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Profitability Evaluation of Vehicle-to-Grid-Enabled Frequency Containment Reserve Services into the Business Models of the Core Participants of Electric Vehicle Charging Business Ecosystem

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Abstract: The current paper defines a framework for the introduction of frequency containment reserve (FCR) services, enabled by vehicle-to-grid (V2G) technology, into the business model of an entity owning and operating electric vehicle (EV) charging infrastructure. Moreover, the defined framework can also be extrapolated, with minor adjustments, to the business models of different core participants of the EV charging business ecosystem. This study also investigates the financial factors impacted by this introduction, eventually evaluating its financial profitability under given assumptions and comparing it to the profitability of the traditional business model of an entity owning and operating a unidirectional EV charging infrastructure. The current research shows that offering additional V2G-enabled FCR services can be potentially more profitable than the existing unidirectional approach if the V2G technology reaches its maturity phase with mass market adoption and economies of scale.

Keywords: V2G (vehicle to grid); business model; grid balancing

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1. Introduction

1.1. Context

The modern world is experiencing a massive electrification trend, and the increasing transition from internal combustion engine (ICE) vehicles to electric vehicles (EVs) is an important part of it. This electrification of transport can potentially place a significant stress on electricity grids by increasing energy demand and peak loads [1,2]. However, EVs can also be an enabler to mitigate this issue through the use of vehicle-to-grid (V2G) technology [1–4].

V2G technology gives the opportunity to discharge the energy from EVs back to the grid, opening the door to grid balancing (flexibility) services, such as frequency regulation and peak shaving [1,3,5]. Therefore, the rising popularity of EVs, in combination with the active use of V2G technology and smart charging, can become a very relevant long-term alternative to the traditional grid reinforcement methods currently employed by grid operators [6,7].

At the same time, provision of the V2G-enabled flexibility services can become a very relevant opportunity for the participants of the EV charging business ecosystem as well, serving as a new value proposition and opening up new significant revenue streams for its participants [6,8–10].

1.2. Literature Overview

1.2.1. V2G Technology

The term V2G was introduced by the research of Kempton et al. in 2001 [11] while they were investigating the technical and financial potential of bidirectional EV charging, including the opportunity of EV participation in ancillary services. Later on, with more and more applications, V2G technology evolved to a V2X concept [12]. As part of the latter, the EV battery can be used to power up various electric appliances (V2L) [13], a home (V2H) [14], a building (V2B) [15], a whole community (V2C) [16], other EVs (V2V) [17], etc.

It is important to mention that V2G technology is not yet in its maturity phase, and there are numerous social (e.g., range anxiety), economic (e.g., high cost of V2G chargers), political (e.g., lack of relevant legislative mechanisms), and technical (e.g., lack of V2G-enabled EVs) barriers to overcome before the technology reaches the mass market [1,11,18]. Many of these barriers represent chicken-and-egg deadlocks in which the technology is not able to be massively adopted before overcoming the barrier, while the technology does not become relevant for the surrounding business ecosystem unless it is massively adopted. For instance, EV manufacturers do not produce the V2G-enabled EVs due to the absence of V2G infrastructure, while the infrastructure is absent due to the lack of a clear financial incentive for the EV charging business ecosystem [1,11,18]. This financial incentive could be provided by the grid operators through the revenues from the V2G-enabled flexibility services. However, the grid operators do not adapt the flexibility market to V2G-enabled solutions due to the absence of these solutions on the mass market. Thus, understanding the business case is key to incentivizing all the involved actors to realize the full potential of the technology by simultaneously collaborating and advancing the technology and reach a win–win situation.

1.2.2. V2G-Enabled Flexibility Services and EV Charging Business Ecosystem

The existing literature offers relatively limited knowledge on the effect of the introduction of V2G-enabled grid balancing services into the business models of the participants of public and semi-public EV charging infrastructures [9,10,19,20]. Moreover, there is a lack of a clear, quantified business model towards capturing value [1,18].

The currently existing EV charging business ecosystem includes numerous interrelated entities acting together to provide EV charging services, the core value proposition of the ecosystem [9]. It is noticeable that the entities owning and operating EV charging infrastructure are at the core of the EV charging business ecosystem, being directly related to the provision of its current core value proposition [9]. Thus, one of the key participants of the EV charging business ecosystem is the charge point operator (CPO)—the entity that manages, maintains and often owns EV charging infrastructure. Therefore, a successful and profitable introduction of V2G technology into the business model of a CPO (and other entities with similar roles) is a major step towards V2G adoption by the whole business ecosystem.

The business model of an archetypical CPO owning and operating a public and/or semi-public EV charging infrastructure is provided in Figure 1 where the changes caused by the introduction of the V2G technology are highlighted in blue.

As shown in Figure 1, the introduction of new technology influences all the business model perspectives (including customer, internal business, value propositions and financial perspectives), as it involves the introduction of—among others—new key activities, customer segments, revenue streams, and cost structure elements.

However, following the logic of the business model innovation mechanism, described in [9], the technological transformation of the business model begins with the introduction of a new key resource—V2G technology. Consequently, it allows the company to offer new value propositions enabled by this new key resource. New value propositions enabled by the V2G technology are mainly related to grid-balancing services (see Figure 1).

