brief explanation provided in the survey. We found that of the 74 respondents who answered in question (10) that they had knowledge of *V2G* technology, as many as 49 of them would be willing to provide *V2G* services in the home. Of the 33 people who answered “No” in question (10), only 9 people would not be willing to provide *EV* discharging services at their home, 12 people do not know, and 12 people would be willing to provide such services. Another group worth examining is the group that marked “I have partial knowledge” in question (10). In this group, 11 out of 23 people would be willing to provide *V2G* services at home, 8 out of 23 people do not know, while only 4 people would not want to provide such services. However, it is important to note that the question asked about discharging at the order of a third-party operator—in this case, *V2Gsp*. An interesting observation arises at this point, which was brought up by the respondents during the interviews or in the comments box at the end of the survey. Several respondents noted that they were not interested in discharging a vehicle at a home station at the order of an operator but would discharge a vehicle for the sake of securing their own household needs during possible blackouts. From the perspective of a potential *V2Gsp*, it would be therefore necessary to develop a good package to encourage users to discharge their vehicles at the order of the operator. In particular, it could include the installation of smart charging stations for *EVs*, allowing the implementation of demand reduction efforts but without compromising the level of available energy in the *EV* battery. *V2Gsp*’s role would also be to promote the habit of plugging the vehicle into a bidirectional charging station when the user is at home.

The next questions concerned the possibility of joining the *V2G* Program when the service provided would involve traveling to the end user and discharging an *EV* battery at that consumer’s facility in exchange for financial benefits. This referred to the service presented in [34], called “Emergency work for the energy consumer”, as an example of a *V2X* service provided by participants. Those who answered “Yes” or “Don’t know” to this question were asked to indicate the hours during which they could provide such a service and the distance they would be able to travel to reach the service delivery point. Figure A9 and Table A9 show responses to question (13) and Figures A10 and A11 show the responses to questions (14) and (15), respectively.

Table A9. Detailed responses to question (13).

Question:	<i>If You Owned an Electric Car, Would You Join a V2G Program Which Involves Traveling to a Point of Service (e.g., an Industrial Facility), Plugging Your Car into a Charging Station at the Order of a Third-Party Operator, and then Discharging the Battery to a Specified Level in Exchange for Financial Benefits?</i>
Yes	30
No	74
Don't know	26
Total number of respondents	130

Figure A9. Responses to question (13). **Figure A10.** Responses to question (14). **Figure A11.** Responses to question (15).

After further analysis of the individual responses, it can be concluded that only 20 people out of the 74 who answered “Yes” to question (10) would be willing to participate in providing vehicle discharging services at the location of any *EndUs*. For those with no knowledge of V2G technology, this number was 5 out of 33. Interestingly, 26 of the 130 respondents would be able to provide services at both their home and *EndUs* locations. It can be noted that for V2X services which involve moving to other points, the willingness to provide it decreased in relation to the service of discharging EV from one’s own home. This is most likely due to a desire to remain flexible and mobile—which was also indicated by additional comments and user interviews. It is also important to note the hours-of-service provision. From the point of view of power system operation, a positive observation is the relatively high interest in providing the service between 12:00 p.m. and 3:00 p.m. These are the hours of peak demand in the summer season, which could suggest that the DSO or TSO through V2Gsp will have the opportunity to acquire new generation capacity at this time. The second interesting observation is the distance that V2G Program participants would be able to travel. The options of up to 1 km or 1–6 km were selected most frequently by respondents. During the follow-up interviews, it was suggested that the distance should be sufficient to easily and quickly change the mode of transportation and travel to the target location. This is important for the design of the V2X service area by V2Gsp [34].

The last results of the survey questions, which will be needed for the application of the vehicle selection and service execution algorithm presented in [34], are related to the service mode selection. In [34], two modes of participation in the V2G Program are presented. The first one—mandatory—relies on staying available to provide the service in exchange for a fixed income, as well as fines for not performing the service. In the second mode—optional—the participant will only receive payment for the discharge service provided (not only for taking), without incurring any penalties for non-performance.

Tables A10 and A11 and Figures A12 and A13 show the answers to questions (17) and (18), respectively.

Table A10. Detailed responses to question (17).

Question:	<i>In Exchange for a Fixed Monthly Remuneration, would you be Willing to Stand by to Discharge an Electric Vehicle during the Hours Set by the V2G Program Operator, being Aware of Potential Fines for not Providing the Service?</i>
Yes	29
No	68
Yes, but with other additional benefits	32
No answer	1
Total number of respondents	130

Figure A12. Responses to question (17).

Table A11. Detailed responses to question (18).

Question:	<i>In Exchange for a Financial Benefit for a Single Discharging Action, Would You Be Able to Provide Discharging Services without Incurring Fines for Not Providing the Service?</i>
Yes	103
No	25
No answer	2
Total number of respondents	130

Figure A13. Responses to question (18).

It can be observed from Figure A13 that the vast majority of respondents would prefer to participate in the V2G Program in optional mode. However, 47% of respondents wanting to participate in the mandatory mode is a positive sign for the development of emergency power services that will be an alternative to today's mechanisms known from the power sector, such as the capacity market. It should be emphasized, however, that the responses to these questions indicated only a general trend, while the detailed methodology for determining the proportion of participants in mandatory and optional mode was established in Section 4.

In addition, in follow-up interviews, current 5 EV users provided detailed views on aspects presented in the survey.

The first EV user stated that mobility is most important to him and therefore he would not like to provide services in places where he would have to travel to. However, he was asked to indicate the distance he would be able to travel. He indicated that it would be a few kilometers within a 30-min drive time. In addition, he emphasized that he would be happy to help rescue the power system by offering energy from his EV in case this solution made sense on a certain scale.

The second EV user indicated that he has an electric vehicle for moving around the city. He assessed that for him, V2G technology would be acceptable only at home and only when he is not using the car. He also noted the problem of battery degradation due to frequent discharges and recharges. Interestingly, the impulse to buy an electric car was for purely economic reasons, specifically enhancing the use of PV plants for EV charging. In terms of BEV operation, he pointed out the problem of traveling long distances due to the not well-developed charging infrastructure.

The third EV user owns not only an EV (Nissan Leaf) but also an electric scooter. Similar to the second EV user, he would be willing to discharge the electric vehicle for his own use—V2H technology. He also emphasized that he would use the BEV to optimize the operation of his PV plant. He also believes that V2G technology makes sense, but only at the level of local energy balancing (small areas or for personal use). He also pointed out that

the benefits of participating in the V2G Program must cover the increased operation of the EV, and the benefits, for example, should cover the first lease payment. He also noted the problem of data privacy issues gathered by V2Gsp. The operator should process personal and location data of the uEV in a reasonable manner and should be held accountable for misuse.

The fourth EV user expressed great willingness to participate in the V2G Program. He owns a PHEV and an ICE. The PHEV is used for city driving only and is charged from a charging station installed in an underground garage. What would be important to him, however, is that the penalties resulting from failure to provide the guaranteed service would be proportional to the monthly revenue earned. He also suggested that the base for mandatory mode remuneration should be the number of interventions (estimated and after later adjustment).

The fifth EV user uses his electric vehicle for business purposes only. He drives an ICE vehicle on a daily basis. He would generally be willing to participate in the V2G Program, as long as there are no penalties for not providing the service. This is especially important for users who would be able to run V2G services with their company vehicles.

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