Charging Ahead: V2G-Enhanced Business Model in the Netherlands

Vehicle-to-Grid Integration in Dutch Public Charging Networks for Charge Point Operators

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Master Thesis Report

by

Ankit kumar Patro

Thesis report submitted to Delft University of Technology in partial fulfillment of requirements for the degree of *Master of Science in Sustainable Energy Technology*

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Preface

As I embark on the journey of presenting this thesis, I am reminded of the countless hours of research, analysis, and contemplation that have gone into its creation. This work represents the culmination of a profound exploration into the intricate world of Vehicle-to-Grid (V2G) technology, Charging Point Operators (CPOs), and the electric mobility landscape in the Netherlands.

The motivation for this thesis stems from a deep-seated belief in the transformative potential of V2G integration and a sincere commitment to advancing the sustainability and efficiency of electric mobility. It has been a voyage guided by intellectual curiosity, driven by a desire to address pressing questions, and enriched by the collaboration and guidance of mentors, peers, and industry experts.

Throughout the chapters that follow, you will find a meticulous investigation into the current state of CPO business models, the technical and financial dynamics of V2G integration, and the formulation of recommendations aimed at optimizing operations and promoting sustainable electric mobility. The research has been underpinned by a dedication to academic rigor and the pursuit of practical insights that can inform real-world decision-making.

I extend my deepest gratitude to all those who have contributed to this journey, directly or indirectly. To my mentors and advisors, thank you for your invaluable guidance and unwavering support. To my peers and colleagues, thank you for the stimulating discussions and shared experiences. To my family and friends, thank you for your encouragement and patience.

This thesis stands as a testament to the power of collaborative inquiry and the potential for positive change in the field of electric mobility. It is my hope that the insights contained within these pages will inspire further exploration and innovation, ultimately contributing to a more sustainable and resilient future.

With utmost sincerity,

Ankit

Ankit Kumar Patro

Acknowledgments

As this two-year journey comes to an end, I find myself filled with a profound sense of accomplishment. I would like to take a moment to reflect on this bumpy ride, acknowledging the immense efforts and support that made this achievement possible.

To my supervisor, Prof. Dr. Jan Anne Annema, and Ph.D. Mylene van der Koogh, I extend my deepest gratitude for your unwavering guidance, wisdom, and patience throughout this research journey. Your mentorship has been invaluable, and I am immensely grateful for your dedication to my academic growth. I also want to express my appreciation to Prof. Dr. Ir. Zofia Lukszo for her contribution as part of the thesis committee and her valuable evaluation of my research work.

To Sjoerd Moorman and Bram van Eijsden, thank you for providing the platform and sharing your knowledgeable insights about the current trends in this niche technology. Your support and the opportunity to work on this project have been instrumental.

To my dear friends, Chinmaya, Naveen, Vaibhav, and Tanmeet, your camaraderie and unwavering support made even the most challenging moments enjoyable. Your insights and companionship have been a constant source of inspiration.

To my friends scattered throughout the world, Vaibhav, Arpit, Sahil, Meraj, Ankita, and Chinmayee, distance did nothing to diminish your friendship. Your encouragement from afar provided much-needed motivation during the long hours of research and writing.

To my cousins, Kanha, Rahul, and Rohan, your enthusiasm and belief in my abilities have been a driving force. Thank you for always cheering me on from the sidelines. Special gratitude to Sraban and Rohit, who have been a consistent source of inspiration, both personally and professionally, guiding me throughout my career.

Last but certainly not least, to my entire family, especially my Bapa, Prabhakar Patro, Maa, Banisri Patro, and my lovely brother, Amit. Your unwavering love, patience, and understanding sustained me throughout this endeavor. Your sacrifices and encouragement have been the bedrock upon which I built this thesis.

Each of you has played a unique and invaluable role in this academic journey, and I am deeply appreciative of your contributions. Thank you for being a part of this significant chapter in my life.

With heartfelt gratitude,

Ankit

Ankit Kumar Patro

Executive Summary

The global transportation and energy sectors are undergoing significant transformation, driven by the increasing adoption of electric vehicles (EVs). As the world grapples with the imperative of reducing greenhouse gas emissions and transitioning to sustainable energy sources, EVs have emerged as a pivotal solution at the intersection of these vital concerns.

EVs have taken centre stage in the global shift towards sustainable transportation. However, the charging infrastructure supporting these vehicles presents unique challenges and opportunities for Charge Point Operators (CPOs). Challenges such as infrastructure costs, grid capacity, and competitive positioning have become pivotal issues for CPOs in this dynamic landscape. In this era of cutting-edge technology, various charging solutions, especially Vehicle-to-Grid (V2G), offer CPOs a compelling opportunity to leverage their role in the EV ecosystem.

While extensive research exists on V2G and its potential benefits, a comprehensive analysis of the financial implications, operational costs, and revenue streams specific to CPOs is notably absent, especially in the energy market.

The principal aim of this thesis is “Gaining Knowledge on Public Charging Network Business Models Through Vehicle-to-Grid Integration in the Netherlands” from a Charge Point Operator’s point of view. To achieve this objective and uncover the dynamics of CPO business models susceptible to energy market influences, the following primary research question was formulated:

To what extent can CPOs in the Netherlands enhance their public charging network business model through V2G in the EPEX DAM market?

The primary research focus is to assess the financial impact of V2G technology on CPO operations and identify key drivers for profitability, considering factors such as electricity procurement costs, user behavior, and location-specific dynamics. This research systematically explores various charging technologies, V2G strategies, and financial implications, revealing insights that illuminate the future of EV charging.

The research methodology adopts a comprehensive approach, combining empirical analysis, simulation modeling, and data-driven insights. It commences with a thorough review of existing literature on EV charging, V2G technology, and CPO business models. Additionally, consultations with key stakeholders in the EV ecosystem provided essential insights into current business dynamics and cost structures.

Following this, an Excel-based simulation model can be seen in Table 1, was developed to replicate various V2G charging scenarios. Leveraging data from the European Power Exchange (EPEX) Spot Day-Ahead Market (DAM), this model was designed with the specific objective of curbing the variable costs associated with electricity procurement. It examines various charging and discharging patterns under V2G simulated scenarios, analyzing their cost implications to identify strategies for reducing electricity procurement costs. It served as a

useful tool for assessing the financial consequences of V2G technology adoption and delving into its potential developments on the profitability of Charge Point Operators (CPOs).

A base case charging scenario was formulated for V2G and regular charging involved a simulation model imitating an EV with a 65 kWh battery. In this scenario, the EV's "arrival" time was set at 7 PM with a 70% State of Charge (SoC), and its "departure" was scheduled for 7 AM the following morning, targeting a 100% SoC. The results obtained from this scenario, applied to both types of charging technology, will be used as inputs in the developed model for assessing the profitability of CPOs in the Public Charging Network business case.

EV Data: 65 kWh Battery, SoC at arrival 70% Available Time: 7 PM to 7 AM	Initial to Target SoC: 70% to 100% 11 kW EVSE, 95% efficiency Time[5]: 1.9 hrs

Time	Price[1] (€/kWh)
4	0.079
2	0.084
3	0.084
1	0.086
24	0.089
5	0.092
23	0.096
22	0.108
6	0.115
21	0.122
20	0.154
19	0.179

V2G Charging					SoC	
Time	Price €/kWh	Time Block	Energy (kWh)	Cost (€)	SoC/Hr	70
19	0.179	-1.000	-10.45	-1.873	-16.07	53.93
20	0.154	-0.865	-9.039	-1.394	-13.9	40.029
21	0.122		0	0	0	40.029
22	0.108		0	0	0	40.029
23	0.096		0	0	0	40.029
24	0.089		0	0	0	40.029
1	0.086	0.765	7.9943	0.6837	12.294	52.323
2	0.084	1.000	10.45	0.8789	16.07	68.393
3	0.084	1.000	10.45	0.8798	16.07	84.463
4	0.079	1.000	10.45	0.8305	16.07	100.53
5	0.092		0	0	0	100.53
6	0.115		0	0	0	100.53
		Total[4]	19.855	0.0055	Cost/[2] kWh	0.0003
		Selling Price[3]		6.9493		

Regular Charging				
Time	Price €/kWh	Time Block	Energy (kWh)	Cost (€)
19	0.179	1.000	10.45	1.8728
20	0.154	0.900	9.405	1.4509
21	0.122		0	0
22	0.108		0	0
23	0.096		0	0
24	0.089		0	0
1	0.086		0	0
2	0.084		0	0
3	0.084		0	0
4	0.079		0	0
5	0.092		0	0
6	0.115		0	0
Cost/[2] kWh	0.1674	Total[4]	19.855	3.3238
		Selling Price[3]		6.9493

1. Ascending order of Price in DAM
2. Cost per kWh to CPO
3. Total selling price to Customer
4. Total Net Energy & Cost per session
5. Charging time from initial to target SoC

Table 1 V2G & Regular Charging Cost Calculation in the EPEX DAM for S1: 65 kWh - 7 PM - 70% SoC (Base Scenario)

Subsequently, an extended Cost-Benefit Excel model was employed to assess the profitability of the CPO's business model after integrating the reduced variable cost of procured electricity through V2G within the evolving landscape of the EPEX DAM. This comprehensive model takes into account various factors, including, customer compensation (For any battery degradation that might happen due to V2G), charging behavior, and market dynamics, to evaluate the profitability of the integrated V2G solution. The base case business model, including the cost and revenue assumptions incorporated in the cost-benefit models for both types of charging solutions and the resulting NPV, can be referred to in Tables 2 and 3 below. The synergy between extensive literature research and the insights derived from the Excel models facilitated the resolution of all three sub-questions designed to address the primary research question.

Quantitative Analysis € in actual figures	2023E	2024E	2025E	2026E	2027E	Total
BENEFITS						
Revenues	6881950	6881950	6881950	6881950	6881950	34409750
Other Benefits	0	0	0	0	0	0
Total Benefits	**6881950**	**6881950**	**6881950**	**6881950**	**6881950**	**34409750**
COSTS						
Non-Recurring	9115000	0	0	0	0	9115000
Recurring	3626000	3626000	3626000	3626000	3626000	18130000
Total Costs	**12741000**	**3626000**	**3626000**	**3626000**	**3626000**	**27245000**
Net Benefit or Cost	**-5859050**	**3255950**	**3255950**	**3255950**	**3255950**	**7164750**
Present Value of Total Benefits M (€):						30
Present Value of Total Costs M (€):						24
Net Present Value M (€)						**5**
Regular Charging Business Case Cost-Benefit						

Table 2 Regular Charging Business Case Cost-Benefit Analysis (Base-Scenario)

Quantitative Analysis € in actual figures	2023E	2024E	2025E	2026E	2027E	Total
BENEFITS						
Revenues	6881950	6881950	6881950	6881950	6881950	34409750
Other Benefits	-350000	-350000	-350000	-350000	-350000	-1750000
Total Benefits	**6531950**	**6531950**	**6531950**	**6531950**	**6531950**	**32659750**
COSTS						
Non-Recurring	10115000	0	0	0	0	10115000
Recurring	3251116	3251116	3251116	3251116	3251116	16255580
Total Costs	**13366116**	**3251116**	**3251116**	**3251116**	**3251116**	**26370580**
Net Benefit or Cost	**-6834166**	**3280834**	**3280834**	**3280834**	**3280834**	**6289170**
Present Value of Total Benefits M (€):						28
Present Value of Total Costs M (€):						24
Net Present Value M (€)						**5**
V2G Business Case Cost-Benefit						

Table 3 V2G Charging Business Case Cost-Benefit Analysis (Base-Scenario)

The simulation models reveal several pivotal findings. Firstly, strategically implemented V2G integration holds substantial promise for boosting CPO profitability by reducing electricity procurement costs from 0.1674 €/kWh with Regular Charging to 0.0003 €/kWh with V2G for the base case charging scenario. The occurrence of charging and discharging patterns in V2G can vary significantly based on factors such as battery size, arrival and departure times, and the battery's initial state of charge (SoC). This variability is further reflected in the differences in reduced electricity procurement costs due to these dynamics.

Second, user compensation schemes, charging patterns, usage rates, and location-specific demand dynamics significantly influence earnings. The Net Present Value (NPV) resulting from the Cost-Benefit analysis indicates that the CPO is expected to yield equivalent profits in both the base case business models for the two charging technologies. However, it's worth noting that V2G entails additional investments in infrastructure and maintenance compared to Regular Charging.

A sensitivity analysis was conducted to gain insights into the factors that impact the profitability of the Business Model, as detailed in Figure 1. Sensitivity analysis underscores the importance of usage rates, cost reduction for the electricity procured in the EPEX DAM, and network expansion in driving profitability. Moreover, advertising revenue from EVSE infrastructure emerges as a potential enhancer of profitability.

To sum up, It's crucial for CPOs to strategically plan their charging network implementation, with a focus on larger cities where higher usage rates and a greater number of required EVSE installations can substantially boost business profitability through V2G. Additionally, the increased number of sessions in these areas contributes further to overall profitability.

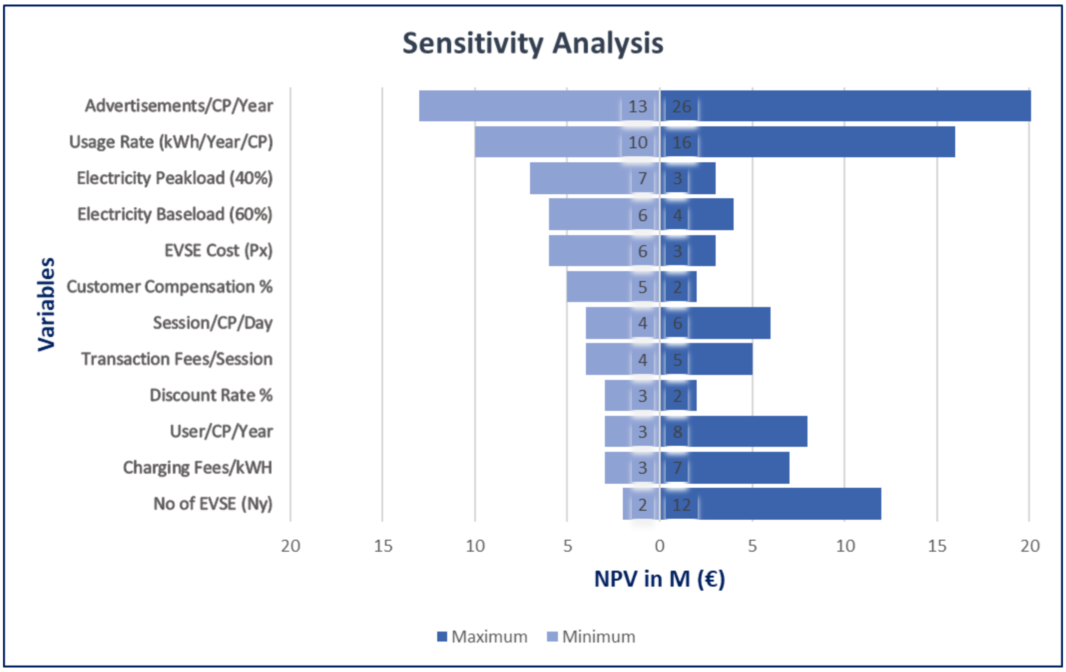

Figure 1 Sensitivity Analysis Graph For V2G Business Case

In conclusion, this thesis tries to unveil the potential of V2G technology in the EV charging landscape. By carefully integrating V2G capabilities to diminish the variable cost of procured electricity in the EPEX DAM, CPOs can enhance their financial viability while contributing to grid stability and renewable energy integration.

Additional Conclusions:

1. The conceptual analysis affirmed the potential of V2G to enhance profits or reduce costs for the electricity procured in the EPEX market.
2. To maximize V2G potential, EVs should connect for longer durations and at higher State of Charge (SoC) levels, notably at peak hours.
3. Charging and discharging patterns occur more frequently when EVs with smaller batteries and higher State of Charge (SoC) levels connect, leading to shorter charging and discharging times and thus, greater V2G advantages.
4. V2G potential will only be able to realized when SoC exceeds the 40% lower threshold and when EVs connect during peak hours.
5. Although the Net Present Value (NPV) for both types of charging is initially the same in the base case scenario, considering factors like societal benefits, technological maturity, and market share, V2G remains an attractive investment.
6. Sensitivity analysis highlights the significance of usage rates and the number of EVSEs, providing strategic guidance for CPOs to focus on densely populated cities to maximize revenue and, subsequently, profits.

Concluding, the NPV for the base case scenario might be the same for both types of charging solutions. From a business perspective, this might not appear as an incentive for CPOs to invest more in V2G. However, from a societal standpoint, it remains a promising investment. Even with additional investments, CPOs can achieve the same level of profit as regular charging. The sensitivity analysis underscores the importance of usage rates and the number of EVSEs, providing strategic insights for CPOs to focus on densely populated cities to maximize revenue and, consequently, profits.

Importantly, the insights gained extend beyond CPOs and are applicable to other stakeholders with similar functions within the EV charging ecosystem. While the focus is on the Dutch EV charging landscape, the findings are relevant to regions with similar demographics and energy market dynamics.

This research highlights the firmness of advancing V2G technology and recommends further exploration into quantifying battery degradation, offering a more comprehensive perspective on the trade-offs between profitability and battery lifespan. Analyzing broader energy market data, including intraday markets with varying time intervals, would provide a more thorough understanding of market dynamics. Simulating a more complex and realistic environment involving multiple EVs with distinct arrival and departure times and varying battery sizes. Investigating the expansion of grid availability for V2G, including complex grid interactions beyond simple energy injection, can yield valuable insights.