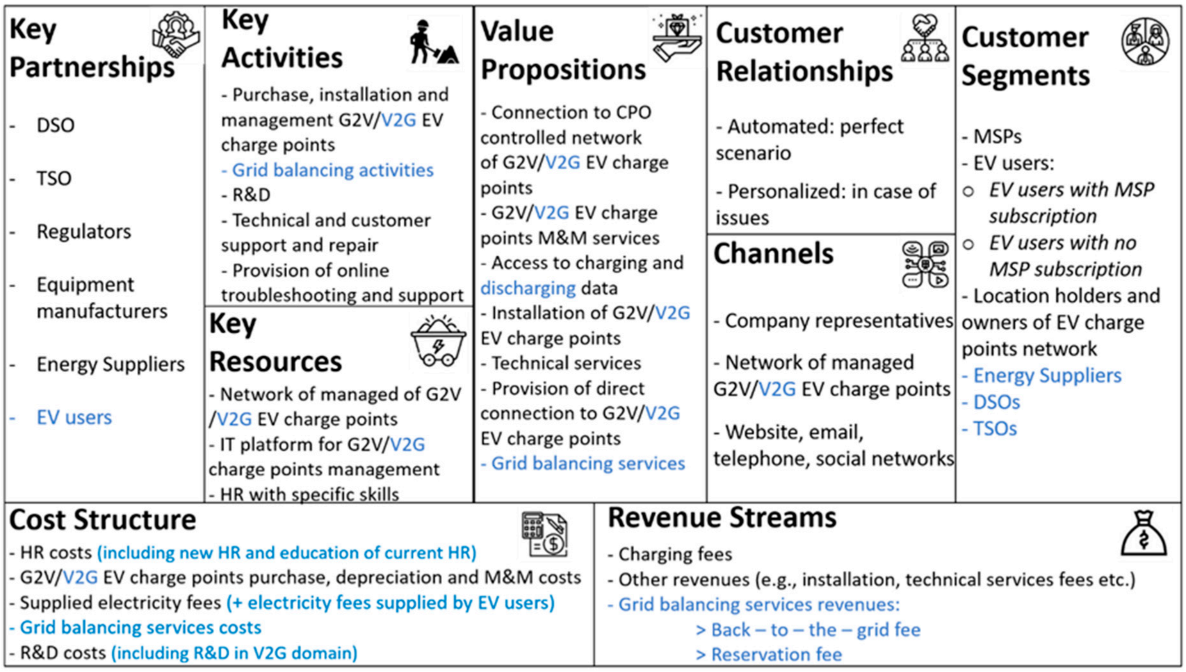


Figure 1. Business model: CPO + V2G (V2G—caused changes are marked in blue) [9].

1.2.3. Grid-Balancing Services

In order to introduce grid-balancing services into the list of its value propositions, an entity owning and operating EV charging infrastructure must contractually become one of the balancing service providers (BSP) connected to the respective transmission system operator (TSO) [21].

According to Elia [22], the Belgian Transmission System Operator (TSO), there are three types of grid balancing services that could be provided by a BSP connected to the grid. These services allow the maintenance of the balance between the energy injection and consumption and maintain the grid operation at a constant frequency of 50 Hz. They are presented in Table 1.

Table 1. Types of grid-balancing services [22].

Type	Description
Frequency Containment Reserve (FCR)	Primary automatic reserve provided by the entity with FCR service contract, reacting within a timeframe between zero and 30 s to a frequency deviation and stabilizing it on a certain level.
Automatic Frequency Restoration Reserve (aFRR)	Secondary automatic reserve provided by the entity with aFRR service contract, restoring the frequency to 50 Hz within a timeframe between 30 s and 15 min.
Manual Frequency Restoration Reserve (mFRR)	Tertiary reserve, provided by the entity with mFRR service contract, manually activated by the TSO in case of major imbalances and congestions. The respective BSPs must make mFRR available not later than 15 min after the TSO's demand.

The currently existing grid-balancing market is designed for large, centralized entities able to operate relatively large power capacities and volumes of energy. The provision of FCR services is typically considered a side activity for these entities. However, due to the large power capacity and energy volumes offered, the generated revenues can reach significant values.

At the same time, the modern world faces the decentralization trend of energy supply caused by the technological developments related to the renewable energy generation, power transfer, and reduction of battery costs [23]. Even though the power capacity that can be offered individually by the smaller entities (e.g., prosumers) is significantly less, the aggregated capacity is potentially able to reach significant values. This creates the opportunity to evolve the traditional business model for FCR services provision and include new decentralized players into the market. Moreover, even though BSPs often interface with DSOs, TSOs have the ability to directly contract BSPs [24].

Even though the decentralization process has already begun, there is still a number of unfavorable conditions for potential smaller decentralized BSPs. This list of unfavorable conditions mainly includes the minimum energy capacity bid size of 1 MW along with the specialized metering equipment on every so-called, "Delivery Point" (EVSE, in case of EV charging infrastructure) [25,26]. However, according to Elia and the Belgian energy regulator CREG (Commission for Electricity and Gas Regulation), grid balancing service conditions for BSPs must evolve in the direction of the reduction of minimal contracted capacity and utilization of standard widely accepted smart meters as metering equipment [27–29].

However, despite the existing decentralization initiatives, the framework offered by the current research (see Section 2.1) and resulting models is still not fully applicable for the residential, fully decentralized V2G EVSE due to the need of an aggregator to aggregate the capacities of multiple delivery points and virtually create a large entity corresponding with the currently existing grid balancing market design. The role of the aggregator, in the case of V2G-enabled flexibility services, can be taken over by a CPO (or other entity-managing EVSE infrastructure willing to become a BSP). The most suitable type of V2G-enabled flexibility service could be the FCR because of the ability of EV batteries to react immediately to a power request and a relative readiness of the TSOs and policy makers to adopt FCR service conditions for smaller decentralized BSPs [28].

The only remuneration foreseen for FCR services is based on the energy capacity offered by the BSP and reserved by the TSO, expressed in €/MW/h price. This price is defined by means of capacity bids on the FCR energy capacity auction, organized by the TSO for the involved BSPs. Due to the symmetric nature of FCR services in Belgium, requiring rapid upward and downward activations of the contracted balancing power capacities, the supplied and consumed energy payments during the activations offset each other, while the TSO offers remuneration for the reserved power capacity [30].

Concerning the risks for the BSP, the participation into FCR services involves potential penalties for: (a) not passing the availability test of the reserved capacity (organized by the TSO) and (b) the inability to activate the reserved capacity. However, the potential financial penalty cannot exceed the remuneration paid for the reserved energy capacity, making the grid-balancing services market, to a certain extent, risk-free [30] except for risks related to the initial investments into the infrastructure.

1.3. Contribution

The current paper adds value to the existing literature by decreasing lack of knowledge on the effect of introduction of V2G-enabled grid balancing services into the business models of the participants of public and semi-public EV charging infrastructures. The list of the contributions of this research includes: (a) definition of the framework for the introduction of the V2G-enabled FCR service into the list of the core value propositions of the business model of different entities (with minor case-dependent adjustments) owning and operating public and semi-public EV charging infrastructure (e.g., CPO, EV charging location holder); (b) evaluation of the profitability of the introduction of this new V2G-enabled value proposition by the means of a set of profitability indicators; (c) comparative profitability analysis with unidirectional EV charging infrastructure business model; and (d) a sensitivity analysis of the profitability of an entity owning and operating public and semi-public EV charging infrastructure (both uni- and bidirectional, offering FCR services), defining the most critical revenue and cost factors.