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List of Abbreviations

- BEV – Battery Electric Vehicle
- BRP – Balancing Responsible Party
- CO2 – Carbon Dioxide
- CP – Charge Point
- CPO – Charge Point Operator
- DAM – Day Ahead Market
- DSO – Distribution System Operator
- EMSP – Electric Mobility Service Provider
- EPEX – European Power Exchange
- EV – Electric Vehicle
- EVSE – Electric Vehicle Supply Equipment
- FCR – Frequency Containment Reserve
- ICE – Internal Combustion Engine
- IDM – Intra-Day Market
- kWh – kilowatt-hour
- MCP – Market Clearing Price
- MWh – Megawatt-hour
- OCHP – Open Clearing House Protocol
- OCPI – Open Charge Interface Protocol
- OCPP – Open Charge Point Protocol
- OEM – Original Equipment Manufacturer
- OSCP – Open Smart Charging Protocol
- PHEV – Plug-in Hybrid Electric Vehicle
- R&D – Research and Development
- SoC – State of Charge
- V2G – Vehicle to Grid

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1 Introduction

The global landscape of transportation and energy is undergoing a profound transformation, catalyzed by the growing adoption of electric vehicles (EVs). As the world grapples with the imperative of reducing greenhouse gas emissions and transitioning to sustainable energy sources, EVs have emerged as a potent solution at the intersection of these critical challenges. In this context, the concept of Vehicle-to-Grid (V2G) technology has risen to prominence as a transformative force, promising not only to revolutionize the way we think about electric mobility but also to reshape the architecture of our electric power grids and a source of financial opportunities within the burgeoning electric mobility ecosystem.

At the forefront of this paradigm shift is the Netherlands, a nation known for its progressive policies and investments in sustainability and electric mobility infrastructure. Within this dynamic landscape, Charging Point Operators (CPOs) are pivotal actors, responsible for the establishment and management of public charging networks that facilitate EV adoption. These CPOs are poised at a critical juncture, where the integration of V2G technology represents both a challenge and an opportunity. How they navigate this juncture has the potential to define the future of electric mobility in the country.

This thesis embarks on a comprehensive exploration of the multifaceted V2G landscape in the Netherlands. Specifically, it seeks to address the question of how CPOs in the country can strategically improve their existing business models while concurrently trying to reduce the electricity costs procured within the European Power Exchange Day-Ahead Market (EPEX DAM). This inquiry is not only timely but also of paramount importance, as it addresses the sustainability, profitability, and grid resilience of EV charging networks in a nation that has embraced the electric mobility revolution.

To begin, the research dives into an extensive examination of the current business model employed by CPOs in the Dutch public charging network. This analysis encompasses a detailed scrutiny of the model's components, operational dynamics, and its intricate relationship with electricity procurement costs within the EPEX DAM market. By understanding the existing framework that governs CPO operations, the foundation for informed and strategic improvements is set.

Subsequently, the thesis delves into the strategic integration of V2G technology, which represents the core mechanism for enhancing CPO operations and reducing electricity procurement expenses. By harnessing the bi-directional energy exchange capabilities of V2G, CPOs can not only optimize their operations but also contribute to the overall stability and resilience of the electric grid. This section of the research explores the technical aspects of V2G integration, its potential impact on the existing charging infrastructure, and the various strategies that CPOs can employ to participate effectively in the EPEX DAM market.

Ultimately, the goal of this study is to provide actionable recommendations for a revised and enchanced business model tailored to the unique Dutch landscape. This model will encompass charging infrastructure deployment strategies, pricing mechanisms that align with V2G capabilities, and participation strategies within the electricity market. The result will be a blueprint that positions CPOs at the forefront of sustainable mobility, grid resilience, and economic prosperity, reinforcing the Netherlands' reputation as a global leader in the realm of electric mobility and renewable energy.

The journey toward a sustainable and economically viable electric mobility ecosystem is complex and multifaceted, and it requires a deep understanding of the intricate interplay between V2G technology, CPO business models, and electricity market dynamics. This thesis endeavors to illuminate this transformative path, offering insights that may not only shape the future of EV charging infrastructure and grid management in the Netherlands but also serve as a beacon for nations and stakeholders worldwide as they navigate the electric mobility revolution.

1.1 Motivation and Context

Pollution and Energy Transition

Since the Industrial Revolution in the 18th century, rapid infrastructure and population growth have led to an increased demand for energy. Fossil fuels and their derivatives became the primary source of energy for the world economy, but this dependence caused pollution to rise drastically. Consequently, it led to unforeseen environmental problems that compelled the human race to transition towards greener, more sustainable energy sources.

Globally, the consumption of energy over the years has been increasing steadily for all sectors. In recent years it has been seen that out of every sector's energy consumption, transportation accounts for 30 % of the total primary energy consumption in the world (Nuclear Power, 2023). The significant amount of energy consumed only by transportation has its own consequences, which results in 23 % of the CO2 emission globally (IEA, 2023). The majority of greenhouse gas emissions, or about 76 percent, are made up of CO2, which raises pollution levels and has a negative impact on the climate (c2es, 2023).

Likewise, it is observed that transportation-related greenhouse gas emissions in the Netherlands totaled 31 million metric tonnes of carbon dioxide equivalent (MtCO2e) in 2019. In the EU, the Netherlands produces the sixth-highest amount of greenhouse gas emissions (Statista, 2019). Numerous alternatives are being adopted in the Netherlands across a wide variety of industries in response to the global shift away from fossil fuels as the source of the world's energy demand.

One of the most significant changes over the past several years has been the transformation of the energy demand towards electrification. A potential reduction in CO_2 emissions is made possible by the switch to electricity. When compared to fossil fuels, electricity produced by renewable energy sources is considered to be CO_2 neutral, allowing it to cut down net carbon emissions. Electrical power can potentially be a more effective way to meet demand than the energy obtained through traditional methods.

Electric Vehicles and Charge Points

The global adoption of electric mobility is regarded as a key step in minimizing emissions of greenhouse gases from the transportation sector, as road transport has been responsible for 80% of the growth in Dioxide (CO_2) emissions over the last 45 years. Compared to cars with internal combustion engines (ICE), electric vehicles generate less CO_2. When the electricity produced for EVs is derived from renewable energy sources, the emission difference is much greater compared with ICE (Bjerkan et al., 2016).

For the past ten years, switching from internal combustion engines to electric vehicles has shown promising results in reducing overall emission levels of greenhouse gases in the transportation industry. The global stocks of EVs have expanded as a result of the sharp rise in public awareness of EV use and the decrease in operating costs between 2015 and 2021, according to the International Energy Agency (IEA) in 2022. The global trend of growth of EVs in the ten-year span can be seen in Figure 1.1. The number of EVs reached 5 million in 2018 alone, an increase of 63% from the number of electric vehicles in 2017 (Mojumder et al., 2022).

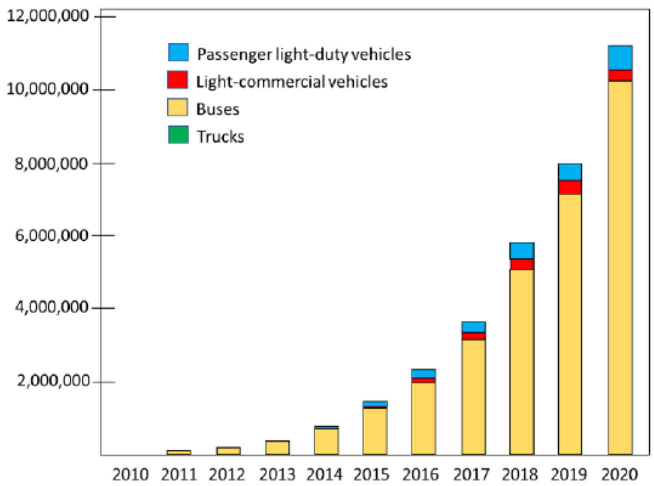


Figure 1.1 Global Trend in Electric Vehicle Stocks (Mojumder et al., 2022)

The Netherlands is likewise promoting the use of electric vehicles in place of traditional internal combustion engines (ICE) for personal and commercial transportation. A battery-powered vehicle's typical range has improved from 200 km in 2015 to 350 km in 2020 (TotalEnergies, 2022), which helps to remove the range anxiety. There is an increasing trend in the number of electric vehicles getting registered in the country as seen in Figure 1.2, which says that it is already making a rapid transition to achieve sustainable goals. The BEV and PHEV getting added to the fleet of passenger cars have seen almost near to four-time fold over the years from 2016 to 2021(RVO-NL, 2023). Through 2030, there is anticipation of about 2 million EVs on Dutch roads due to these various push and pull factors. Moreover, all newly sold vehicles must be electric (TotalEnergies, 2022).

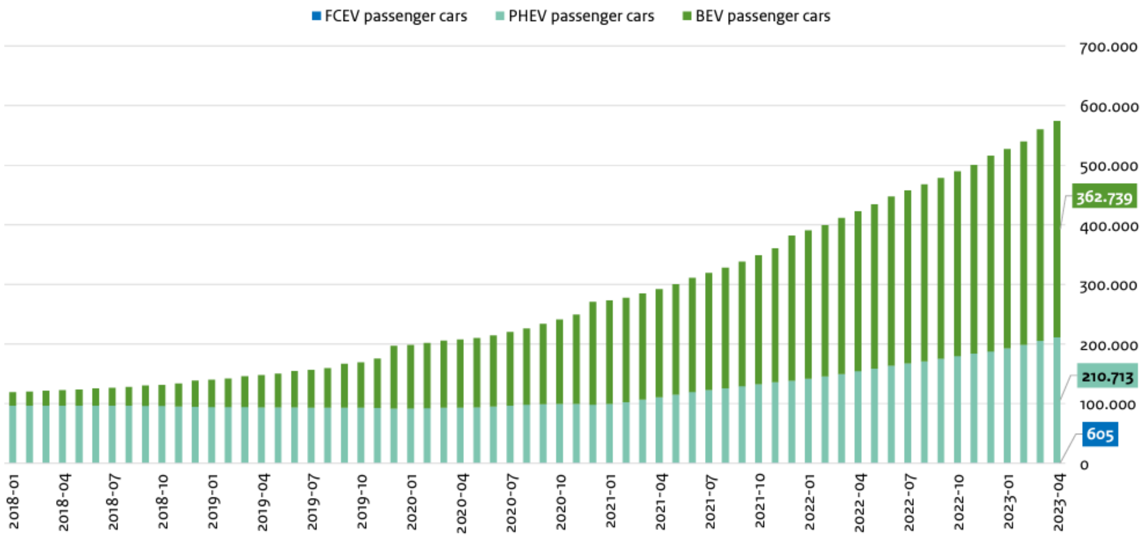


Figure 1.2 EVs Registration in the Netherlands (RVO-NL, 2023)

However, electric vehicles come with various shortcomings, one being obvious as they cannot be refuelled instantly as their counterpart ICE vehicles. These vehicles need to be plugged into the charge points to get fully charged before they are ready to hit the road. But the major demerit is that they take a longer duration compared to ICE to get charged, and range proximity is also a major concern for intercity travellers. Thus, a supporting charging infrastructure to cater to these individuals' needs is crucial for the successful implementation of electric mobility. Electric vehicles can be recharged using personal charge points at home, public stations, or charge points at the workplace.

As a result, the Netherlands and the rest of Europe will need to build a sizable public charging infrastructure. Some 50 % of all the charge points are concentrated in just two EU countries. Surprisingly, the Netherlands is at the forefront of installing public electric vehicle charging stations across the EU. In Figure 1.3, it is seen that the Netherlands accounts for 29,4% of all charging stations in Europe, approximately 90,000 chargers. Charging stations are still in great demand due to the rapid expansion of EVs throughout Europe. The installation of roughly 14,000 charging stations every week is anticipated to be necessary within Europe by 2030 to achieve the proposed 55% reduction of CO_2 for passenger automobiles (ACEA, 2022).

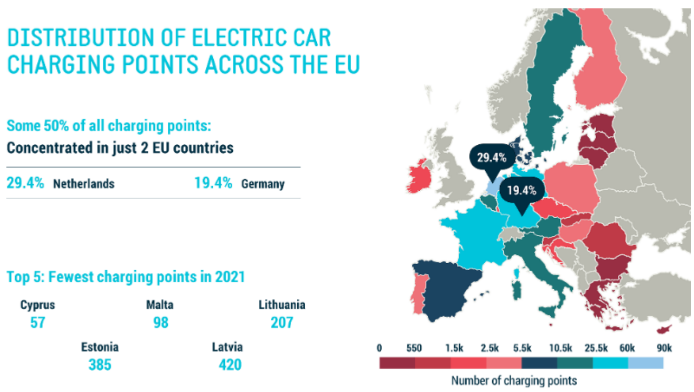


Figure 1.3 Distribution of Charge Points in EU (ACEA, 2022)

Challenges in the Electricity Grid

Moreover, the expansion of electric cars (EVs) and charging their batteries will have consequences for the energy grid. The adoption of EVs might have a minimal effect on overall electricity demand, but charging EVs will raise peak demand and may result in more strain on the grid leading to distribution problems (Duleep, 2011). So, the electrification of energy demand could create new difficulties for the power infrastructure. Also, it is very much possible to see a rapid shift towards more environmentally friendly and renewable energy sources that will be used to generate power in the electrical system. However, the integration of these intermittent energy sources will be very challenging at the distribution grids to create a balance between the supply and the demand.

In the Netherlands, over the past few years, the proportion of renewable electricity in the country's overall electrical mix has increased from 1% in 1990 to 13.8% in 2017. In addition to introducing a move away from CO_2-intensive sources, the increase in renewable energy sources also introduces a change away from centralized power generation and a move to a more decentralized system. Decentralized renewable electricity generation is a distinctive feature of solar and wind energy, two significant forms of renewable sources in the country (van ’t Wel, 2019).

The low-voltage grid will have significant effects if these renewable energy sources are introduced in large quantities. In addition to moving electricity generation away from fossil fuels, the transition towards more renewable energy sources may also affect how quickly supply and demand are met. This will have an effect on the energy markets as well, which are not yet sufficiently prepared for decentralized capacity, in addition to the local energy grid infrastructure (Klaassen et al., 2017).

Grid operators are looking into several ways to meet these advances and the future electrical system with more distributed energy resources or decentralized systems. Distribution system operators (DSOs) are responsible for ensuring that their customers can always get power. DSOs deploy large-capacity equipment in order to supply electricity during periods of peak demand. Hence, DSOs are looking for a clever way to postpone investments in existing infrastructure due to the rise in peak demand on the local grid and the rising instability of the decentralized system. They consider local storage as one of the smart viable options to support the future system (van ’t Wel, 2019).

Various local storage options might be available to facilitate the expansion of local grids. The low voltage (LV) grid may be upgraded with new batteries to offer services that aid the local grid, according to research done by (Klein Entink, 2017). Congestion control and the use of used batteries are other options. The balance of demand and supply of electric power is known as congestion management. Finally, (Kempton & Tomić, 2005), explains the potential for using electric vehicle batteries to help in the operation of the local grid system.

Introduction to Vehicle-to-Anything (V2X)

In reality, a car is typically parked for 95 % of its lifetime. That provides a chance to use the charging stations connected with these vehicles to their best capabilities while giving the power grid versatility. This area of research, known as Smart Charging, has already received much attention. V1G - unidirectional controlled charging, often known as Smart Charging, and V2X - vehicle-to-anything or bi-directional Charging, where X can be Grid, Building, or Home, are the various forms of Smart Charging, a pictorial representation of the system can be found in Figure 1.4. According to the Smart Charging theory, whenever an EV is plugged into a charge point, it might be charged or drained at different speeds in an optimized way, ensuring the users' needs. This can ease the load on the electrical grid, provide the user with more affordable charging options, and give them the option to charge more responsibly by using renewable electricity whenever available (IRENA et al., 2019).

Over the past decade, the battery's discharging cycle has greatly enhanced, increasing the viability of commercializing the V2G technology. By creating interaction and control links between each entity in a setting of the bi-directional flow of energy among loads, electric vehicles, and electric grids, it is possible to ensure perfect synchronization and minimize loss. Regulated V2G scheduling would help lower demand for peak loads, provide space for the integration of renewable energy sources, and lower charging prices (Mojumder et al., 2022).

The concept behind vehicle-to-grid is essentially the same as that of standard Smart Charging. Smart Charging, often referred to as V1G charging, makes it possible to regulate the charging of EVs so that the charging power can be boosted or reduced as necessary. To balance fluctuations in energy output and consumption, V2G or vehicle-to-grid technology takes things further and facilitates the charged electricity to also be briefly transferred back to the electrical grid from EV batteries when necessary (Virta Global, 2023).

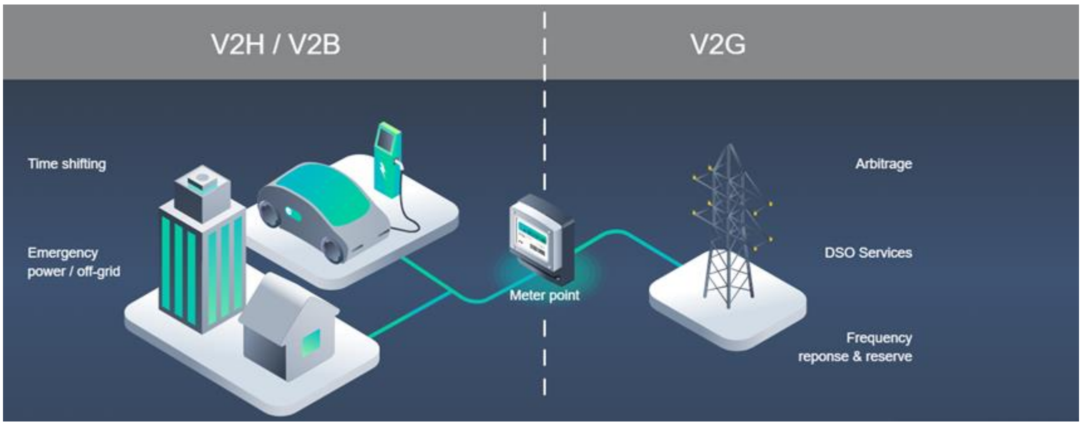


Figure 1.4 V2X System, X – Home, Building, or Grid (v2g-hub, 2023)

As stated by (Virta Global, 2023), *"Globally there will be 140-240 million electric vehicles by 2030. This means that we'll have at least 140 million tiny energy storages on wheels with an aggregated storage capacity of 7 TWh"*. Using the existing fleet of vehicles to its fullest potential will only be made possible by V2G technology. Through the Vehicle-to-grid, numerous actors, including EV makers, Electric Vehicle Supply Equipment (EVSE) OEMs, EV Owners, aggregators, Charge Point Operator (CPOs), Electricity Suppliers, Distribution Service Operators (DSOs), and more will be part of the system directly or indirectly. They all will benefit by providing various ancillary services and/or applying optimization techniques to the system (v2g-hub, 2023; Virta Global, 2023).

1.2 Past Literature over the Decade

The literature review in this study is grounded in a comprehensive examination of existing scholarship concerning Vehicle-to-Grid (V2G) technology, public charging networks, and the roles of Charging Point Operators (CPOs) within the domain of electric mobility. Its objectives are twofold: firstly, to assess the contemporary knowledge landscape within these domains, and secondly, to pinpoint critical knowledge gaps and potential avenues for future research. The review process entailed an extensive exploration of peer-reviewed academic journals, conference proceedings, industry reports, and governmental publications, drawing upon a diverse set of electronic databases including but not limited to the TU Delft repository, IEEE Xplore, MDPI, Google Scholar, and Scopus. Employing systematic and iterative methods, the search was guided by specific keywords such as "V2G," "CPOs," "public charging networks," "electric mobility," "EPEX DAM," "flexibility," "optimization," and related terms. Boolean operators and filters were used to refine search results, emphasizing studies relevant to the Netherlands, V2G integration, public charging networks, and CPO business models. This literature review seeks to consolidate current knowledge, elucidate prevalent trends, and illuminate areas necessitating further investigation while also contextualizing the evolution of V2G technology over the past decade, providing valuable historical insights into its ascent as a transformative force within the electric mobility landscape.

When the light vehicle fleet and also the heavy-duty vehicles made a move towards electric drive (Hybrid, battery, and fuel cell vehicles), it created a not-to-miss opportunity for the “Vehicle-to-Grid” (V2G) power. The study conducted by (Kempton & Tomić, 2005), tells that V2G makes sense if there is a match between the vehicle and the power market. For example, V2G does not look suitable for baseload power as it can be provided comparatively cheaper by large generators. However, V2G is more promising in terms of quick-response, high-value electric services. The results from the study suggest that the engineering rationale and economic motivation for V2G power are compelling.

Another study done by (Sovacool & Hirsh, 2009), disputes the idea that the technical barrier is the only one for the failure of wider use of PHEVs, a likely precursor to V2G, and large-scale implementation of V2G transition. It also states that a significant mostly overlooked barrier, social barriers are one of the major reasons for the failure of these technologies. They also mentioned that a V2G configuration will help EV owners to get additional revenue who wants to sell power back into the grid. At the same time, it will benefit the electric utility system by drawing power from those vehicles in a time of need. However, everything remains impeded by socio-technical obstacles, which further suggests that the R&D pathways need to be changed and that the work to improve technical performance should be coupled with economic, behavioural, and infrastructural obstacles.

Another journal (White & Zhang, 2011), explores the potential in terms of financial returns when using a PHEV as a grid source. They found evidence that it has significant returns when V2G service is used for frequency regulations, however not so promising financial returns when exclusively used for peak-load reduction. Eventually, they proposed a "dual-use" program as these two services are not mutually exclusive, so the regulation can be used on a regular basis to make good profits and the peak reduction can be used during days with a high demand for power. The profit for an individual in the dual-use program would be close to or even greater than the profits made in either of the single services, which will help in inducing more participants for V2G.

A paper on capacity estimation for V2G frequency regulation with Smart Charging mechanisms was researched by (Lam et al., 2014), and they spotted a problem that the most difficult problem is incorporating renewables into the energy system due to their intermittent nature. Ancillary services like frequency regulation, spinning reserve, supplement reserve, and voltage control bridge the actual gap between the demand and the supply in the real-time market. These reserves are for unexpected events whereas frequency regulation tracks on a minute-to-minute basis. For the system to work properly, the frequency should be maintained in its nominal value e.g. 60 Hz in the U.S. Frequency regulation or 50 Hz in other countries is maintaining the system frequency by injecting small power (positive or negative) into the grid. They modeled an aggregation of EVs with a queueing network, that allowed them to realize the both regulation-up (RU) and regulation-down (RD) capabilities separately. That further can help the aggregator to set up a contract with the grid operator to facilitate a new business model in V2G. They introduced a Smart Charging mechanism to make this requirement work, which does not require the EVs' initial SoCs, stay duration, and the lower and upper threshold of SoC specifically.

Another similar research conducted by (Wang & Wang, 2013), implied that EV battery-pack can have an important role to help balance out the supply and the demand by valley filling and peak shaving. The battery can be charged during low demand at night and can be fed into the grid during peak demand, hence helping to stabilize the grid during imbalance. During the off-peak time, the system is usually underutilized as they are designed to meet the highest demand. They concluded that if there are enough EVs in an area, the V2G system can completely replace other methods used for peak-shaving and valley-filling services.

One of the recent research performed by (Yan et al., 2023), developed an online algorithm based on Lyapunov optimization techniques to realize the aggregate EV power flexibility using real-time feedback in an online manner. Charging a fleet of EVs in an uncontrolled way might cause various problems in the power system like voltage deviation, line overload, and huge transmission losses. There have been many studies focusing on the optimal online EV charging strategy. Their focus was to develop an algorithm to directly control a fleet of EVs as it has high computational complexity. The paper suggested considering the differing interests between the operator, aggregator, and EVs while developing the flexibility region for future research.

(Goncearuc et al., 2023), explored the profitability evaluation of V2G in a different service, namely Frequency Containment Reserve services (FCR) by developing a business models considering the core participants of the EV charging ecosystem. They defined a framework for introducing the FCR services, integrating through V2G in to a business model, considering the financial factors impacted by the introduction of this service, ultimately, analysing the profitability of this business model as compared to the traditional model of the entity owning and operating the EVSE infrastructure. Under the current market condition, V2G DC EVSE market price showed that the entity owning a network of conventional unidirectional chargers is more profitable than V2G, and further interesting research should be done with other services or market for the entity owning and operating the EVSE or other member of the EV charging ecosystem.

The extensive literature review was carried to understand the development of the technology over the past decade and has provided a comprehensive overview of the key concepts and developments in V2G technology, participants of the EV charging ecosystem, and potential services or market that can be exploited through V2G.

In summary, numerous studies have explored V2G and its potential for leveraging bi-directional energy flow to achieve financial gains, benefitting various stakeholders such as grid operators, EV owners, and participants in the EV ecosystem. Previous research has also delved into complex algorithms for optimizing EV charging schedules in the context of V2G. However, still a gap exists in the literature, particularly in terms of conducting a detailed analysis of the financial implications, operational expenses, and revenue streams specific to CPOs with regards to V2G charging and the energy market . This gap becomes even more apparent when considering the potential reduction in variable costs achievable through energy market strategies and the need for simulation models to optimize charging for cost reduction. This foundation informs subsequent chapters and underscores the significance of the research in addressing critical challenges and opportunities at the intersection of V2G integration, energy market, and CPO business models, for taking the path towards electric mobility sustainability.

1.3 Knowledge Gap

The existing knowledge base lacks a comprehensive understanding of how Charging Point Operators (CPOs) in the Netherlands can strategically incorporate Vehicle-to-Grid (V2G) technology into their current business models within the public charging network. While V2G's financial benefits for EV owners, grid operators, and other actors involved in the ecosystem have been studied, there is a lack of detailed analysis concerning the financial implications, operational costs, and revenue streams specific to CPOs, especially in the energy market. This gap is particularly evident in the absence of a detailed exploration of the technical and financial implications of V2G integration, its relationship with electricity procurement costs in the EPEX DAM market, and the formulation of actionable recommendations for an improved business model tailored to the Dutch context. As previously mentioned in Section 1.1, the Netherlands has experienced a significant rise in EV registrations over the past five years. Moreover, the country has taken the lead in installing Electric Vehicle Supply Equipment (EVSE) within its public charging network in the European Union. However, there is currently a lack of a proper framework for the CPOs Business Model to fully exploit this potential. Addressing these knowledge gaps is essential for empowering CPOs to enhance their operations, minimize costs, and contribute to the sustainability and resilience of the electric mobility ecosystem in the Netherlands.

1.4 Problem Statement and Research Questions

The problem at hand is the absence of a comprehensive strategy for Charging Point Operators (CPOs) in the Netherlands to effectively integrate Vehicle-to-Grid (V2G) technology with the energy market, into their existing business models within the public charging network. This lack of strategic guidance hinders the enhancement of operational efficiency, cost reduction, and participation in the European Power Exchange Day-Ahead Market (EPEX DAM), for a CPO. Addressing this problem is imperative to position CPOs at the forefront of sustainable electric mobility, grid resilience, and economic prosperity within the Dutch context.

So this thesis aims at ***"Enhancing Public Charging Network Business Models Through Vehicle-to-Grid Integration in the Netherlands"*** from a Charge Point Operator's point of view.

This goal has led to the following research questions:

Main Research Question:

"To what extent can CPOs in the Netherlands enhance their public charging network business model through V2G in the EPEX DAM market?"

Sub-Research Questions:

1. "What constitutes the current CPO business model in the public charging network and its relation to electricity costs in the EPEX DAM market?"
2. "How can V2G integration enhance CPO operations and reduce electricity costs in the EPEX DAM market?"
3. "What recommendations can be made for a revised business model that incorporates V2G to minimize electricity costs and sustainability in the Dutch public charging network?"

1.5 Research Objective

The overarching objective of this study is to contribute to the existing knowledge by investigating, analyzing, and proposing strategies for the enhancement of Charging Point Operators' (CPOs) business models operating within the Dutch public charging network through the integration of Vehicle-to-Grid (V2G) technology in the Energy Market. This research endeavor holds paramount societal relevance as it contributes to the advancement of sustainable electric mobility, reducing carbon emissions, and promoting eco-friendly transportation solutions. From a business perspective, it addresses the financial viability and competitiveness of CPOs in an evolving market, potentially bolstering their profitability and market share. Moreover, this study fills critical knowledge gaps in the scientific domain by scrutinizing the technical intricacies and financial dynamics of V2G integration, offering empirical insights into the V2G EV charging ecosystem, delving into the CPOs Business models for profitability and the integration of V2G with the energy market especially EPEX DAM, that can inform decision-making and drive further research in the fields of electric mobility, Vehicle-to Grid, energy market, renewable energy integration, and grid management. Ultimately, the research seeks to formulate actionable recommendations that not only enhance CPO business models but also try to contribute to the broader societal and scientific goals of sustainability, efficiency, and resilience in the context of electric mobility.

1.6 Research Scope and Methodology

The scope and methodology employed in this study is designed to rigorously address the research questions at the core of the investigation, focusing on how Charging Point Operators (CPOs) in the Netherlands can enhance their public charging network business models through Vehicle-to-Grid (V2G) integration while reducing variable costs of procuring electricity within the European Power Exchange Day-Ahead Market (EPEX DAM). To answer these questions effectively, a multi-faceted research approach has been devised, encompassing data collection, analysis, and the formulation of actionable recommendations.

Research Scope:

As discussed earlier in the motivation and context (Section 1.1), the shift to electrification is a significant move away from traditional energy sources to meet the growing energy demands while preserving the environment. Electric mobility plays a pivotal role in reducing emissions, and the Netherlands has witnessed a substantial increase in EV registrations over the past five years. Additionally, the country has been a frontrunner in deploying Electric Vehicle Supply Equipment (EVSE) across its public charging network in the European Union. This extensive infrastructure offers numerous advantages and opportunities for the stakeholders in the public EV charging ecosystem. Charge Point Operators (CPOs) are well-positioned to leverage modern charging technologies like Smart Charging and Vehicle-to-Grid (V2G) for various services, including load balancing, balancing reserves, FCR services, and energy arbitrage in the energy market.

Therefore, this study narrows its focus to one of the central actors in the EV charging ecosystem: the Charge Point Operator (CPO). CPOs are responsible for installing and managing EVSE in the Netherlands' Public Charging Network. The research investigates how CPOs can harness their EVSE and the network to capitalize on the energy market, specifically the EPEX SPOT Day-Ahead Market (DAM), by leveraging V2G technology, and further develop the existing Business Model integrating V2G.

Several essential assumptions and fixed parameters as a part of this research scope that underlie this study, which have been derived from an analysis of the current CPO business model and potential avenues for enhancing it through V2G integration:

1. The study revolves around the business case for a CPO operating within the Public Charging Network in the Netherlands.
2. It focuses on exploiting bidirectional EVSE in the EPEX SPOT DAM through V2G technology.
3. Data from the EPEX DAM for September 4th and 5th, 2023, is used as a reference.

4. Energy procurement consists of 40% peak load at the EPEX DAM and 60% baseload purchased via bilateral contracts.
5. The study primarily concentrates on charge points located outside or near residential areas.
6. The evening peak is identified as the opportune moment for energy arbitrage in the EPEX market when EV owners return home from work with a specific State of Charge (SoC) before connecting their charge points overnight.
7. Various scenarios for charging sessions are employed in the V2G Excel simulation model to reduce variable costs for CPOs in procuring energy from the EPEX market.
8. The research assumes compliance with 11 kW DC Bi-Directional Chargers, as lower-power or slow chargers are better suited for V2G applications.
9. Injection back into the grid is considered feasible at any time.
10. Initial SoC of the battery is a known parameter.
11. Plug-in and plug-out times are also known.
12. Cost and revenue assumptions for the business model are based on consultations with stakeholders, existing literature, and government surveys and statistics.
13. A five-year evaluation period, with capital investment occurring in the first year, and constant costs and revenues every year, over the entire five-year period

Research Design:

To address the primary research question, **"To what extent can CPOs in the Netherlands enhance their public charging network business model through V2G in the EPEX DAM market?"** this study adopted a systematic approach. It involved a step-by-step exploration of each of these following sub-questions, ultimately leading to the central point of focus.

1. What constitutes the current CPO business model in the public charging network and its relation to electricity costs in the EPEX DAM market?

To uncover the intricacies of the current CPO business model across different charging technologies within the Dutch Public Charging Network and their correlation with electricity costs in the EPEX DAM market, a thorough literature review was conducted. This encompassed scholarly journals, industry reports, government publications, and relevant databases, shedding light on established practices and models. In parallel, consultations and discussions with key industry stakeholders (experts from the Business Development Team at TotalEnergies) offered practical insights into the current business landscape. This approach not only facilitated a deeper comprehension of the existing business scenario but also illuminated the potential of emerging charging solutions, such as Vehicle-to-Grid (V2G), in enhancing the conceptual framework of the business model. It particularly emphasized aspects like the current business case, associated stakeholders, and the constituent elements of the business, including various cost and revenue structures within the system. This comprehensive analysis was influential in identifying elements within the business case that could be enriched through V2G, thus paving the way for a more robust and sustainable CPO business model, addressing the first sub-research question.

2. How can V2G integration enhance CPO operations and reduce electricity costs in the EPEX DAM market?

The conceptual insights into enhancing the CPO Business Model led to the initial development of a V2G simulation model, set to integrate with the EPEX SPOT DAM. This integration aimed to use the dynamic tariffs offered by the EPEX SPOT DAM and reap the potential benefits. The assessment of V2G's capacity to improve CPO operations and reduce variable electricity procurement costs involved both quantitative and qualitative methods. Data about V2G technology, charging infrastructure, and electricity market dynamics were gathered and analyzed.

To replicate V2G operations and their interaction with the EPEX DAM, Excel-based simulation models were developed. These models aimed to mimic how EVs charge and discharge in a V2G scenario while strategically aligning with EPEX DAM tariffs to reduce energy procurement costs. Additionally, other simulation models were designed to explore different charging scenarios. These scenarios included EVs with similar battery capacities but arriving at different times, varying levels of charge when they arrived, and different battery capacities but arriving at the same time and charge level. These simulations within the Excel model provided a comprehensive understanding of energy market dynamics and the variable outcomes of V2G exploitation under different conditions. These simulation models were based on a strong understanding of V2G and the energy market, serving as reliable predictive tools.

A base case charging scenario was formulated for V2G and regular charging involved a simulation model imitating an EV with a 65 kWh battery. In this scenario, the EV's "arrival" time was set at 7 PM with a 70% State of Charge (SoC), and its "departure" was scheduled for 7 AM the following morning, targeting a 100% SoC. The results obtained from this scenario, applied to both types of charging technology, were used as inputs in the developed model for assessing the profitability of CPOs in the Public Charging Network business case.

The insights from these models, particularly the effects of V2G integration on electricity procurement costs, provided crucial information for analyzing the business case with V2G integration, which was part of the third sub-research question. In the end, this thorough analysis significantly contributed to addressing the second sub-research question.

3. What recommendations can be made for a revised business model that incorporates V2G to minimize electricity costs and sustainability in the Dutch public charging network?

Following this, an extended Cost-Benefit Excel model was utilized to evaluate the profitability of the CPO's business model after integrating the reduced variable electricity procurement costs through V2G within the dynamic EPEX DAM environment. This comprehensive model considers multiple variables, including customer compensation (For any battery degradation that might happen due to V2G), charging behavior, and market dynamics, to assess the profitability of the integrated V2G solution.