2. Methods

2.1. V2G-Enabled FCR Services into the Financial Perspective of the Business Model

The current paper focuses on the introduction of V2G technology into the business model and V2G-enabled grid balancing opportunities, while more elaborate definitions of revenue streams and cost structure of entities owning and maintaining EVSE networks can be found in [31]. According to [31], the generalized financial framework can be defined as follows (Equations (1) and (2)):

$$\text{Revenues} = \text{TF} + \text{OR}, \tag{1}$$

- TF: total fee received from the charging activities on the EVSE network.
- OR: other revenues generated by side activities not directly related to the EV charging (e.g., advertisement, technical fees, etc.).

$$\text{Costs} = \text{C}_{Infrastructure} + \text{C}_{Electricity} + \text{C}_{MP} + \text{C}_{HR} + \text{C}_{Other}, \tag{2}$$

- $C_{Infrastructure}$: depreciation, management and maintenance costs of EVSE infrastructure.
- $C_{Electricity}$: electricity costs paid to the energy suppliers.
- C_{MP}: costs for accessing the common interoperable marketplace for EV charging business ecosystem.
- C_{HR}: costs related to the human resources.
- C_{Other}: other additional costs, not represented by the previous categories.

As it is explained in Section 1.2.2, currently, the most convenient type of V2G-enabled grid balancing service for an entity owning and operating EVSE network is the FCR service, adding an additional revenue stream paid by the TSO to the BSP (Equation (3)):

$$\text{Revenues} = \text{TF} + \text{OR} + \text{R}_{FCR}, \tag{3}$$

- R_{FCR}: revenues generated through FCR flexibility services

The formula for the revenues generated by the means of V2G-enabled FCR services can be defined as follows (Equation (4)):

$$\text{R}_{FCR} = \text{FCR}_{Bid} * \sum_{y=1}^{Z} \left(K_y * N_y * (CR_\text{y} - UR_\text{y}) \right) * T \tag{4}$$

FCR_{Bid}: average FCR capacity bid (in €/MW/h) during the considered time period (T) on the energy capacity auction organized by the TSO.

y: type of V2G EVSE

K_y: power level of EVSE type y

CR_y: connection rate of EVSE (in%), being the percentage of the considered period (T) that the considered EVSE type y was connected to an EV.

UR_y: usage rate of EVSE (in %), being the percentage of the considered period (T) that the considered EVSE type y was actively engaged into the EV charging process.

N_y: number of EVSE type y

T: considered EVSE availability period

The difference between CR and UR can be considered the EVSE idle time available for the provision of the FCR services. Regarding the cost structure, while the introduction of V2G technology does not bring any new cost elements to the list, it does increase the existing ones. This raises concerns mainly related to the costs of the EVSE infrastructure ($C_{Infrastructure}$), i.e., depreciation, management and maintenance, and software and HR costs.

2.2. Profitability Evaluation

The current study's comparative profitability evaluation model is based on several common profitability indicators. The list of these profitability indicators includes earnings before interests and taxes (EBIT), earnings before interests, taxes, depreciation, and amortization (EBITDA), and the margins of these indicators and the annualized ROI [32–34]. The definitions of the chosen indicators can be found in Table 2.

Table 2. Profitability indicators with definitions [32–34].

Indicator		Generalized Formula	Definition
EBIT	=	$Revenues - Costs$	EBIT is the difference between company's operating revenues (not including the interest revenues) and costs (before the inclusion of tax-related expenses).
EBITDA	=	$EBIT + Depreciation + Amortization$	EBITDA repeats the definition of EBIT but does not include the depreciation and amortization into the costs list.
EBIT margin (%)	=	$\frac{EBIT}{Revenue} * 100\%$	EBIT margin is a company profitability ratio, indicating the relative part of the revenues preserved after the deduction of expenses (before interests and taxes).
EBITDA margin (%)	=	$\frac{EBITDA}{Revenue} * 100\%$	EBITDA margin repeats the definition of EBIT margin but does not consider the depreciation and amortization costs.
ROI (%)	=	$\frac{EBIT}{Total\ investment} * 100\%$	ROI shows the ratio of company's EBIT to the total amount of the invested capital.

The selection of EBIT as a profitability indicator allows to avoid the peculiarities of different taxation mechanisms, providing the opportunity to extrapolate the results of the current study to different geographic regions [31]. The use of EBITDA allows the capital-intensive companies (e.g., entities owning EVSE networks) to obtain alternative view on the operating financial perspective of their business models, taking the costly assets with long depreciation periods out of scope [33]. High EBIT and EBITDA margins indicate a higher efficiency of the company, where a significant part of revenue is retained by the company [34]. Finally, the ROI, one of the capital return profitability ratios, considers the total investment and allows the evaluation of the profitability of the company with respect to the total invested capital [34].

2.3. Sensitivity Analysis

EBIT is the central profitability indicator of the current research and is considered in the calculations of all the other indicators. As EBIT is the difference between a company's operating revenues and costs, its calculation comprises numerous revenues and costs factors (described in Section 2.1, Section 2.2, and Section 3.1). However, not all the factors play equal roles, as EBIT might be more sensitive to the changes in one factor over the other. In order to assess the importance of the factors driving the EBIT calculation, the current research offers a sensitivity analysis (Section 3.4) based on the nominal range sensitivity method [35].

The nominal range sensitivity method implies choosing the base case value for the dependent variable and fixing the independent variables on the correspondent values. Thereafter, one (or each individually) of the independent variables is elected to vary across the predefined percentual range, while all the other independent variables remain fixed. Clearly, the changes in input, ceteris paribus, cause changes in output. Thus, after running this algorithm with all the independent variables, it becomes possible to compare the intensiveness of the reaction of the dependent variable to the changes of each independent variable and assess the importance of each input factor [35].

However, it is important to mention that this method has a significant disadvantage, that could be addressed by future research. Namely, the nominal range sensitivity method isolates the selected independent variable by fixing all the others on a certain value and does not take into consideration the potentially present interrelations [36].

2.4. Values of the Relevant Factors

The values of the factors participating into the aforementioned revenues and cost calculations, along with the sources validating these values, are provided in Table 3.