The base case business model, which includes the cost and revenue assumptions for both charging solutions, forms the basis for calculating the Net Present Value (NPV) to evaluate the CPO's business model's profitability. Additionally, sensitivity analysis was conducted to grasp the dynamics influencing the business model. Furthermore, insights from an expert in the Business Development Team at TotalEnergies, obtained during a consultation, and a discussion with a specialist from a leading EVSE OEM's Technical Service Team, were used to validate the real-world aspects concerning the cost and revenue structure in the CPO's business model.

Formulating recommendations for a revised business model involved synthesizing findings from the literature review, industry insights, and simulation results within an Excel Model. Recommendations were developed iteratively, taking into account both technical and financial implications of V2G integration. Expert validation and stakeholder consultations played a crucial role in refining these recommendations.

The seamless connection between extensive literature research and insights derived from the Excel models successfully addressed all three sub-questions designed to tackle the primary research question.

Data Collection and Analysis:

Quantitative data analysis involved statistical techniques to assess cost trends, while qualitative data analysis encompassed thematic coding to identify patterns and themes from expert consultations and discussions with the key stakeholders. The use of simulation models in Excel facilitated scenario testing and predictive analysis.

1. For the Excel-based simulation model, to replicate V2G operations and their interaction with the EPEX DAM. The EPEX DAM price data was collected for September 4th and 5th, 2023 (EPEX-SPOT, 2023).
2. The values, figures, or any multiplication factors used in the Cost-Benefit Excel model were sourced from past literature, governmental agencies' websites, journals, and analyses related to EVs from reliable sources like Statista, rvo.nl, ECORYS, reports by EVSE OEMs, and CPOs, among others. Additionally, a consultation was conducted with an expert from the Business Development Team at TotalEnergies, and a discussion was held with an expert from the Technical Service Team at a leading EVSE OEM. These consultations aimed to validate and acquire as realistic data as possible for use as input parameters in the model to ensure the output reflects real-world scenarios accurately.

1.7 Report Structure

This thesis is organized into several distinct sections, each designed to progressively unfold the research journey and its findings.

Chapter 1 introduces the research topic, including the motivation, background, significance, literature review, research gaps, questions, research scope, and methodology that guide this study.

Chapter 2 offers a comprehensive background on theory and fundamentals. It delves into key concepts in the EV charging ecosystem, such as Vehicle-to-Grid (V2G) technology, public charging networks, the role of Charging Point Operators (CPOs) in the electric mobility ecosystem, and the Energy Market of the Netherlands. This chapter provides the necessary theoretical foundation for understanding the study.

Chapter 3 forms the foundation of the research and addresses the first sub-research question. This conceptual framework chapter analyzes the current business model used by CPOs in the Dutch public charging network. It scrutinizes the components of this model and their implications for electricity procurement costs in the European Power Exchange Day-Ahead Market (EPEX DAM). The chapter also aims to conceptually identify elements in their current business, whether Regular or Smart Charging, that can be improved through Vehicle-to-Grid.

Chapter 4 shifts the focus to the strategic integration of V2G technology. The first half explores how V2G can enhance CPO operations, reduce electricity expenses, and facilitate participation in the EPEX DAM market. The second half presents the findings, offering insights into the relationship between V2G integration, CPO business models, and electricity market dynamics. The chapter also introduces the Excel-based model developed for the Cost-Benefit analysis of the CPO's business model integrated with V2G, addressing the second and third sub-research questions.

Finally, Chapter 5 & 6 provide a comprehensive summary, conclusion, and discussion. They encapsulate the key findings and their implications, concluding with suggestions for further research in this evolving field.

Throughout the report, readers will find a wealth of data, analysis, and recommendations aimed at addressing the central questions of this study and shedding light on the path toward enhancing public charging network business models for CPOs through V2G integration in the Netherlands.

*Thus, this research will focus on "**Enhancing Public Charging Network Business Models Through Vehicle-to-Grid Integration in the Netherlands**" from a Charge Point Operator's perspective. The main objective of this study is to provide insight into whether the (expected) business case of a public charging network with V2G for a CPO, is plausible in the market to gain an advantage over their competitors, and at the same time, it helps them to gain more financial benefits in their business while driving towards sustainable goals.*

2 Theory and Fundamentals

In the Theory and Fundamentals chapter, the focus is on delving into the foundational theories required to understand and support this study directly, and the rest surrounding theories to the EV Charging ecosystem can be referred in the Appendix below. This chapter forms the intellectual basis for the research, where a thorough exploration of the key theories, principles, and technical aspects that shape the investigation into Vehicle-to-Grid (V2G) integration, Charging Point Operators (CPOs), Energy Market and the complex world of electric mobility ecosystem in the Netherlands takes place. By examining these theoretical concepts, a strong foundation is established for the empirical analysis and recommendations that follow. The aim here is to provide a clear and comprehensive understanding of the core factors driving sustainable electric mobility in the V2G era.

2.1 Charging Technologies

Charging technology for electric vehicles (EVs) has evolved significantly to meet the demands of modern mobility. Three key charging methods have emerged: "Dumb" or Regular Charging, "Smart" Charging, and Vehicle-to-Grid (V2G) technology. In this section, we'll dig into these charging technologies, exploring their capabilities, benefits, and implications for the future of sustainable transportation. The definitions surrounding these charging technologies has been derived from (ECORYS, 2020; Lam et al., 2014; Virta Global, 2023), and some analysis from ChatGPT and own.

2.1.1 Regular Charging

Regular Charging or Dumb Charging, is a method of charging in which the electric car battery is charged at the maximum power that the battery and charging infrastructure can handle, as soon as the vehicle gets connected to the charger, regardless of the battery's level of charge or the grid's demand for electricity.

They are usually known as Level 1 (120V) and Level 2 (240V) charging, which is the standard method for charging electric vehicles. Level 1 uses a standard household outlet and is slower, while Level 2 chargers are faster and common in homes, workplaces, and public stations. Unlike "Smart" Charging, it lacks advanced features like scheduling or remote control.

"Level 1" or "Level 2" charging, involves using a conventional alternating current (AC) power source to charge the EV's battery over a longer period of time compared to faster charging methods like DC fast charging. However, these methods lack advanced features like scheduling or remote control, making them straightforward but less flexible compared to Smart Charging or V2G.

2.1.2 Smart Charging

Smart Charging is charging an electric vehicle that can be regulated externally (i.e. "altered by external events"), allowing for adaptive charging habits and allowing the EV to integrate into the entire power system in a grid and user-friendly manner. Smart Charging must facilitate supply security (reliability) while fulfilling the user's mobility limits and requirements.

It is an advanced method for electric vehicle (EV) charging, offering features like scheduling, remote control, and load management. It optimizes charging times, considering factors like electricity rates and grid demand, making it more cost-effective and grid-friendly compared to traditional "dumb" charging methods

2.1.3 Vehicle-to-Grid

Vehicle-to-Grid (V2G) is a pioneering technology that has garnered significant attention and interest in the realm of electric vehicles (EVs) and sustainable energy systems. It represents an innovative approach to optimizing the utilization of electric vehicle batteries beyond the traditional scope of transportation. In essence, V2G refers to the bi-directional flow of electrical energy between electric vehicles and the electric grid. This bidirectional energy exchange enables electric vehicles to not only draw energy from the grid for propulsion but also to supply surplus energy back to the grid when needed.

The vehicle's battery can be employed as a buffer to store energy during periods of high (sustainable) energy production, as well as an energy source during periods of low (sustainable) energy production. Vehicle-to-grid technology can also help to optimize sustainable energy consumption.

The bi-directional property of this technology allows EVs to become grid assets, supporting grid stability during peak demand and integrating renewable energy sources. V2G offers grid services, potentially generating revenue for EV owners and operators while enhancing overall grid reliability and sustainability.

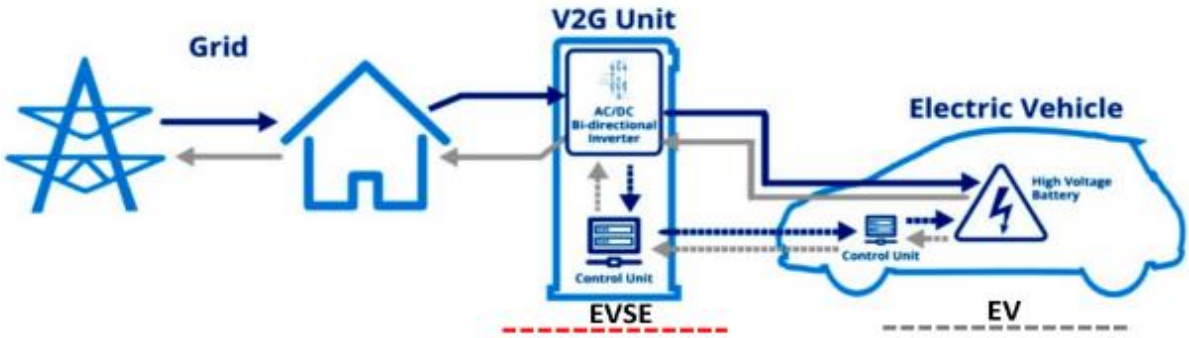


Figure 2.1 Vehicle-to-Grid System (Jaman et al., 2022)

2.2 EV Charging Ecosystem

This section will cover all the details related to electric vehicle charging and the various devices or types of equipment used in the ecosystem along with various protocols that are in place that ensure the system is viable for operation and usage of the system by the end users, the details are referred from the definitions and explanation report published by (NEA-EV definitions, 2019).

2.2.1 Charge Stations

Charging Station / Charging Pole / Charging Dock / Electric Vehicle Charging Station (EVCS)

A Charging Station is a physical item that contains one or more charging ports and a common user identification interface. The charging station houses all of the physical "human-machine" interfaces. Some charging stations have a badge / RFID reader, as well as buttons, displays, and LEDs. Other stations are 'Plug & Charge', with no buttons, display, or other features. A vehicle is automatically identified in these circumstances. A charging station usually consists of one physical object and one user interface.

Charging Point / Charging Position / Electric Vehicle Supply Equipment (EVSE)

The electric energy is given via a charging station. In order to accept multiple connector types (which are discussed further in the Appendix below), a charging point may include one or more connectors (outlets or plugs). One cannot be utilized at the same time. Charging one vehicle at a time defines a charging point. In other words, the number of charging points and (dedicated) parking slots per charging station is the same.

2.2.2 Charging Power and Charging Type

AC Charging

The car converts AC from the grid into DC, which is required for charging the battery. The capacity of the AC-DC converter in the car dictates how much of the charging station's available charging capacity can be used. AC charging often results in a reduced charging speed (however AC fast charging (> 22 kW) is feasible).

DC Charging

The charging station converts the AC from the grid into DC, which is required for charging the battery. The charging point can charge at high power (> 22 kW) thanks to direct current (DC). The charging station is in direct touch with the vehicle's battery.

2.2.3 Accessibility

Public Charging

A charging station that allows users non-discriminatory access 24 hours a day, seven days a week. Non-discriminatory access may involve various authentication, usage, and payment terms.

A charging parking spot is a space designated for parking your automobile while it is being charged. Cars other than electric vehicles or electric vehicles that are not charging are not permitted to park in this space. There isn't usually a reserved parking spot for each charging point. This is determined by local policy.

Semi-public charging points

Semi-public charging stations are open to the public, but public access may be limited due to parking or opening hours. Charging stations at underground parking garages, hotels and restaurants, and service stations are some examples. There may be usage restrictions, such as the obligation to use the connected facilities.

2.2.4 Charging Protocols

OCPP - Open Charge Point Protocol

The Open Charge Point Protocol (OCPP) was conceived and developed to standardize communications between an EV charge station and a central system used for charge point operation and management. The free and openly accessible communication protocol ensures the ability to migrate from the charging network without having to replace all charging stations or considerable programming, providing compatibility and access to electric grid services.

ISO 15118

ISO 15118 is a global standard governing communication between electric vehicles (EVs) and charging stations. It establishes a secure, streamlined "Plug and Charge" process, emphasizing data security, enabling bi-directional communication, and supporting dynamic charging control for applications like Vehicle-to-Grid (V2G) and demand response in electric mobility.

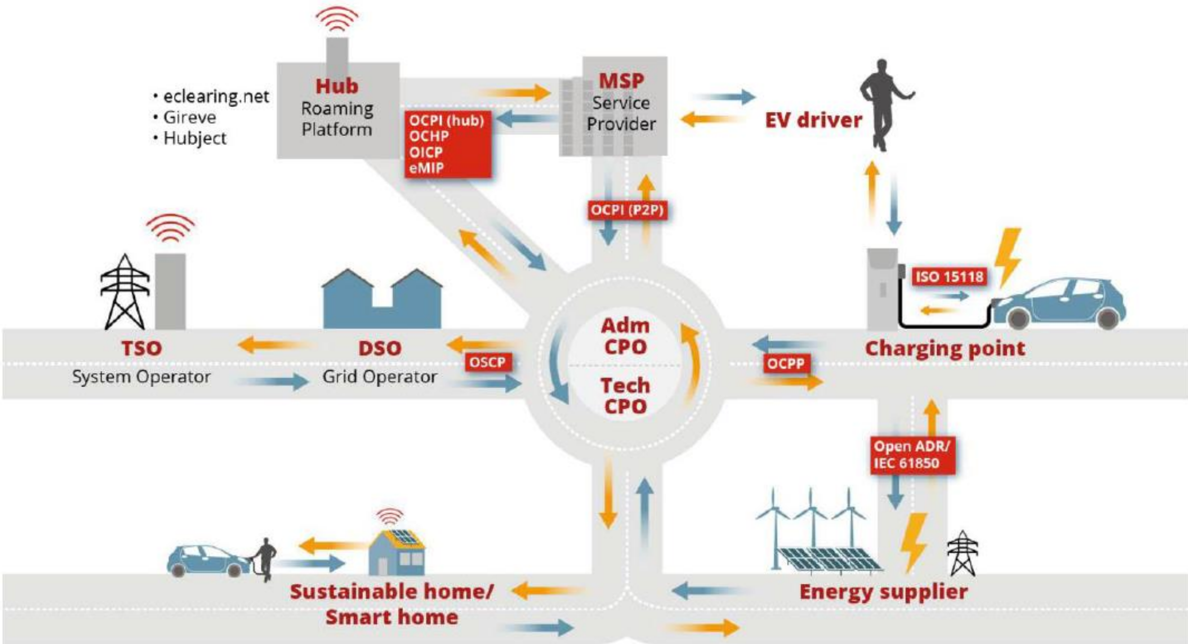


Figure 2.2 EV Market Protocol (NEA-EV definitions, 2019)

2.3 Key Actors in the EV Charging Ecosystem

This section will tell more about the key actors involved in the public charging network for a charge point operator (CPO) in the EV ecosystem, which is referred from the (NEA-EV definitions, 2019), and a schematic of the same can be seen in the Figure 2.3.

Charge Point Operators (CPOs): CPOs own and operate charging stations. They are responsible for installing, maintaining, and managing the charging infrastructure. CPOs often offer charging services to EV drivers and may set pricing, provide access control, and offer customer support.

Electric Vehicle Manufacturers: EV manufacturers, like Tesla, Nissan, BMW, and others, play a role in promoting the adoption of EVs. Some manufacturers invest in their own charging networks or collaborate with CPOs to ensure convenient access to charging stations for their customers.

Energy supplier: Energy suppliers provide the electricity that powers charging stations. They work with CPOs and other stakeholders to ensure a reliable and sufficient supply of electricity to meet the growing demand for EV charging.

Government and Regulators: Government agencies and regulatory bodies establish policies, regulations, and standards for EV charging infrastructure. They may offer incentives, subsidies, or grants to encourage the deployment of charging stations and ensure safety and environmental compliance.

Local Authorities and Municipalities: Local governments often play a role in permitting, zoning, and providing public spaces for the installation of charging stations. They may also offer incentives to CPOs to expand charging networks within their jurisdictions.

Distribution System Operator (DSO): The body in charge of designing, operating, and maintaining the public distribution medium and low voltage grid that supplies charging stations. The charging stations are linked to a private grid (house, building, installation site, etc.) that is linked to the DSO grid.

Transport System Operator (TSO): A party in charge of ensuring a stable power system (high voltage) operation (including physical balance organization) in a geographical area via a transmission grid. The System Operator will also be in charge of determining and managing cross-border capacity and exchanges. He may cut assigned capacity if necessary to guarantee operational stability.

Balancing Responsible Party (BRP)

The BRP manages a portfolio of energy producers and consumers, submitting energy supply and demand to the wholesale market. The TSO monitors all BRPs and requires them to produce daily schedules of predicted consumption and supply.

E-Mobility Service Providers (EMSP): Service providers offer various services related to EV charging. This can include payment processing, access and billing platforms, mobile apps, and customer support. Roaming platforms allow EV drivers to access charging stations across different networks seamlessly.

Data Aggregators: Data aggregators collect and analyze data from charging stations, providing insights into usage patterns, grid performance, and more. This data is valuable for optimizing charging network operations and planning future expansions.

End Users (EV Drivers): EV drivers are the primary users of public charging stations. They interact with CPOs and service providers to access charging, pay for services, and receive information about available charging locations.

Charging Equipment or EVSE Manufacturers: Companies or OEMs that design and manufacture charging hardware and software are crucial in providing the technology needed for public charging stations.

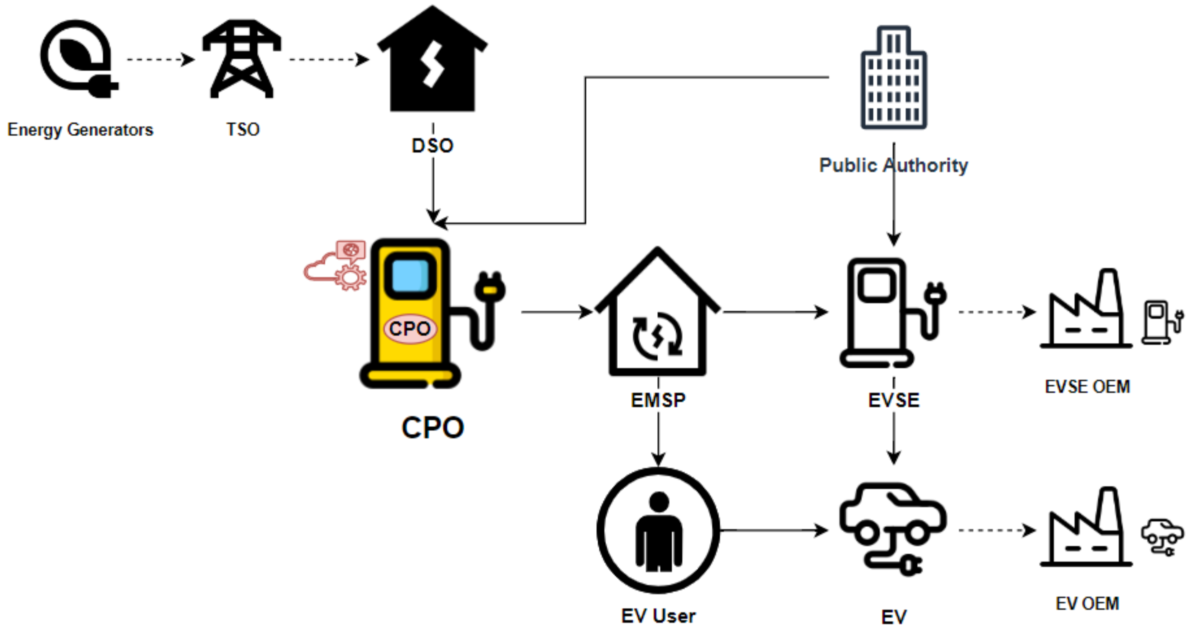


Figure 2.3 Key Actors in the EV Charging Ecosystem (NEA-EV definitions, 2019)

2.4 Dutch Energy Market

The Netherlands offers a number of energy trading markets. Market participants can trade electricity on two recognized exchanges: the EPEX SPOT (previously known as APX) (EPEX-SPOT, 2023) and the ICE Endex (ICE Endex, 20223). The EPEX SPOT is an independent electronic exchange for spot market trading.

EPEX SPOT - Day Ahead Market (DAM)

EPEX SPOT is a prominent European power exchange and one of the largest platforms for spot electricity trading in Europe. It facilitates the trading of electricity in real-time and intraday markets across multiple European countries. EPEX SPOT provides a transparent and efficient marketplace for market participants, including power producers, suppliers, and traders, to buy and sell electricity for immediate or short-term delivery.

The exchange operates various market segments, such as continuous intraday trading, day-ahead auctions, and reserve markets, allowing participants to respond to changing electricity supply and demand conditions. EPEX SPOT contributes to price discovery, market liquidity, and grid balancing by enabling market participants to trade electricity in a secure and regulated environment, promoting the efficient functioning of European electricity markets (EPEX-SPOT, 2023).

A day before delivery, market players trade energy using an auction method to shape their hourly demand for energy curves. The supply, as well as the demand energy bids, are presented in the form of an energy bid ladder. The energy supply and demand bid curve are stepwise functions that describe the price of energy (in €/MWh) at the power level (in MW) that is either being produced or consumed.

The Market Clearing Price (MCP) is calculated by aggregating all supply and demand bid curves. All supply bids that are equal to or less than the MCP are despatched, and all demand bids that are equal to or greater than are met. Below Figure 2.4 depicts an example of an energy demand-supply bid curve and market-clearing price calculation.

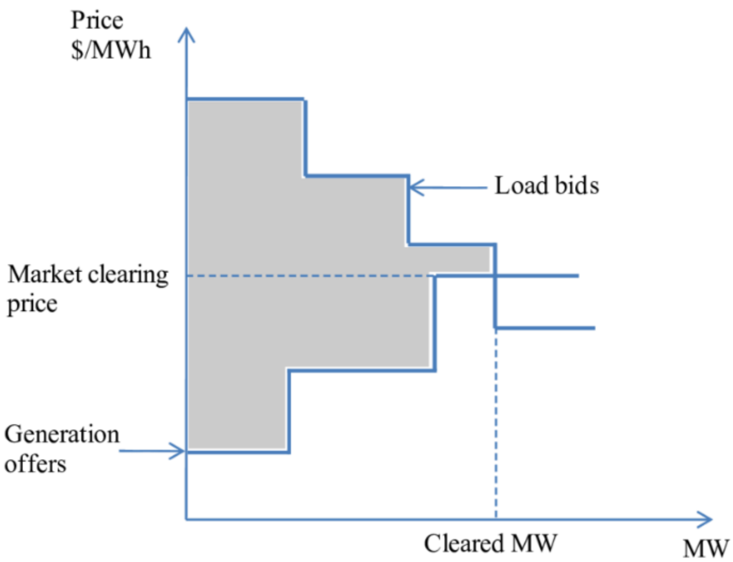


Figure 2.4 Energy Supply & Demand Bids with MCP (Prabodanie, 2010)

The MCP in the EPEX SPOT DAM is calculated on an hourly basis. As a result, market participants offer their energy supply and demand bid curves hourly. As a result of load shifting, CPOs can submit energy demand bids at times when MCPs are lower, lowering energy purchasing costs, which mostly relates to Smart Charging.

The extended version would be to discharge at the peak hours and charge at the off-peak hours to lower the net energy purchase cost further, which is possible in V2G. The distribution and 24-hour average of the EPEX SPOT DAM price are depicted in Figure 2.5. As can be seen, there are price peaks in the morning and evening, which correspond to the average national energy demand (Tennet, 2023). As a result, CPOs can use the EVSE portfolio's flexibility to direct load away from peak demand or arbitrage energy and reduce the net energy procurement costs. As a result, the EPEX SPOT DAM is regarded as a feasible integration for CPOs.

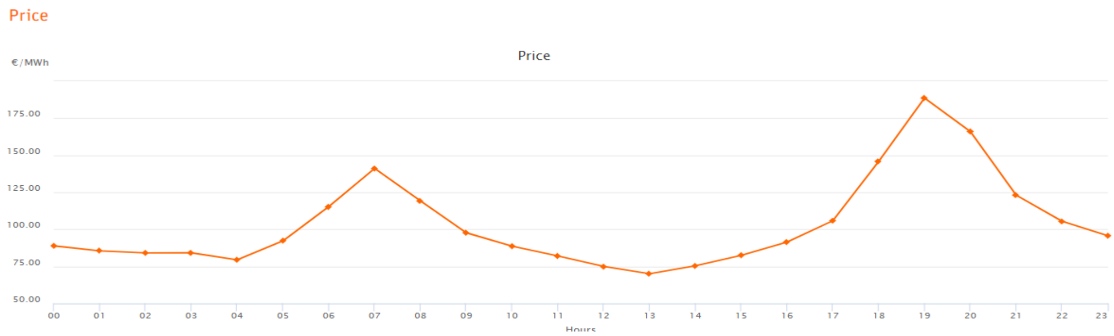


Figure 2.5 24 Hours Average EPEX SPOT DAM Example (EPEX-SPOT, 2023)

Henceforth, this chapter has provided an essential overview of the technologies and parameters crucial for a comprehensive understanding of this research study. It has also played a significant role in delineating the scope and methodology outlined in Section 1.6. Specifically, it has emphasized the relevance of the public charging network for a CPO in the Netherlands and the utilization of V2G to harness the potential of the EPEX market through DC Bi-directional chargers.

3 Conceptual Framework for CPOs Business Model

In this chapter, the intricate web of Charge Point Operator (CPO) business models in the public charging network is explored, with a particular focus on the transformative potential of Vehicle-to-Grid (V2G) integration, while addressing the first research question. The core components of the current CPO business model are dissected, followed by a case study on the GreenCharge project to reveal key findings and strategic recommendations that can reshape the conventional CPO business model within the public charging network, harnessing the untapped potential of V2G technology.

3.1 CPOs Current Business Model Analysis

To address the first research question, it's important to understand what a business case is and why it's relevant for bringing about change or improvement in a business. This involves identifying the parameters and elements that can help effect the desired change. Therefore, this section aims to explore the current state of business for public charging networks from the perspective of a Charge Point Operator (CPO), including the challenges they typically encounter. It also seeks to conceptually identify the elements in their current business involving Regular or Smart Charging that can be improved through Vehicle-to-Grid, in order to create a stronger and more beneficial case for the CPO.

1. Business Case

A business case is a written argument for a proposed business project or activity. It often contains details on the project's goals, advantages, risks, expenses, and other significant aspects that will affect the firm. A company that is doing business will always look for a positive business case. It makes a strong case for why the project should be implemented by emphasizing the advantages it can have for the business as well as its stakeholders (Larson, 2017).

A successful business case often frames the advantages of the proposed project in terms of monetary gains, such as higher revenue, decreased costs, or enhanced profits. Strong business cases, however, may also emphasize non-financial advantages like greater employee morale, higher consumer satisfaction, or increased company social responsibilities. It should also convince decision-makers that the proposed initiative is worthwhile and that the prospective benefits outweigh the project's expenses and concerns (Larson, 2017).

However, reliable forecasts and a thorough analysis should support a strong business case rather than unrealistic expectations or wishful thinking. The potential merits and threats of the proposed initiative should be presented in a transparent and unbiased manner, and alternative strategies or scenarios should be taken into account (Carolyn O’Hara, 2014).

2. Business Case for Public Charging Network

The successful development of a public charging network for a Charge Point Operator (CPO) in the Netherlands depends on a well-written business case. With a goal of having entirely zero-emission vehicles on its roads by 2030, the Netherlands is a nation that is leading the transition to electric vehicles (EVs) (RVO-zero emissions, 2023). Because of this, the need for EV charging infrastructure is growing quickly, and CPO competition is getting more intense. Because of this, having a strong business case can help a CPO stand out from the competition and draw in investors and clients.

Moreover, a business case offers a comprehensive knowledge of the project's prospective costs, advantages, risks, and returns on investment. Also, it aids in determining the target market, price strategy, and marketing plan. A well-crafted business case can persuade potential financiers and investors to fund the project and assist the CPO in negotiating favorable contracts and agreements with pertinent parties, such as municipalities and utilities (M. Weeda & M. Olsthoorn, 2018).

For a CPO in the Netherlands to be successful in the cutthroat and quickly changing market for EV charging infrastructure, a business case must be developed. It offers a distinct vision, a realistic evaluation of the project's viability, and a plan for its execution. A strong business case can procure funding, establish alliances, and guarantee the project's long-term viability and sustainability.

The current climate crisis and recent global initiatives to accelerate decarbonization have raised awareness of the EV market and presented new opportunities for businesses. This statement is not just a hunch - a quick search on Google Trends shows that the topic of EV charging is now more popular than ever as seen in the Figure 3.1 below. However, while the world of EV charging offers immense potential for businesses and utility providers, it also comes with numerous complications, specialized roles, and obligations. Therefore, it is crucial for businesses seeking to launch electric vehicle charging services to fully comprehend their options (Virta-EMSP&CPO, 2022).

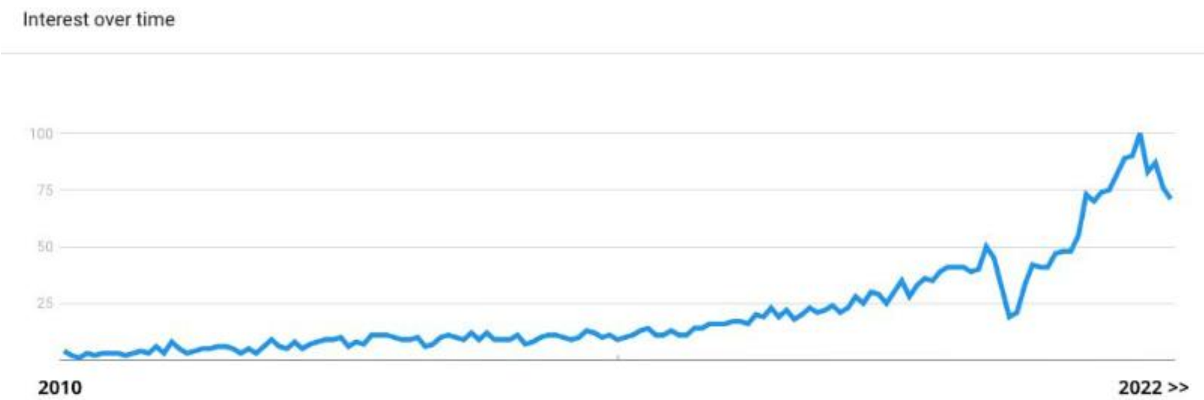


Figure 3.1 Google Trends of EV charging over time (Virta-EMSP&CPO, 2022)

3. Current Business Case of a CPO in the Netherlands, "Example: TotalEnergies"

In this section, the business case of TotalEnergies Mobility as an example of a Charge Point Operator will be explored, based on the insights gained through consultations and discussions with the experts from the Business Development team from the company and take a deep dive into understanding the business model of a CPO in the public charging network in the Netherlands. The market for the public charging network is examined and the various costs involved in setting up a charging station for the public i.e., municipality, as well as potential revenue streams. Analyzing how a CPO like TotalEnergies plans to generate revenue and achieve sustainability in the market. Furthermore, assess the charging solutions that TotalEnergies currently offers and their plans for future implementations to enhance competitiveness and bring more value to their business, as a Charge Point Operator.

Introduction to TotalEnergies

TotalEnergies is a major energy company that strives to provide reliable, affordable, and sustainable energy to people worldwide. Their diverse portfolio includes traditional energy sources such as oil, gas, and petroleum products, as well as advanced renewable energy options like solar and wind power, to meet the diverse needs of customers around the globe. Against the backdrop of the energy transition and the evolution of land transportation towards electrification, there has been a growing recognition of the pivotal role of electricity. As a result, the long-standing leader in energy intends to position itself as a prominent figure in the realm of sustainable energy and continue to provide innovative solutions for a more greener future.

In 2019, TotalEnergies established a new international business line called EV Charge, which focuses on developing electric mobility solutions. EV Charge oversees the development of hardware, software, and professional services to support the growth of electric mobility. As an integrated player in mobility, TotalEnergies is committed to minimizing the environmental impact of their activities, including green energy production and supply through their subsidiaries, TotalEnergies Solar and TotalEnergies. They are also innovating the distribution model by installing charging stations at homes, workplaces, and on the road, providing a seamless experience for electric vehicle users while encouraging responsible energy use. Overall, TotalEnergies aims to be a leader in sustainable mobility and a driving force for a greener future (TotalEnergies-EV, 2023).

TotalEnergies is extending its public charging infrastructure in prominent European cities such as Paris, Amsterdam, Brussels, and London. To enhance the convenience of electric vehicle (EV) users across Europe, the company has established a roaming agreement with other energy companies, which allows EV drivers to access TotalEnergies' charging network via the Open Charge Interface Protocol (OCPI). This enables hassle-free charging while traveling in different parts of Europe with their own vehicles. The mobility business of TotalEnergies is actively determining the direction of mobility in the continent with a strong focus on sustainability and innovation.

TotalEnergies Mobility Netherlands

TotalEnergies Mobility, a subsidiary of TotalEnergies, is dedicated to providing eco-friendly transportation solutions and helping businesses and individuals reduce their carbon footprint in the Netherlands. The company aims to expand its market presence by supporting the growing demand for electric vehicles and investing in the necessary infrastructure. TotalEnergies Mobility collaborates closely with the government and organizations to accelerate the adoption of EVs in the country, by providing cutting-edge charging solutions and a robust electric vehicle infrastructure to support the demand in the future. By doing so, the company not only benefits EV users and society but also advances its own business interests.

TotalEnergies as a Charge Point Operator in the Netherlands is responsible for deploying, operating, and maintaining a large number of charging stations in various public and private spaces. The company provides the necessary hardware and software for EV users to access these points and charge their vehicles. TotalEnergies has a greater presence in the public charging domain than the private sector, which contributes to the majority of the company's revenue. To better understand the company's business model, we will focus specifically on the public charging network and identify areas for improvement to increase their business advantages.

TotalEnergies currently manages more than 12,000 charge points in its public charging portfolio in the Netherlands and aims to expand that number to about 30,000 by 2030. As the number of charge points increases, the system becomes more complex due to various communications that occur among the EV user, the charging operator, and the utility company that provides or sells power to the operator. To optimize the system for the benefit of all the actors involved in the system, the company consistently introduces new advanced charging solutions.

The company currently offers three types of charging solutions, two of which are still in their niche stages. However, the company is highly motivated to expand these solutions into the market on a large scale, which would not only benefit their business but also contribute to a more environmentally friendly future by reducing the physical impact on the grid. The available charging solutions include:

1. Regular or Traditional Charging
2. Smart Charging (Pilot Projects)
3. Vehicle-to-Grid (Pilot Projects)

Various Costs and Pricing Involved in the Public Charging Network

In order to set up its charge points, a CPO must first win a tender from the municipality or government, competing against all other companies. Once the tender is secured, the company can then use the provided space to install chargers and operate as a Charge Point Operator. However, they must also ensure that certain prerequisites are met, such as the availability of a grid system that can support the load at the installation site.