Table 3. Values of the factors participating into the profitability evaluation of the business models [19,37–52].

<table>
<tr><th>#</th><th>Parameter</th><th>Symbol</th><th>Unit</th><th colspan="3">Value</th></tr>
<tr><td>1</td><td>EVSE type</td><td>y</td><td>/</td><td>Unidirectional AC charger</td><td colspan="2">V2G charger</td></tr>
<tr><td>2</td><td>EVSE power level [37]</td><td>Ky</td><td>kW</td><td colspan="3">11</td></tr>
<tr><td rowspan="4">3</td><td rowspan="4">EVSE price [19,37–39]</td><td rowspan="4">Py</td><td rowspan="4">€</td><td rowspan="4">1200</td><td>DC Current</td><td>5000</td></tr>
<tr><td>DC Break-even</td><td>3999</td></tr>
<tr><td>DC Estimated</td><td>3500</td></tr>
<tr><td>AC Estimated</td><td>1200</td></tr>
<tr><td>4</td><td>EVSE installation cost [37,40]</td><td>Iy</td><td>€</td><td colspan="3">1000</td></tr>
<tr><td>5</td><td>Charging fee [40–43]</td><td>CFy</td><td>€/kWh</td><td colspan="3">0.35</td></tr>
<tr><td>6</td><td>Maximum yearly availability time</td><td>T</td><td>hours</td><td colspan="3">8760</td></tr>
<tr><td>7</td><td>Maximum yearly charging capacity</td><td>MCy</td><td>kWh/year</td><td colspan="3">96,360</td></tr>
<tr><td>8</td><td>Connection rate [43–46]</td><td>CR_y</td><td>%</td><td colspan="3">42</td></tr>
<tr><td>9</td><td>Charging usage rate [43–46]</td><td>UR_y</td><td>%</td><td colspan="3">7</td></tr>
<tr><td>10</td><td>Electricity price [47]</td><td>$C_{Electricity}$</td><td>€/kWh</td><td colspan="3">$0.9636 * (MCy * URy * Ny)^{-0.126}$</td></tr>
<tr><td>11</td><td>Average FCR capacity bid [48]</td><td>FCR_{Bid}</td><td>€/MW/h</td><td colspan="3">16.6</td></tr>
<tr><td>12</td><td>Useful lifetime [49,50]</td><td>Ly</td><td>years</td><td colspan="3">10</td></tr>
<tr><td>13</td><td>Salvage value [49,50]</td><td>Sy</td><td>%</td><td colspan="3">5</td></tr>
<tr><td>14</td><td>HR cost [43]</td><td>C_{HR}</td><td>€</td><td colspan="3">$1000 * Ny$</td></tr>
<tr><td>15</td><td>Cost of accessing the marketplace [51,52]</td><td>C_{MP}</td><td>€</td><td colspan="3">15,000</td></tr>
<tr><td>16</td><td>Miscellaneous costs [43,49,50]</td><td>C_{Other}</td><td>€</td><td colspan="3">100 000</td></tr>
<tr><td>17</td><td>Management and maintenance costs [43,49,50]</td><td>$C_{M\&M}$</td><td>€</td><td colspan="3">$10\% * (Py + Iy)$</td></tr>
<tr><td>18</td><td>Total initial investment</td><td>/</td><td>€</td><td colspan="3">$(Py + Iy) * Ny$</td></tr>
<tr><td>19</td><td>Number of EVSE</td><td>Ny</td><td>Units</td><td colspan="3">Variable</td></tr>
</table>

Having defined the values of the factors from Table 3, a justification of the chosen values is provided below as their retrieval is not always straightforward. First, since the V2G technology is not yet in its maturity phase, the price of V2G EVSE (Py) has not yet reached its mass market value. Therefore, the current research uses four different V2G EVSE pricing methods (see Table 3, #3). The first one is the currently existing V2G DC EVSE market price, which is considered to be too high over a longer period of time due to the current lack of mass production and potential future economies of scale [19]. The second is a so-called, "break-even price", indicating the V2G DC EVSE price ceiling at which the

EBIT of the entity owning a network of unidirectional EVSE equals the EBIT of the entity providing additional V2G-enabled FCR services. The third is the estimated V2G DC EVSE price in its maturity phase. Finally, the fourth price setting indicates a presumable V2G AC EVSE price equalized with the current price of unidirectional AC EVSE of a comparable power level. However, it is important to mention that the V2G AC EVSE is currently absent on the market due to the lack of the necessary communication protocols between the vehicle and charger. Moreover, the technology also requires acceptance from the EV manufacturers' side [53].

Another factor value that requires further explanation is the electricity price ($C_{Electricity}$ in Table 3, #10). The formula provided in Table 3 is represented by the following trendline (Figure 2) of the electricity price data of annual consumption bands for non-households in Belgium, provided by Eurostat [47].

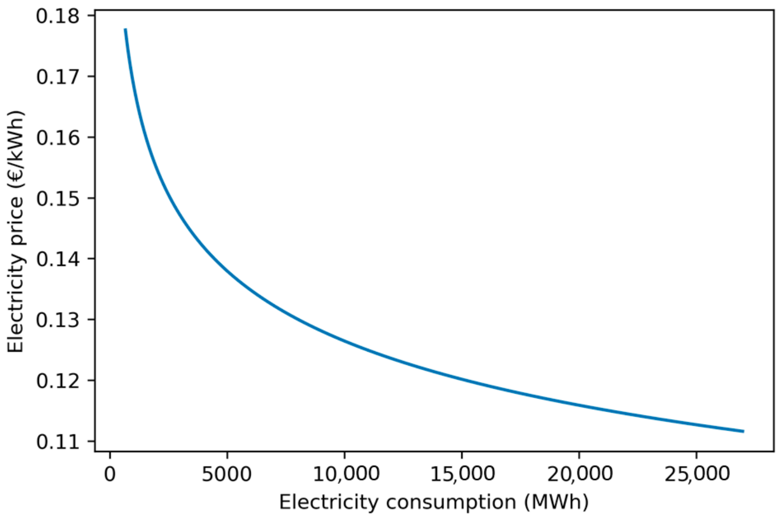


Figure 2. Electricity price trendline (based on 2011–2021 data) for Belgian non-household users in function of consumption [47].

The trendline shown in Figure 2 shows a clear negative relation between the electricity price and consumption; the increase in consumption causes the decrease in electricity price per kWh. The curve is steeper on the left side of the graph at a relatively small volume of electricity consumption, while further increase in consumption has a noticeably smaller effect on price. For instance, considering the values of the parameters presented in Table 3, a small network of 5 EVSE generates the consumption of 34 MWh per year, which leads to an electricity price of 0.26 €/kWh. The expansion of the EVSE network to 2000 units, consuming 13,500 MWh, decreases the electricity price to 0.12 €/kWh. However, doubling of the network size to 4000 EVSE, consuming 27,000 MWh, would cause only a further (minor) reduction of electricity price to 0.11 €/kWh. Moreover, this effect is not infinite, and the energy price stabilizes at a very high level of consumption of around 500 GWh (e.g., at large energy-intensive industries) [48].

Drawing back to the $C_{Electricity}$ formula from Table 3, the trendline provided by Figure 2 shows the following dependency between the consumption and the price (Equation (5)):

$$C_{Electricity} = 0.9636 * Electricity\ Consumption^{-0.126} \quad (5)$$

Translation of Equation (5) in terms of the model used by the current paper leads to Equation (6), provided in Table 3:

$$C_{Electricity} = 0.9636 * (MCy * URy * Ny)^{-0.126} \quad (6)$$

It is also important to mention that while the Equation (6) delineates the dependency between the electricity price and the internal electricity consumption of the company, the changes in the electricity price can be also caused by factors external to the company.

The currently ongoing energy crisis can serve as a very relevant example of such an external factor. Equation (6), along with the trendline provided in Figure 2, is based on the electricity price data for the period between 2011 and 2021, while the electricity price in Belgium in 2022 is significantly higher due to the ongoing geopolitical processes. For instance, a small network of 5 EVSE generating the average yearly consumption of 34 MWh would pay 0.85 €/kWh (September 2022 electricity prices) [54] instead of the previously valid price of 0.26 €/kWh (see Figure 2). At the same time, the trendline showing the relation between electricity price and consumption remains unchanged—the more energy consumed the lower is the price per kWh.

Electricity price is an important factor, having, ceteris paribus, a significant influence on the EBIT of current research's focal entities (see Section 3.4). Consequently, these entities must react to such a drastic increase in electricity price with a rise in charging fee (*CFy*), attempting to maintain the financial viability of the company. This step involves potential risks related to the decrease in customers' loyalty. However, due to the lack of historical data and the uniqueness of the situation, it is currently impossible to make any trustworthy projections about the customers' reaction and the future profitability of these companies.

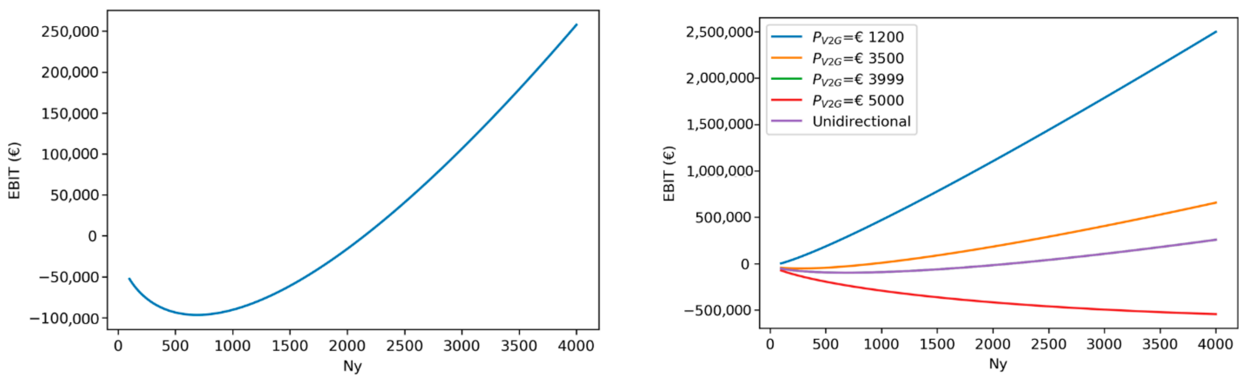
Thus, according to these data availability requirements, the time scope of the current research is limited to the period between 2011 and 2021. However, due to the importance of the ongoing unprecedented processes on the energy market, the collection of the present-day data, their analysis, and the comparison of results with the results of the current research (see Section 3) are among the most relevant future research steps.

3. Results

In this section, we provide the results of the calculations of the aforementioned profitability indicators for two types of business models, namely the entity owning and operating a network of unidirectional EVSE and the one additionally providing V2G-enabled FCR services.

3.1. EBIT and EBIT Margin

The first profitability indicator evaluated by the current study is EBIT (Figure 3):



(**a**) (**b**)

Figure 3. (**a**) EBIT of an entity owning a network of unidirectional EVSE in function of *Ny*; (**b**) EBIT of an entity owning a network of V2G EVSE in function of *Ny*.

Figure 3a shows the EBIT of an entity owning and operating a network of unidirectional EVSE in function of the number of EVSE into the network (*Ny*). It is noticeable that the EBIT in Figure 3a shows a negative trend for low *Ny* values. The reason behind that is twofold. First, the revenues from a small EVSE network are not able to cover high initial costs (C_{HR}, C_{MP}, C_{Other}), that must be paid from the very beginning. Secondly, as was explained in previous section, the electricity price diminishes with the growth of consumption. Thus, a smaller EVSE network is not able to consume sufficient electricity to negotiate a favorable electricity price. However, as the number of EVSE grows further, the EBIT trend switches to positive, reaching the break-even point at 2150 EVSE units. After the point where EBIT becomes positive, it grows even stronger, due to the growing energy consumption causing higher revenues and diminishing per kWh electricity prices.

Figure 3b shows the EBIT of an entity owning a network of bidirectional EVSE, including four different EBIT curves, each of which represents a different V2G EVSE pricing method (described in the previous section). It is noticeable that with the currently existing V2G DC EVSE market price, the EBIT shows a negative trend and is not able to reach the break-even point (see Figure 3b, red curve). However, the decrease in V2G DC EVSE price to EUR 3999 (see Figure 3b, green curve), would already lead to the equalization of EBIT with the one presented in Figure 3b. A further decrease in V2G DC EVSE price, estimated by the currently existing literature (Figure 3b, yellow curve), would intensify the CPO EBIT growth, allowing achievement of the break-even point at 929 V2G EVSE units. Finally, the introduction of V2G AC EVSE with the price equalized to that of unidirectional EVSE of a comparable power level (Figure 3b, blue curve) could give an enormous boost to the EBIT, changing the break-even quantity to 89 V2G EVSE units in the network.