In most cases, the space used by a CPO is provided free of cost by the municipality, as it is in the municipality's interest to increase the availability of more charging points at that particular location. However, there are rare cases where the charge point operator may receive compensation if the municipality wants to push for a charging station in a location that is not necessarily beneficial for the operator's business. Alternatively, if the operator sees good business potential in a location where the local government is not interested, they may offer compensation to use the space. Nevertheless, these scenarios are uncommon, so it is safe to assume that the space used by the operator is typically free of charge. However, there are various other costs, both direct and indirect, involved in establishing a public charging network, resulting in a cumulative cost. Those costs are:

1. Capital Cost

In the context of a public charging network for a Charge Point Operator (CPO), the initial cost of constructing or installing charging stations or other relevant infrastructure is known as a capital cost. This includes the price of the charging hardware, electrical components, labor charges for installation, paperwork, and any required site preparation work such as trenching, concrete work, and landscaping. Additionally, the cost associated with using the grid that is paid to the grid operator is also considered part of the capital cost for the CPO.

For CPOs, the capital expense represents a significant portion of the investment, which can vary depending on the size and complexity of the charging network. The capital cost is influenced by several variables, including the region, power capacity, number of charging points, and type of charging system.

It is crucial to ensure that the capital expense is financially feasible and that it can be recovered through revenue from charging fees or other sources, such as advertising or government subsidies. The capital expense is typically considered as part of the business plan for a CPO to ensure a successful charging network.

2. Operational Cost

Operational costs are the ongoing costs a Charge Point Operator incurs to operate and maintain a public charging network. These expenses can include electricity usage, maintenance and repair of charging hardware, payment service fees, network administration and support, yearly fees to the grid operator, marketing, and client engagement. The size and complexity of the network, type of charging devices, power capacity, and the number of charging stations can all have a significant impact on operational costs.

3. Variable Cost

As a Charge Point Operator, you may incur variable expenses that are directly related to the volume of charging activity on a public charging network. These expenses, such as electricity use, payment processing fees, and customer support expenses, fluctuate in direct proportion to how much the network is utilized.

For example, if more customers use the charging stations, the amount of electricity used and the cost of processing payments will rise accordingly. Similarly, TotalEnergies incurs variable costs such as buying power in the EPEX Day Ahead Market (DAM) as per the load forecast.

4. Other Costs

As a Charge Point Operator, maintaining a public charging network involves a number of additional expenses. Additional to fixed expenses, operational costs, and variable costs, they can include:

- Regulatory and compliance costs
- Insurance costs
- Financing costs
- Marketing and customer acquisition costs
- Technology and infrastructure costs

Ensuring a sustainable and profitable business model is crucial for Charge Point Operators (CPOs) in operating a public charging network. The variety of expenses involved in the operation of the charging network requires careful management to maintain high-quality charging services while remaining competitive in the market. From initial capital expenditures to ongoing operational costs, CPOs must carefully assess each expenditure and ensure that it aligns with the company's business plan. By managing costs effectively, CPOs can provide high-quality services to customers and maintain a competitive edge in the industry.

5. Pricing structure

CPOs often consider these operational and variable costs when deciding on pricing structures for charging services. However, the operator decides the proper pricing points for charging services that assure profitability while being competitive in the market mostly by having a solid understanding of their variable costs. Managing these expenditures is critical for maintaining a successful business model and providing clients with high-quality charging services.

Effective cost management tactics include investing in energy-efficient charging equipment, deploying Smart Charging solutions to optimize energy usage, and utilizing data analytics to improve network management and lower maintenance costs. In some cases, operational costs associated with specific services, such as Smart Charging, may be outsourced to third-party vendors.

For example, TotalEnergies has outsourced the Smart Charging solution used in some of their pilot projects to a third-party vendor, which is commonly known as a CPO management provider. The Smart Charging algorithm optimizes energy usage as per the EPEX DAM, which helps to reduce the variable costs for the operator. These vendors are usually responsible for tracking communication between all charge points involved in Smart Charging and providing CPO's IT team with relevant data. This sub-cost associated specifically with Smart Charging can also be considered as a back-office cost. TotalEnergies is able to efficiently manage their expenses and boost profit by contracting out this operational cost to a third-party partner.

Revenue and Profit

1. Revenue streams

Charge Point Operators (CPOs) can make money and gain profit from their public charging network in a number of ways, including:

- Charging Service Fees: CPOs have the right to impose fees on users of their charging infrastructure. The cost of charging might change depending on the charging rate, the amount of energy consumed, the location, and the time of day.
- Membership costs: Several CPOs offer membership programs that provide consumers access to waived recharging fees or other advantages like priority access to the charging spots or special discounts.
- Advertising: By enabling businesses to place advertisements on their charging points or network infrastructure, CPOs can make money through ad campaigns and partnerships.
- Government subsidies: In some markets, government support may be offered to help with the installation of infrastructure for public charging. These subsidies can be used by CPOs to reduce some of their capital expenses and boost profitability.
- Auxiliary services: CPOs can also provide ancillary services to third-party partners, like utilities or fleet operators, in order to generate additional income streams. These services include remote monitoring and diagnostics, network administration and support, and data analytics.

2. Selling price

The selling price of a charging service provided by a Charge Point Operator (CPO) can be affected by several variables, such as the location of the charging station, charging speed, charging connector type, and time of day. To remain competitive in the market, CPOs often base their selling prices on a well-planned pricing strategy that considers their expenses, revenue goals, and competition. The selling price of a charging service is a crucial factor in determining the financial viability of a charging network for a CPO. Thus, an effective pricing strategy must carefully balance costs, revenue objectives, and market dynamics to ensure that the price remains competitive while generating enough income to cover costs and deliver a sustainable business model.

TotalEnergies generates most of its revenue as a Charge Point Operator by selling power through its charge points to end-users at a fixed price. The charging tariffs can be based on *€/kWh, €/min, €/session*, or a combination of these tariff units, depending on the country or the regulations followed in that particular region. In the Netherlands, there are no such restrictions, but charging follows the pricing structure set by market players. Users in the Netherlands are charged based on the amount of energy consumed in a session at ***€/kWh***.

Pricing strategies are influenced by various key actors who play different roles in the system. Firstly, the CPO defines pricing policies in accordance with the charging network owner, which in this case is mostly the municipality, and negotiates agreements with mobility operators.

Secondly, the Electric Mobility Service Provider (EMSP) provides payment and mobility card services to consumers, as well as a mobile application for accessing the CPO's charge points through a map. CPOs usually partner with companies like TotalEnergies, Eneco and Shell to provide these services to customers in the Netherlands, and they determine the selling cost of the charging session.

The payment for a charging session can be made by a credit card or a mobility card provided by the EMSP, although the pricing may vary based on the payment mode used by the user. The cost of a charging session to the consumer is influenced by the energy delivered, the duration of the connection, and the session of the charging. The cost of a charging session to the consumer can be calculated as the amount of energy consumed by the electric vehicle multiplied by the selling price per kWh set by the EMSP (TotalEnergies-Pricing, 2022).

3. Break-even Point

The breakeven point is a crucial concept for Charge Point Operators (CPOs) as it represents the level of activity or usage required in the charging network to cover all expenses and achieve a net profit of zero. This point is determined by the total revenue generated being equal to the total expenses incurred.

To determine the breakeven point, CPOs can conduct a breakeven analysis that takes into account fixed costs, variable costs, and selling prices of their charging services. The breakeven point can be determined by using the following formula:

Breakeven Point = Fixed Costs / (Selling Price - Variable Costs)

Fixed costs refer to expenses that do not change based on activity or usage levels, such as the upfront costs of setting up charging stations and administrative salaries. In contrast, variable costs, such as electricity consumption and payment processing fees, change with the volume of activity or usage. The selling price of the charging service is the cost incurred by the customer.

By analyzing the breakeven point, CPOs can evaluate the level of activity or consumption necessary to achieve profitability. With appropriate pricing strategies and cost control, CPOs can aim to surpass the breakeven point and generate net profits. For TotalEnergies, this means determining the optimal amount of energy to sell in ***€/kWh*** to reach the breakeven point is crucial for knowing their payback period, and further gives clarity on the recovering costs, and achieving profitability of the charging network. Additionally, analyzing the breakeven point is essential to determine the financial viability of the project and establish a robust business model.

Different Charging Solutions and their Revenue Model

1. Regular Charging

Regular charging is a method of charging in which the electric car battery is charged at the highest power that the battery and charging infrastructure can take, regardless of the battery's level of charge or the grid's demand for electricity. The charging happens without any monitoring and control, so commonly it is called Dumb Charging. The charging process is straightforward and continuous until the EV is disconnected or reaches a predefined charging limit. Although Regular charging may be quicker, it may not be the most effective approach to charging an EV because it puts an additional load on the electrical system.

A CPO like, TotalEnergies uses traditional charging or Regular charging devices for all public network chargers, allowing the charger to charge the car at maximum capacity as soon as it is connected. However, this approach is not optimized and may result in the vehicle being charged at high prices during peak hours, leading to larger variable costs for the CPO and potential grid instability. Additionally, the charge point may remain occupied even after the car is fully charged, rendering it useless until the owner removes it.

As a result, the CPO's profit is determined by the difference between the amount of energy sold to the EV user at a fixed price of €/kWh and the variable cost incurred for the blocks of power purchased from the EPEX DAM during charging hours.

2. Smart Charging

Smart Charging or unidirectional controlled charging is the process of optimizing how electric vehicles are charged by considering variables such as grid demand, electricity rates, and the vehicle owner's needs. By lowering the variable cost of electricity usage for the CPO, Smart Charging can help ease the burden on the grid during periods of high demand.

Various tactics can be employed for Smart Charging, such as scheduling charging times during off-peak hours, reducing the charging rate during periods of heavy grid demand, and adjusting the charging rate based on the battery's state of charge and the charging infrastructure used. Overall, Smart Charging focuses on charge optimization to lower costs and load on the electrical grid.

For example, a CPO like TotalEnergies have solutions in-house or outsourced from external vendors for their pilot projects to implement Smart Charging solutions, which also adds to the back-office cost. The Smart Charging algorithm optimizes energy usage according to the EPEX DAM, which will reduce the overall variable costs for the operator. The algorithm shifts the load to off-peak hours to charge at a lower price or charges the vehicle at a lower rate during peak hours based on the operator's data on EPEX DAM price, load forecast, and the vehicle's availability.

As a result, the vehicle is charged in an optimized manner for the time it is available at the charge point, either at a lower price during off-peak hours or at a lower rate during peak hours. This increases the net profit for the operator compared to Regular charging, based on the reduction of the variable cost incurred for the blocks of power purchased from the EPEX DAM in a charging session.

3. Vehicle-to-Grid

Vehicle-to-Grid, also known as Bi-directional charging, enables electric vehicles to not only consume electricity from the grid but also act as a source when needed. By using this charging technique, an electric vehicle's battery can discharge energy back into the grid, providing the grid with electricity during high-demand periods or for other grid requirements.

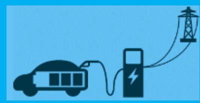
This technology promotes the expansion of renewable energy sources and reduces the load on the electrical system during peak periods. However, using this technique may require additional infrastructure and technology, and it can put additional stress on the battery, ultimately shortening its lifespan.

Due to its directional charging properties, any CPO like TotalEnergies can be advantageous, utilizing the charging network with an optimization algorithm can help reduce the overall variable cost of charging a vehicle in a session. The algorithm would be an extension of the Smart Charging solution, charging the vehicle during off-peak hours at a lower price and discharging it into the grid during peak hours for a higher cost. This approach will help the operator optimize the cost of power purchased from the EPEX DAM based on factors such as the initial state of charge of the vehicle, EPEX DAM price, the possibility of injecting power into the grid, load forecast, and vehicle availability.

Currently, the public charging protocol does not provide data regarding the initial state of charge of the vehicle. However, the future implementation of ISO 15118 will provide this necessary data to the operator. Additionally, the CPO is not directly involved with DSO for FCR services, limiting their knowledge of whether injecting power into the grid is possible or not. Therefore, understanding the scope of profit for a CPO conceptually requires considering two key assumptions for the V2G solution: knowing the initial state of charge of the vehicle and the possibility of injecting power into the grid.

As a result, the optimization algorithm can further reduce the overall variable cost for power purchased from the EPEX DAM based on optimized power usage. The optimization should mainly focus on buying power at a lower price during off-peak hours and selling it during peak hours, which is also known as arbitrage of power. Compensation for the asset used of the EV user’s battery and for any wear and tear due to the bi-directional charging process should also be considered by the CPO, depending on the analysis of battery degradation in cycling aging compared to calendar aging. The net profit for the CPO by selling a kWh of energy will depend on considering all these costs and compensations involved. However, implementing a V2G algorithm in a public charging network should sound more financially beneficial for a CPO compared to Regular or Smart Charging.

In summary, a CPO's ability to profit from V2G technology in the day-ahead market is influenced by various factors, including electricity prices, demand response initiatives, and legal frameworks. Therefore, when deciding to invest in V2G technology, CPOs must carefully consider these factors and weigh the advantages and disadvantages of the technology.

	**Regular Charging** 	**Smart Charging** 	**Vehicle-to-Grid** 
Technology	**Unidirectional**	**Optimized Unidirectional (V1G)**	**Bi-directional (V2G)**
Location/Land	Provided free by Municipality	Provided free by Municipality	Provided free by Municipality
Capital Cost	Low	Moderate	More for Bi-directional Hardware
Operational Cost	Low	Moderate (Software)	Moderate to High (Hardware and Software)
Variable Cost (Only Energy Cost)	Maximum	Less than Dump Charging	Estimated to be Least
Revenue Streams	Selling Power	Selling Power (Optimized)	Selling Power (Optimized) and Auxiliary Services
Selling Price	€/kWh	€/kWh	€/kWh
Charging Method	Charge at full capacity	Load Shifting to Off-Peak, Lower rate at Peak Hours	Charge at Off-Peak Hours, Discharge at Peak Hours
EV Status	Consuming (Until full) Then Idle	Managed Charging	Consuming and/or Supplying
Grid Strain (Peak Hours)	More	Less/Reduced	Less/Reduced
Requirement	None	Communication Capabilities, Optimization Software/Tool	Bi-directional Charge Point, Communication Capabilities, Optimization Software/Tool
Constraints/ Factors	None	Time, Grid Demand, EPEX DAM Price	Time, Grid Demand (Injecting), EPEX DAM Price, Battery SOC
Benefits	Convenient, Efficient Charging	Efficient and Cost-effective Charging, Reduced Grid Load	Cost Savings, Revenue Generation, Reduced Grid Load, Integration of Renewables
Profit	None	Cost Savings	Cost Saving Various Revenue Streams

Profit Scope	None	Operator, Potentially for EV Owners	CPO, Grid Operator, Potential Compensation for EV Owners (For Battery Degradation)
Actors Involved	EV owner, charging station owner/operator	EV owner, charging station owner/operator, software provider	EV owner, charging station owner/operator, software provider, utility/grid operator

Table 3.1 Summary of Findings from CPOs' Current Business Model for Various Charging Technologies ((Virta Global, 2023), Stakeholder Consultations and ChatGPT)

4. Challenges Faced by CPOs

1. Interoperability: With a growing number of EV models and charging standards, it can be challenging for CPOs to ensure that their charging infrastructure is compatible with all EV models and charging standards. This can create issues for EV drivers who may find it difficult to locate a compatible charging station.

2. Cost of infrastructure: Installing and maintaining public charging infrastructure can be expensive, and CPOs may struggle to recoup these costs through charging fees alone. This can make it challenging for CPOs to expand their charging networks and ensure that there are enough charging stations to meet demand.

3. Grid capacity: As the number of EVs on the road continues to grow, there is a risk of overloading the grid in certain areas. This can be a particular challenge for CPOs in densely populated urban areas where there may be limited grid capacity available.

4. Permitting and zoning: In order to install charging infrastructure in public spaces, CPOs must navigate a complex web of local and national regulations, permits, and zoning requirements. This can create delays and increase costs, making it more difficult for CPOs to expand their charging networks.

5. Competition: With a growing number of CPOs entering the market, there is increasing competition for customers and charging locations. This can make it more challenging for CPOs to build a profitable business model and may lead to pricing pressure and lower margins.

5. Elements of a business case for Regular/Smart Charging can be improved through V2G

The following elements are commonly included in a business case for a CPO (Charge Point Operator) for Smart Charging that can be enhanced by V2G (Vehicle-to-Grid) in the public charging network:

1. Revenue generation: With V2G technology, a CPO can create new revenue streams by reselling excess energy that was previously stored in EV batteries to the grid or other energy markets. This could boost the charging infrastructure's overall profitability.
2. Cost reduction: By maximizing energy utilization and removing the need for pricey peak-demand power plants, V2G technology can help lower the overall cost of operating the charging infrastructure. For the CPO, this may result in lesser operating expenses and higher profitability.
3. Load management: By matching the demand for charging with the availability of electricity from the grid or other sources, V2G technology can assist CPOs in managing the load on their charging infrastructure. This can lessen the need for expensive grid infrastructure upgrades by preventing system overload during periods of high demand.
4. Energy storage: V2G technology enables CPOs to employ EV batteries as a kind of energy storage, which can assist in grid stabilization and lessen the requirement for pricey peak-demand power plants. As a result, the grid's dependability and resilience may increase, and the cost of electricity as a whole may decrease.
5. Customer retention: By differentiating themselves from rivals and providing V2G services, CPOs may draw in and keep consumers who are looking for more sophisticated and environmentally friendly charging solutions. This may help boost customer retention rates and raise the charging infrastructure's general profitability.

Overall, integrating V2G technology into public Smart Charging infrastructure can offer CPOs a number of advantages, such as improved load control, cost reduction, revenue creation, customer retention, and energy storage. These advantages can support the larger energy system while also enhancing the charging infrastructure's overall profitability and sustainability.

3.2 GreenCharge Project Case Study

This section thoroughly analyzes the GreenCharge project to understand the dynamics of the Exponential Market Place Business Model. The outcomes are then considered as a basis for recommending key findings to build a similar innovative business model for a CPO. This aims to increase their value proposition and maximize the value for each of the stakeholders in the EV charging ecosystem, as discussed in Section 3.3.