The EBIT margin, being the ratio of EBIT to its revenue component, is presented below in Figure 4.

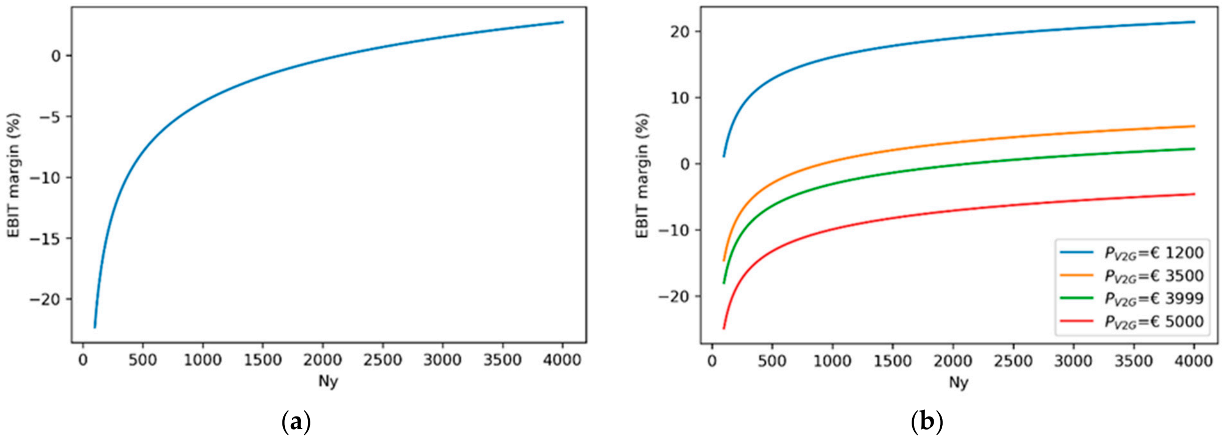
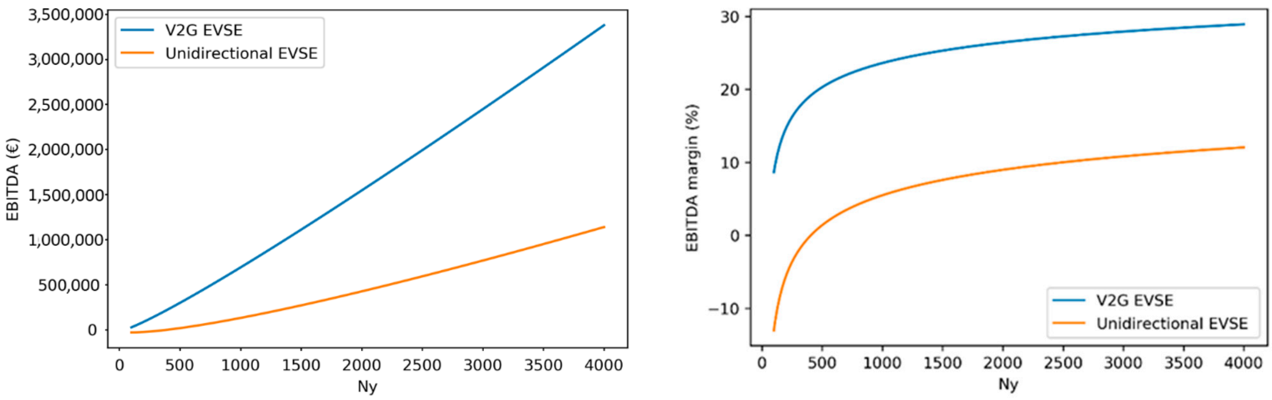


Figure 4. (**a**) EBIT margin of an entity owning a network of unidirectional EVSE in function of *Ny*; (**b**) EBIT margin of an entity owning a network of V2G EVSE in function of *Ny*.

The EBIT margins of the described business models are in general relatively low. In most of the scenarios, they do not reach 5% at a reasonable EVSE network size. This is due to high operational costs offsetting a major part of the revenues and indicating a low profitability efficiency. However, there is also an exception represented by the case of V2G AC EVSE (see Figure 4b, blue curve). A lower V2G AC EVSE price significantly cuts the depreciation expenses and gives a relatively high EBIT margin of 20% with a network size of 4000 EVSE.

3.2. EBITDA and EBITDA Margin

As described in Section 3.1, EBITDA is the profitability indicator excluding the depreciation and amortization costs. Therefore, the division of V2G EVSE pricing methods, present in the EBIT calculations in the previous section, becomes irrelevant for EBITDA calculations. The following figures present EBITDA and EBITDA margins (Figure 5a,b, respectively) both for business models of entities owning a network of unidirectional and V2G EVSE:



(a) (b)

Figure 5. (**a**) EBITDA of entities owning a network of unidirectional and V2G EVSE in function of *Ny*; (**b**) EBITDA margins of entities owning a network of unidirectional and V2G EVSE in function of *Ny*.

A typical business model of an entity, owning and maintaining numerous assets (e.g., CPO with EVSE network) with long depreciation periods, is relatively capital-intensive. Therefore, it becomes difficult to define the operational profitability of the company, as every asset must be depreciated and becomes the part of costs. In this case, EBITDA can become and interesting profitability indicator, concentrated on the current situation.

As becomes clear from Figure 5a,b, the business model which includes the provision of V2G-enabled FCR services is significantly more efficient in terms of this profitability indicator, generating a positive EBITDA from relatively small EVSE network sizes and reaching the EBITDA margin of 30% at the network size of 4000 EVSE.

3.3. ROI

In contrast to the profitability indicator discussed in the previous section, the current section evaluates the ROI (Figure 6), the profitability ratio directly related to the amount of capital invested into the company.