1. What is a Business Model?

Before discussing the development and innovation of the business model for V2G, it is important to understand what is a business model and what should be updated. Broadly, the business model can be described as a unit of analysis that explains how a firm's operations are conducted (Gassmann et al., 2013). The business model is often seen as a broad idea that considers all of the parts that make up a firm and combines them into a cohesive whole (Demil & Lecocq, 2010). There is always a disagreement in the business model literature as to the precise elements that make up a business model (Scholten et al., 2018). The business model explained in the St. Gallen Business Model framework will be used to develop the business model for V2G because it includes an easy-to-use canvas tool and defines the key components of a business model. The four key components of a business model are the subject of this canvas tool: the Who, the What, the How, and the Value (How much). The model will help to provide a clear illustration of the V2G business model. In below Figure 3.2, the St. Gallen business model concept can be visualized.

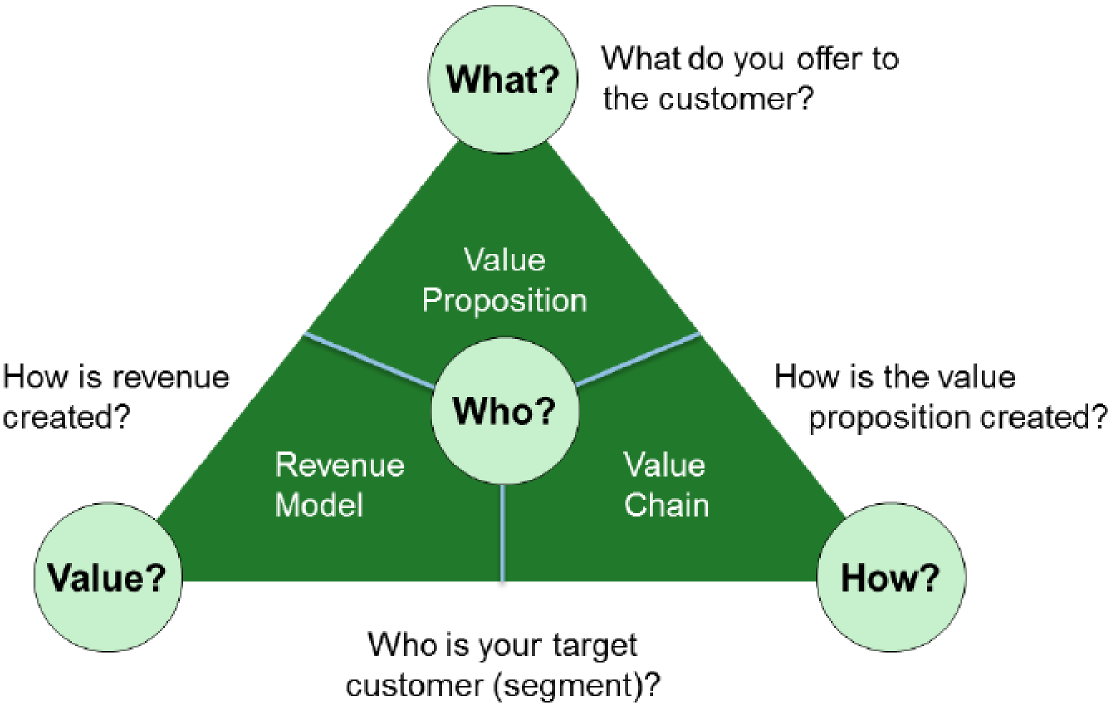


Figure 3.2 Business Model Definition – The Magic Triangle (Gassmann et al., 2013)

The following is a description of the four dimensions that make up business models:

- **Who:** Each business model caters to a particular customer base (Chesbrough & Rosenbloom, 2002). A new business model is designed using this dimension as its focal point. The answer to the question "Who is the customer?" will provide the *Who* (Magretta Joan, 2002).
- **What:** This dimension outlines the products or services that are supplied to the intended consumer (*Who*). The *Value Proposition* is the name given to this dimension in the St. Gallen business model. It can be characterized as a comprehensive picture of a business's selection of products and services that are valuable to customers (Osterwalder, 2004).

- **How:** A company must be skilled in a number of processes and activities in order to create and disseminate the value proposition. The third dimension of the St. Gallen business model is made up of these processes and activities, as well as the associated resources (Hedman & Kalling, 2003), capabilities (Morris et al., 2005), and how they are orchestrated in the internal value chain.
- **Value:** The fourth component, which explains why the business model is able to sustain itself financially, is concerned with the company's revenue. Aspects are united, including, for instance, the cost structure and the used revenue mechanisms. This raises the fundamental concern of any company: how to generate revenue?

The business model of a company becomes real and a common ground for rethinking is reached by identifying the target customer, the value offered to the consumer, the value chain behind the creation of this value, and the revenue model that captures the value.

2. Inspiration for the V2G Business Model Adoption

GreenCharge Project

The GreenCharge (Scholten et al., 2018) is working on a project that could help us realize one of the goals associated with modern cities: a zero-emission transportation system based on electric cars powered by renewable energy, where traffic congestion and parking issues are a thing of the past. They are developing a Smart Charging system that enables users to schedule charging in advance so they may quickly obtain the energy they require. Therefore, they are creating software for autonomous energy management in local areas to balance supply and demand. In this delicate balancing act, public resources and locally generated renewable energy are combined, local storage is used as a buffer, and charging times for automobiles are spaced apart.

So to realize this change, GreenCharge is developing and testing business models that promote the usage of electric vehicles and resource sharing, enabling all parties to work together in an economically viable manner. Testing all of these enhancements is done in real-world settings in Barcelona, Bremen, and Oslo. These trials collectively examine a wide range of variables, including vehicle type (scooters, cars, buses), ownership model (private, shared individual use, public transportation), charging locations (private houses, businesses, public spaces, transportation hubs), energy management (using solar power, load balancing at one charging station or within a neighborhood, battery swapping), and charging support (reservations, priority charging).

Project Aim

Innovative Business Models, is one of the three main sets of results from the project, which aims to assist municipalities and localities in making the switch to zero-emission/sustainable mobility. *Technical Support,* for Utilizing the flexibility of the load and the storage potential of nearby stationary batteries and parked EVs, and to coordinate the power requirement of charging with other local demand and local RES; and *Guidelines* for the implementation and operation of EV charging infrastructure that is both affordable and effective are the two other sets of results. The *innovative business models* are motivated by concepts from the sharing economy, demonstrating how to use and share the excess capacity from individual RES, personal charging stations, and the batteries of parked EVs in ways that are advantageous to everyone involved, both financially and otherwise.

Workshops were employed to create the initial business models for the GreenCharge project using a business model canvas based on Osterwalder's business model canvas. Stakeholders from each of the experimental locations participated in the Business Model Innovation (BMI) Game to provide feedback for the business model innovation process. PNO Consultants and TNO from the GreenCharge developed this game about business model innovation as a part of the H2020 Inspire project. Several other workshops were held to further redesign the initial business models, identify acceptable price levels, define evaluation methodologies, and build innovative business models which cannot be applied to the pilots for the purpose of simulation, after defining and characterizing the initial set of business models based on the feedback from the BMI game.

Methodology Followed in GreenCharge Model Development

Based on the St. Gallen business model concept, the initial business models created for GreenCharge were presented as pipeline models. In each demonstrator, business models were created for each stakeholder. Companies can regulate a linear series of activities to produce value by employing a pipeline strategy. Inputs at one end of the chain flow through a series of processes to become output with a higher value. These first business models are illustrated by a few examples below in the Figure 3.3 Initial Business Models for the Oslo Demonstrator.

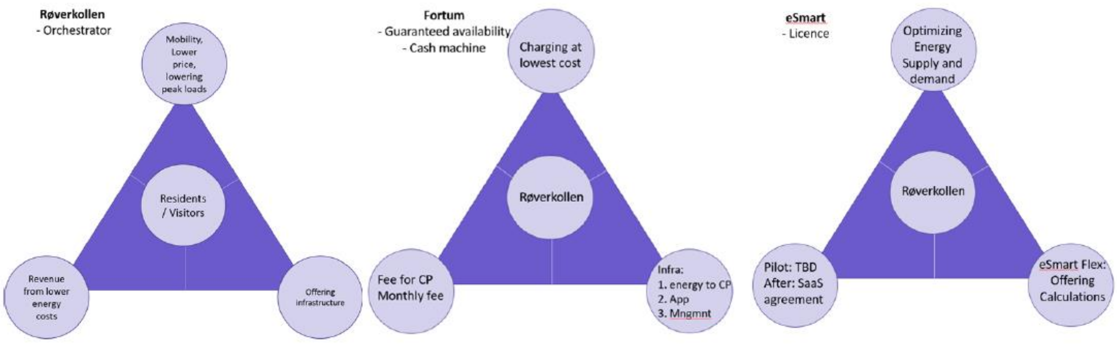


Figure 3.3 Initial Business Models for the Oslo Demonstrator

When the initial business model of GreenCharge was approached in a linear manner, the coherence between the many ecosystem participants is not given much thought, and each stakeholder solely considers what is in their own best interests. Approaching the business model as an ecosystem and recognizing what each stakeholder contributes to the common interest allows for greater value to be created in a cost-effective manner. This market place or platform strategy allows businesses to leverage the physical infrastructure and assets of other businesses. It also offers the infrastructure and regulations for a market place that connects producers and customers. To transform the business model to market place model, online workshops were aided for each of the demonstrators, so as to increase the scalability and exponentiality of business models. A different format canvas was used to develop these market place models, which can be seen in the Figure 3.4

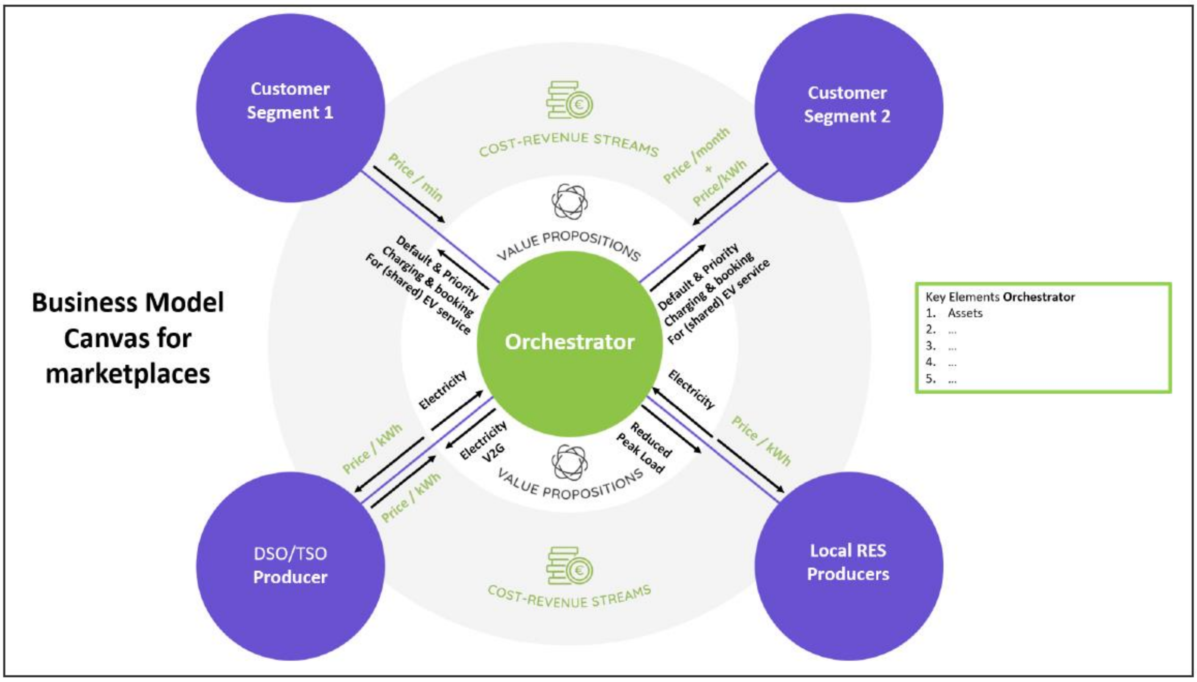


Figure 3.4 Market Place Business Model Canvas

The various players who comprise the ecosystem are depicted in the canvas's corners, with the market place orchestrator (the Owner) in the center. It depicts the essential components of a business model: 1) customers segments (who?); 2) value propositions (what?); 3) key activities and assets (how?); 4) cost and revenues (how much?), and; 5) producer segments (who?). Business models for the marketplace develop cross-side network effects by linking clients to energy and/or mobility solution providers. The orchestrator connects all players in the ecosystem and facilitates information and/or energy exchanges. As a result, all stakeholders maximize the value captured.

Principles of Final/Exponential Business Models

An exponential business model examines the same major areas as a standard business model, but with drastically different objectives. Most company plans are linear, with the goal of increasing revenues or decreasing costs by 10%. They aimed in terms of changes that are 10 times more or less than today's value when using an exponential business model—the standard abbreviation for this goal is simply "10X." Increasing the business model from 10% to 10X requires more than just scaling.

Often, an entirely new perspective for the company and the industry it serves is required. Exponential business models necessitate exponential creativity. Furthermore, in order to achieve tenfold, the value must be created through the use of technology in at least one important building component, such as the value proposition, channels, or key resources.

Amazon, Facebook, Airbnb, Snap, Alibaba, and Slack to name a few of the companies that have done it successfully. For example, Airbnb developed a software platform for people who needed lodging and connected with the one who had it. They liberated a massive, underutilized resource and created 10X value without owning a single room by integrating existing technology with a competing value proposition.

Final/Exponential Business Models Outcome

The business model innovation process, which was carried out in collaboration with PNO and the various stakeholders at the demonstrators, lead to the development of the first, updated, and final business models. Some of the key takeaways have been highlighted by the PNO during this process. The subsequent are the most essential lessons acquired through the iterations:

1. A single business model for all stakeholders per demo, rather than a business model for each stakeholder
2. A multifaceted market encourages collaboration and maximizes value for all stakeholders.
3. Keep the business model test minimal so that demos are practical.
4. In an exponential business model, both energy producers and consumers must receive a fair price.
5. Agile methods should be used to organize business model measurement testing.

An exponential business model captures the value it creates for customers through revenues and costs, which are evaluated in terms of earnings. Earnings are the financial flows generated by the business concept. The calculation of the revenues/earnings are explained briefly in the upcoming Section 4.2. An exponential business model results in network effects that can be assessed in terms of savings per consumer (and per producer) rather than a pipeline business model. Customers (using energy) benefit from these network effects because they do not have to pay for marketing. Usually, customers market themselves because they recommend the adoption of the business model to other customers in the exponential business model. This incentivizes customers to attract additional customers, who in turn attract more suppliers. The greater the number of producers and customers, the lower the expenses per customer and the higher the revenue per producer (of energy) for the service.

Conclusion of GreenCharge Project

Traditional business models are pipelines, with each link adding value in a linear fashion. They do not scale quickly since they are usually asset-heavy and require significant marketing expenses. They do not encourage collaboration among all stakeholders because a higher margin for one link in the chain comes at the expense of the other. The benefit of a pipeline business model is not maximized for every stakeholder.

GreenCharge's new collaborative business models are multi-sided market places that establish a stakeholder's ecosystem linked by an orchestrator. As all stakeholders can collaborate, take benefit from network effects, and optimize value, the ecosystem can grow exponentially. Increased consumers will attract more energy producers, and vice versa. Therefore, market place firms can expand at an exponential rate.

The future exponential business model comprises of a market place model that connects renewable energy producers and prosumers with renewable energy customers and prosumers. The orchestrator's battery storage and load balancing software helps balance the supply and demand for (green) electricity. More renewable energy producers will attract more renewable energy users to this model, and vice versa. As a result, network effects will yield economies of scale, which will have a significant influence on lowering CO2 emissions. This potential business model is an expansion and scale-up of the business case of the demonstrators in Oslo, that looks into the Smart Charging market for housing cooperatives and their residents/visitors.

3.3 Innovative Business Model for CPO

In line with our discussions in the GreenCharge project (Scholten et al., 2018), it becomes evident that the exponential marketplace business model holds the potential to usher in a new era of electric mobility, particularly within the public charging network of the Netherlands. This model not only presents a multitude of advantages but also significantly amplifies value for all stakeholders within the ecosystem. This is in stark contrast to the conventional linear pipeline business models, where value is incrementally added to the chain.

By embracing the exponential marketplace model in the context of a Charge Point Operator (CPO) in the Netherlands, we can embrace a transformative paradigm where the integration of electric vehicles, charging infrastructure, and the energy grid takes center stage. This approach will lay the foundation for sustainable transportation, while the inclusion of Vehicle-to-Grid (V2G) technology within this model acts as a catalyst for innovation. This model will embark on a comprehensive exploration of the theoretical foundations, practical implementations, regulatory considerations, and potential benefits of this pioneering approach, adding to the discourse on advancing V2G technology and shaping a more sustainable, interconnected future for the Netherlands' public charging network.

Implementing an exponential marketplace business model for a Vehicle-to-Grid (V2G) in the public charging network as a Charge Point Operator (CPO) in the Netherlands involves creating a platform that connects electric vehicle (EV) owners, charging station operators, grid operators, municipalities, and other stakeholders. This model focuses on enabling bidirectional energy flow between EVs and the grid, allowing EVs to both charge from and supply energy back to the grid. This can be more explicitly integrated with the existing charging infrastructure which will lead to increased utilization of charging infrastructure, improved user experience, and scalability.