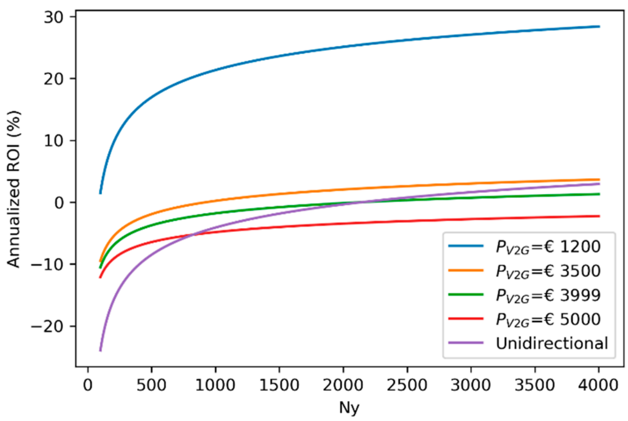


Figure 6. ROI of entities owning a network of unidirectional and V2G EVSE in function.

Entities owning EV charging infrastructure participate in a capital-intensive industry, having, in general, a relatively low EBIT margin (as described in Section 3.1). The combination of these two factors leads to a relatively low ROI, barely differentiating from zero, at the network size of 4000 EVSE. The obvious outlier with significantly higher ROI is the blue curve, indicating the V2G AC EVSE network with lower capital cost, creating a relatively high ROI of 30% within the network size of 4000 EVSE.

We also observe that the ROI curve of the entity owning a network of unidirectional EVSE (Figure 6, purple curve) shows a slightly different behavior. At a small network size, the ROI values shown by the purple curve are significantly lower than the rest, while the growth of EVSE network gives it a stronger boost, outperforming the curves indicating the application of current and break-even V2G DC EVSE prices and almost crossing the yellow curve (indicating the estimated long-term V2G DC EVSE price) at a network size of 4000 EVSE. From this observation, we conclude that V2G-enabled FCR services allow achievement of profitability faster, but the less-capital-intensive EVSE can generate a higher ROI on larger network sizes.

3.4. Sensitivity Analysis

In this study, EBIT is the central profitability indicator influencing all the other indicators. Therefore, after the definition of all the profitability indicators, it is also interesting to assess the importance of the individual influence of revenue and cost factors on EBIT.

The conducted sensitivity analysis is presented in Figure 7 and shows the EBIT sensitivity to the list of selected factors playing major roles in the business model of an entity owning and operating EV charging infrastructure: (1) the number of EVSE into the network (*Ny*); (2) the network usage rate (*URy*); (3) network connection rate (*CRy*); (4) electricity costs (*Ce*); and (5) charging fee (*CFy*). Each of these factors individually fluctuates, ceteris paribus, within a range of −10% to +10% from its base case value, which corresponds with the break-even point (EBIT = EUR 0) of unidirectional EV charging network.

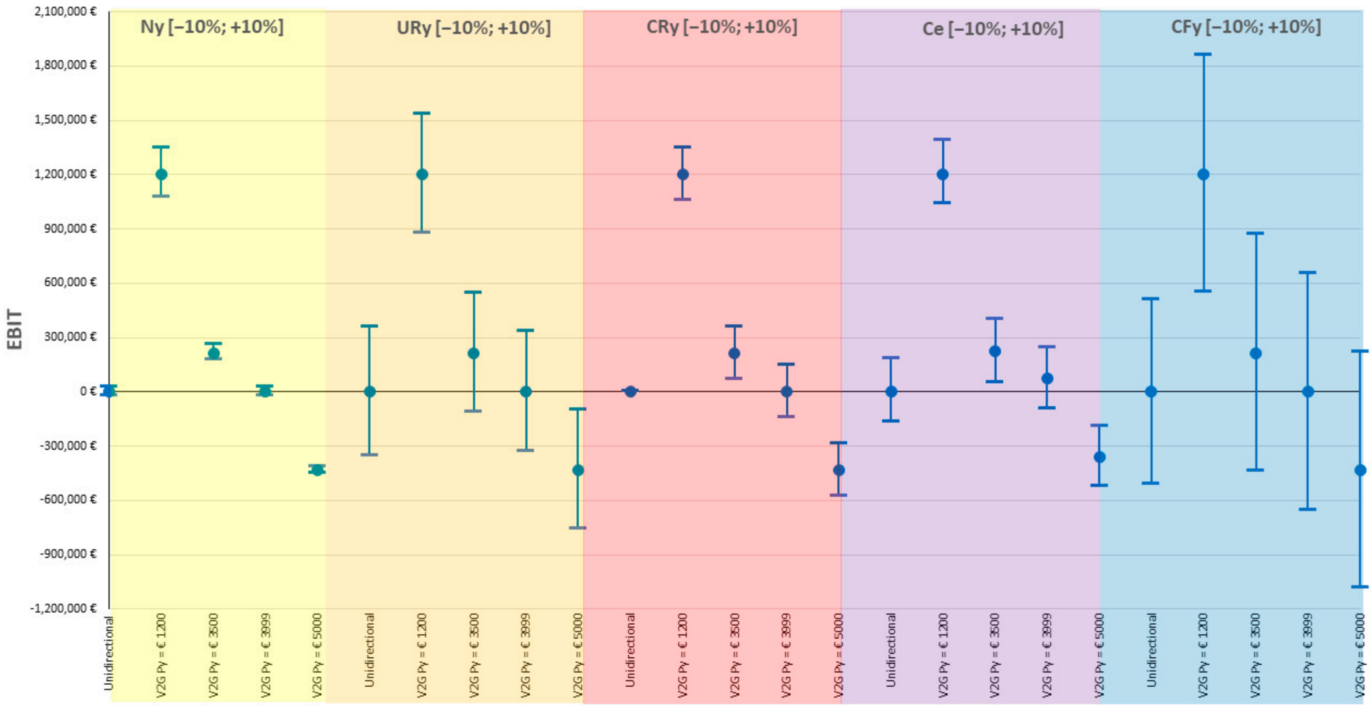


Figure 7. EBIT (EUR) sensitivity to elected revenues and costs.

Moreover, owning and operating an EV charging infrastructure implies participation into a capital-intensive industry, where the initial cost of capital in significant. Therefore, the analysis is conducted for each considered EVSE price level individually, for every selected factor.

In Figure 7, it is visible that the most significant factor influencing the EBIT is the EV charging fee (*CFy*), for which a 10% change in *CFy* causes a change in EBIT of around EUR 600,000. This observation is valid both for the business model of the entity owning and operating a unidirectional EV charging infrastructure and for the one providing additional V2G-enabled FCR services. This allows us to conclude that even after the transformation by the introduction of V2G-enabled FCR services, the business model of the focal entities still remains very dependent on its initial core value proposition. Moreover, this conclusion is also supported by the high importance of EV charging infrastructure usage rate (*URy*) and electricity costs (*Ce*) factors, directly influencing the revenues and costs related to the EV charging services.

However, it is also important to notice the differences in EBIT sensitivity to the EV connection rate (*CRy*) between unidirectional and V2G-enabled FCR business models. While in the first case, sensitivity is absent, the addition of V2G-enabled FCR services makes it an important factor, as the connected EVs are able to generate significant revenues during idle connection time, making the FCR services another important value proposition.

Finally, the influence of number of EVSE into the network (*Ny*) is relatively small, as the depreciation of the expensive assets eventually undercuts profitability. However, the obvious outlier, showing significant EBIT sensitivity to the minor changes in infrastructure size, is the less-capital-intensive AC V2G EVSE infrastructure case, for which the generated revenue not only allows to cover the initial capital costs but also gives a substantial boost to the EBIT.

4. Discussion

After the presentation of results, it is important to note that even though the defined model is based on the currently existing archetypical business model of a CPO [3,31], it could be also extrapolated, with minor adjustments, to other participants of the EV charging business ecosystem that perform similar functions. For instance, a location holder owning an EVSE network can hire an external CPO to operate this network for a fixed fee. In this case, the revenue and costs model remains unchanged except for the addition of the CPO fee to the list of costs. It should be underlined that the scope of the framework presented in this study is limited to public and semi-public EVSE infrastructure.

It should be also pointed out that the performed sensitivity analysis (see Section 3.4) does not take into account the interrelations between the input factors (e.g., the rise of *CFy* can potentially exceed the customers' willingness to pay and decrease the *URy*, which would lead to a negative impact on EBIT). Therefore, the study on interrelations between the input factors would be a useful future research direction.

5. Conclusions

The current paper defines a quantitative framework for the introduction of the V2G-enabled FCR services into the business model of an entity owning and operating public and/or semi-public EV charging infrastructure. It also evaluates the profitability of this introduction by the means of a set of profitability indicators. Furthermore, a sensitivity analysis is performed on the major factors influencing the profitability of the proposed business model. Moreover, the current study provides the comparison of the values of the profitability indicators for the business model, implying the owning and operating of the network of unidirectional EVSE only, and the one providing additional V2G-enabled FCR services.

The analysis of the profitability indicators allows to conclude that under the current market conditions with a V2G DC EVSE market price of EUR 5000, the existing business model of an entity owning a network of unidirectional chargers is more profitable than the business model after the introduction of V2G-enabled FCR services. However, V2G technology has not yet reached its technological maturity phase and lacks the benefits of economies of scale. Therefore, the estimated target price of V2G DC EVSE (EUR 3500) is significantly lower than the one currently existing on the market. The introduction and mass adoption of V2G AC EVSE (having potentially significantly lower prices than V2G DC EVSE and being comparable to the current prices of unidirectional AC EVSE) would thus allow the business model of an entity owning and operating EV charging infrastructure and offering additional V2G-enabled FCR services to strongly outperform—in terms of profitability—the business model offering the unidirectional charging of comparable power level. In fact, even the reduction in the V2G DC EVSE price below the break-even level of EUR 3999, would, ceteris paribus, already show a higher profitability.

From the sensitivity analysis, it can be concluded that the EVSE price is not the only factor playing an important role. The strongest impact on the EBIT of both types of business models comes from changes in the EV charging fee (*CFy*). In combination with a relatively high impact of EVSE usage rate (*URy*), this indicates that, even after the introduction of V2G-enabled FCR services, the business model remains quite dependent on its initial core value proposition. While changes in *URy* have a strong influence on the EBITs of both types of considered business models, changes in the connection rate (*CRy*) impact the available energy capacity for grid–balancing services, which considerably affects the revenues generated by the V2G-enabled FCR services. These changes do not influence the EBIT of the entity operating the network of unidirectional EVSE. Thus, the idle *CRy* factor, traditionally unused in unidirectional EVSE business model case, could become very useful for the new additional V2G-enabled revenue stream and decrease the dependency of the business model on the core value proposition.

Finally, as was already mentioned in Section 2.1, FCR is only one of the three existing grid balancing services. Therefore, another interesting research step would be to study the potential integration of V2G-enabled aFRR and mFRR services into the business models of the participants of EV charging business ecosystem.

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Nomenclature

Abbreviations

Abbreviation	**Definition**
aFRR	Automatic frequency restoration reserve
BSP	Balancing service provider
CPO	Charge point operator
CREG	Commission for electricity and gas regulation
EBIT	Earnings before interests and taxes
EBITDA	Earnings before interests and taxes depreciation and amortization
EV	Electric vehicle
EVSE	Electric vehicle supply equipment
FCR	Frequency regulation reserve
ICE	Internal combustion engine
mFRR	Manual frequency restoration reserve
ROI	Return on investment
TSO	Transmission system operator
V2G	Vehicle-to-grid

Variables

Symbol	Variable	Unit
y	EVSE type	/
Ky	EVSE power level	kW
Py	EVSE price	€
Iy	EVSE installation cost	€
CFy	Charging fee	€/kWh
T	Maximum yearly availability time	hours
MCy	Maximum yearly charging capacity	kWh/year
CR_y	EVSE connection rate	%
UR_y	EVSE charging usage rate	%
$C_{Electricity}$	Electricity price	€/kWh
FCR_{Bid}	Average FCR capacity bid	€/MW/h
Ly	Useful lifetime	years
Sy	Salvage value	%
C_{HR}	HR cost	€
C_{MP}	Cost of accessing the marketplace	€
C_{Other}	Miscellaneous costs	€
$C_{M\&M}$	Management and maintenance costs	€
Ny	Number of EVSE	Units
R_{FCR}	Revenues generated through FCR flexibility services	€
TF	Total fee received from the charging activities on the EVSE network	€
OR	Other revenues generated by side activities not directly related to the EV charging (e.g., advertisement, technical fees, etc.).	€

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