A detailed approach for the implementation of an exponential marketplace business model conceptually developed for Vehicle-to-Grid (V2G) in the public charging network by a Charge Point Operator (CPO) in the Netherlands can be seen below (Scholten et al., 2018) and the developed market place business model for V2G charging for CPO can be referred in Figure 3.5:

1. **V2G-Enabled Public Charging Stations:**
    - **V2G Charge Points:** Install V2G-capable charging stations in strategic locations within the existing public charging network. These stations should be able to charge EVs as well as provide bidirectional energy transfer for V2G.
2. **Platform Development:**
    - **Multi-Functional Platform:** Build a comprehensive digital platform (website or app) that supports traditional EV charging as well as V2G capabilities. This platform will act as a hub for electric vehicle owners, charging point operators, and grid operators.
    - **Additional Information:** The portal should give information regarding V2G-enabled stations, their availability, charging and energy transaction prices, and the opportunity for users to adjust their V2G preferences.
3. **Network Effects and Value Proposition:**
    - **EV Owner Benefits:** Highlight the advantages of V2G participation, such as earning money by selling excess energy back to the grid, lowering charging costs, and helping in stabilizing the grid.
    - **Charging Station Operators:** Emphasize how V2G integration may attract more electric vehicles to their charging stations and create additional revenue streams.
4. **Charging Station Integration:**
    - **V2G-Enabled Stations:** Collaborate with charging station manufacturers to deploy V2G-enabled stations across the Netherlands' public charging network. To ensure seamless platform integration for real-time data exchange.
    - **Grid Integration:** Partner with grid operators to provide the necessary technological infrastructure for bidirectional energy flow.
5. **User Engagement and Experience:**
    - **EV Owner Profiles:** Allow EV owners to create profiles for V2G that include vehicle information, charging preferences, and energy selling preferences.
    - **Energy Management:** Provide EV users with tools to configure their energy preferences, such as when to charge, when to supply energy back to the grid, and energy pricing.

6. **Energy Trading and Monetization:**
    - **Energy Transactions:** Facilitate transactions for energy supplied back to the grid between EV owners and grid operators. Each successful energy transaction should be charged a transaction fee.
    - **Premium Subscriptions:** Provide EV owners with premium subscription options that provide benefits such as priority access to V2G-enabled stations and greater data insights.
7. **Grid Integration and Regulation:**
    - **Grid Operators:** Check with the grid operator to ensure that bidirectional energy flow is in accordance with grid requirements and regulations.
    - **Regulatory Knowledge:** Keep up to current on Dutch rules and policies pertaining to V2G integration, energy trading, and EV charging.
8. **Data Utilization and Innovation:**
    - **Data Insights:** Data from V2G transactions and energy flows can be used to provide insights to grid operators and regulators. This information can help with grid optimization and future energy planning.
    - **Innovation:** Continuously investigate novel ways to improve the V2G experience, such as incorporating renewable energy sources, applying smart grid features, and optimizing energy trading algorithms.
9. **Partnerships and Expansion:**
    - **Renewable Energy Providers:** Partner with renewable energy providers to allow EV owners to pick clean energy sources for charging as well as energy trading.
    - **EV Manufacturers:** Consider forming collaborations with electric vehicle manufacturers to assure compatibility and encourage V2G usage.
10. **Customer Support:**
    - **Customer Service:** Offer assistance to EV owners in configuring their V2G options and resolving any technical, platform usage, energy trading, or billing concerns.

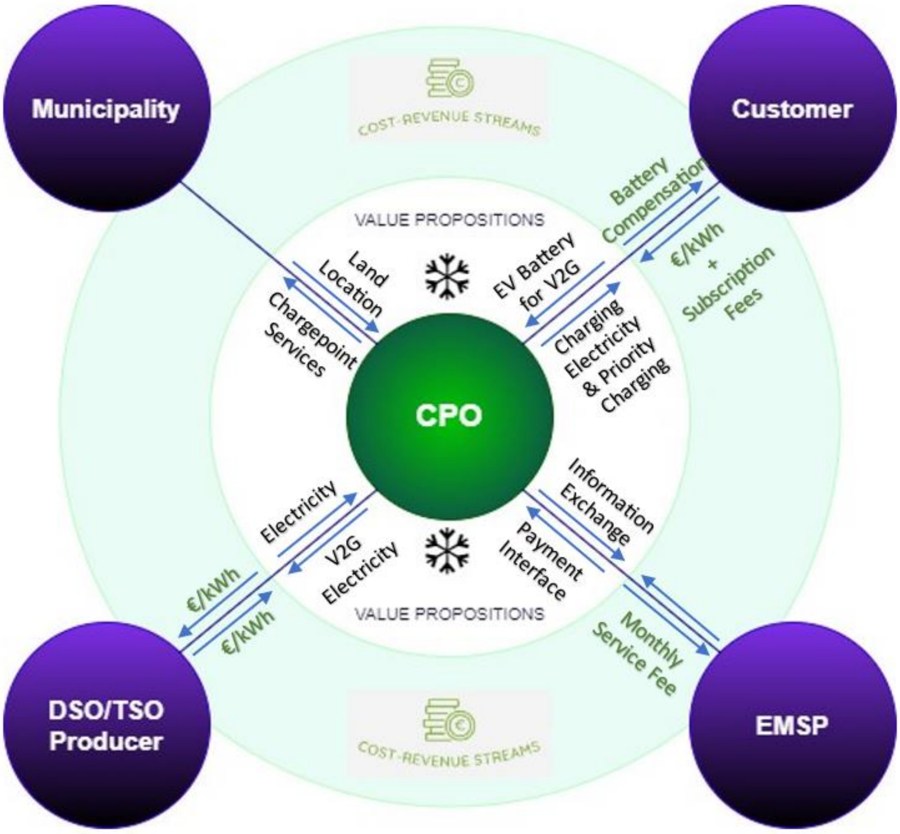


Figure 3.5 Developed Market Place Business Model for CPOs with V2G Charging (Scholten et al., 2018)

4 Simulation Model Framework for V2G Integration

This chapter examines the strategic dimension of integrating Vehicle-to-Grid (V2G) technology into the operations of Charging Point Operators (CPOs) within the Dutch public charging network and will address the second and the third sub-research question. It explores how V2G can be harnessed as a transformative tool, enhancing CPO efficiency, reducing electricity expenses, and enabling participation in energy markets. An Excel-based simulation model will be developed to replicate various V2G charging scenarios, with a specific objective of curbing the variable costs associated with electricity procurement. Further, an extended Cost-Benefit Excel model will be employed to assess the profitability of the CPO's business model after integrating the reduced variable cost of procured electricity through V2G within the evolving landscape of the EPEX SPOT DAM.

4.1 V2G Integration Strategies

This section delves into the technical intricacies of V2G implementation, emphasizing its crucial role in advancing sustainable electric mobility. By dissecting these strategies, the goal is to unlock the full potential of V2G in the EPEX DAM. This will propel CPOs toward a future of optimized operations and greater contributions to grid resilience and sustainability. The ultimate aim is to formalize the required framework for the V2G simulation model in Excel to reduce the cost of procured electricity in the EPEX market, while answering the second sub-research question.

4.1.1 V2G Integration with EPEX Formulization

A Charge Point Operator (CPO) acquires electricity in two categories for EVSE energy needs: baseload and peakload. Baseload represents the minimal power demand required continuously over a 24-hour period to sustain constant operations (also known as continuous load). Peakload, conversely, corresponds to periods of high electricity demand, often lasting only for a short duration (Sinovoltaics, 2023).

To fulfill baseload requirements, CPOs engage in bulk purchases via bilateral contracts with electricity suppliers. These contracts are made well in advance, typically a week, month, or year ahead, based on future load forecasts. However, for the remaining energy needed to meet real-time demand on the day of delivery, CPOs turn to the EPEX SPOT Day-Ahead Market (DAM). Here, they procure energy in hourly blocks, aligning with the net electricity needs accounting for the discrepancy between baseload power and expected demand during the delivery period. Figure 4.1 illustrates both types of loads typically necessary to meet energy demand.

This study assumes that 40% of the total energy requirement, the peakload block, is traded on the EPEX SPOT DAM. The rest 60 % of the energy required by the EVSE system is secured through bulk purchases from the supplier well in advance of the delivery time. The following section delves into how the bidirectional capability of V2G can optimally use this energy block. Such optimization holds the potential to reduce electricity procurement costs in the EPEX SPOT market, a critical consideration for CPOs looking to enhance their operational efficiency.

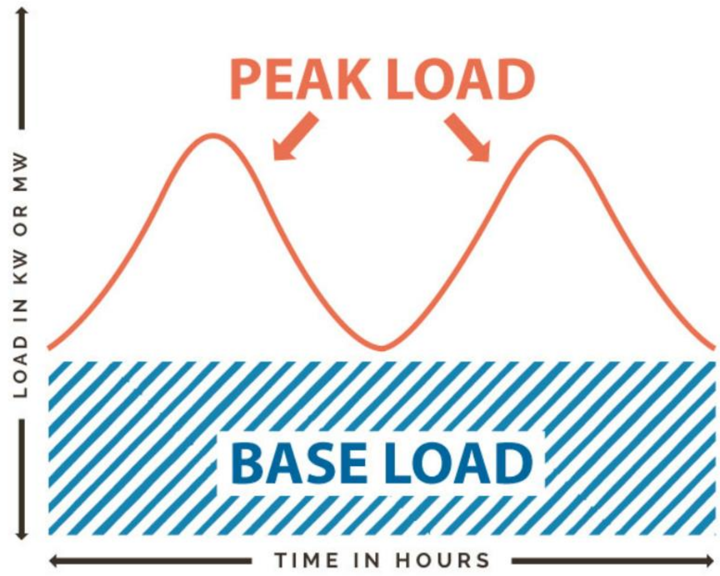


Figure 4.1 Peakload & Baseload of Electricity Demand (Sinovoltaics, 2023)

In the EPEX SPOT market, the Market Clearing Price (MCP) is established in hourly blocks, allowing market participants to submit their supply and demand bids on an hourly basis. This structure presents an opportunity for a CPO to engage in energy arbitrage, capitalizing on price differentials within the marketplace for the same asset, using EVs equipped with V2G charging technology.

Figure 4.2, displayed below, illustrates EPEX SPOT DAM prices for two consecutive days, specifically, the 5th and 6th of September 2023. It becomes evident that two peak time trends occur during each day. These periods present a favorable opportunity for the CPO if the EV is connected at the beginning of these intervals with a higher State of Charge (SoC). In doing so, energy can be discharged during peak hours and subsequently replenished during off-peak hours at a lower cost. This results in a net advantage for the CPO in terms of reducing overall prices in the EPEX SPOT market by the end of the charging session.

Figure 4.2 EPEX SPOT DAM Price for Two Consecutive Days (5th & 6th September 2023) (EPEX-DAM, 2023)

The data from the EPEX SPOT DAM prices on these two days will be incorporated into further evaluations as part of the enhancement technique through a simulation tool applied to reduce cost for the procured electricity for a charging session utilizing V2G technology. Two consecutive day prices were selected to utilize real-time price data for a charging session that can commence in the evening and conclude the following morning. The price values on an hourly basis for this twelve-hour duration, ranging from 7:00 PM in the evening until 7:00 AM the next day, are detailed in Table 4.1 below.

Time	19	20	21	22	23	24	1	2	3	4	5	6
€/kWh	0.179	0.154	0.122	0.108	0.096	0.089	0.086	0.084	0.084	0.079	0.092	0.115

Table 4.1 EPEX SPOT DAM Electricity Prices from 19:00 until 7:00 the Following Day

As previously discussed, the bi-directional capabilities of V2G technology can significantly aid a CPO in reducing the overall cost of procured electricity in the EPEX SPOT DAM market for charging EVs. Now, let's briefly explain the actual V2G simulation model for cost reduction in one particular charging session scenario works, which can be referred to in Table 4.2. This study primarily focuses on optimizing sessions during the peak trend observed in the evening.

In this specific charging scenario, certain key assumptions are considered. During the evening time, many EV users return home from work with a fully charged EV. When they reconnect to the public charge point near them in the evening, the battery has a specific State of Charge (SoC). They leave the vehicle at the charge point until the following day morning, before heading to work again. When the EV gets connected to the EVSE in the public network of the CPO, the initial SoC of the battery is assumed to be 70%. The vehicle remains connected from 7:00 PM in the evening until 7:00 AM the following day. The EV is equipped with a 65 kWh battery, which is considered a standard average battery size available in EVs today, although the market offers a range from 30 to 110 kWh in energy capacity (Mojumder et al., 2022). The target SoC at the end of the charging session is 100%, achieved using an 11 kW Bi-directional DC charger with 95% efficiency. In the V2G charging process, during the battery discharge phase, energy must be injected back into the grid while ensuring grid stability. Therefore, a key assumption is that injection into the grid through V2G is consistently feasible.

To sum up this scenario, which serves as the baseline, an EV equipped with a 65 kWh battery arrives at 7 PM with a 70% State of Charge (SoC). It departs from the charging station at 7 AM the following morning, with the goal of reaching a 100% State of Charge (SoC). The model below explains the cost reduction process through V2G simulation model in the EPEX SPOT, resulting in the cost reduction of procured electricity in Euros per kilowatt-hour (€/kWh). Additionally, the corresponding cost calculation for Regular Charging in the same scenario is also incorporated into Table 4.2.

During V2G Charging

The charging time depends on four of these factors, battery size, current/starting charge level, and target charge level which are the SoC of the battery at arrival and targeted before departure from the charge point, and charging power of the charger(ThinkEV, 2023).

Additionally, charging time can be affected by the battery's efficiency, which, in turn, depends on factors like the type of charger (on-board or off-board), charging cable length, ambient temperature, battery's current state of charge (SoC), and the charging power. Higher charging power generates more heat, resulting in increased losses. Certainly, longer charging cables and elevated temperatures can reduce the efficiency of the charging process(go-e, 2023).

On-board chargers vary in efficiency, typically ranging from 75% to 95%, with some having lower efficiency due to the on-board conversion process from AC to DC (go-e, 2023). Among them, some of the 11 kW DC EV chargers are claimed to have 95% efficiency by EVSE OEMs (Rectifier Technologies, 2023), while others boast even higher peak efficiency, reaching up to 97.2% (Techtalk, 2021). However, for this study, an 11 kW Bi-directional DC charger is employed, assuming a 95% efficiency rate in both the charging and discharging processes.

Hence, the charging time can be calculated using the following Equation 1 (ThinkEV, 2023):

$$Charging\ Time\ (hr) = \frac{Battery\ Capacity\ (kWh) \times (Target\ SoC - Current\ SoC)\%}{Charge\ Power\ (kW)\ \times 0.95} \tag{1}$$

Under ideal conditions, assuming no losses and constant power, the rate of State of Charge (SoC) change during both the charging and discharging processes in Vehicle-to-Grid (V2G) operation can be assumed the same, where Charging Rate (kW) equals Discharging Rate (kW). This assumption has been applied in this study, particularly when using the same charger and/or inverter for both processes in V2G operation.

Taking into account all these factors and the previously mentioned assumptions, along with Equation 1 and the data specific to this scenario presented in Table 4.2, the rate of State of Charge (SoC) change per hour for a 65 kWh battery being charged with a 95% efficient 11 kW

V2G DC charger is calculated to be 16.07 SoC/hr. This results in an energy change of 10.45 kWh being charged or discharged per hour.

In the model, the price values for EPEX SPOT DAM electricity costs are arranged in ascending order, corresponding to the twelve-hour period blocks. This is done to aid in identifying the optimal hour blocks for charging, discharging, or taking no action, considering the prices and any State of Charge (SoC) constraints that may apply within the model.

The top half of the blocks with lower prices are recommended for charging at a reduced rate, while the lower half is suggested for discharging at a higher price. The green blocks indicate charging hours, while the red ones show the discharging hours within the session.

To accommodate user convenience, it is assumed that the EV owner may need to remove the vehicle from the charge point at any time before the expected departure time the following morning. In such cases, a certain minimum State of Charge (SoC) level is maintained in the EV battery to ensure the vehicle has at least 40% SoC at any given moment, allowing for unexpected trips. So the last row in the V2G charging model accounts for this 40% SoC limit during the discharge activity.

The Time Block parameter for each hour in the model can range from -1 to 1, with positive values representing charging, negative values indicating discharging, and 0 denoting no activity for that specific time block. The value assigned to each block initially depends on maintaining the minimum 40% State of Charge (SoC) limit. If there's room to discharge from a higher SoC compared to the lower limit, and the electricity price for that hour is favorable, then it takes on a negative value to discharge the EV. This process continues until the State of Charge (SoC) reaches 40% or until discharging energy back to the grid becomes profitable at a higher price. The aim is to take advantage of price disparities, ensuring that the energy can later be replenished into the EV at a lower price, resulting in a net profit.

The Time Block also governs the Energy and SoC/hr blocks, whose values are directly proportional to the Time Block value (-1 to 1). In this scenario, there's a maximum of 10.45 kWh energy change and a 16.07 SoC/hr rate of SoC change for a charging or discharging activity. The Cost block is updated based on the energy change multiplied by the corresponding electricity price in the EPEX DAM market for that specific hour.

Under V2G operation, the time needed to discharge and then recharge the same amount of energy back to the EV should be evenly distributed within the available net time frame, considering the actual charging period (in Regular Charging) from the total EVSE connected time. This ensures that there is always time available to recharge the energy back into the EV at a lower price, following the energy discharge at a higher price, all within the same session. This approach guarantees that the targeted State of Charge (SoC) is achieved by the end of the session while reducing costs.

During Regular Charging

In this scenario, the EV charges at its maximum power level immediately upon connection to the EVSE, regardless of the electricity price at that hour in the EPEX SPOT DAM. In essence, there is no scheduling or flexibility in the charging process; it's a straightforward process that continues until the EV is fully charged, and it remains connected to the charge point until unplugged. The cost of charging is calculated as the total energy consumed multiplied by the price for that specific hour. The charging calculation model for regular charging is presented in Table 3.1 below.

4.1.2 V2G Integration with EPEX Simulation Model

To comprehend the functionality of the V2G model compared to the Regular Charging, let's consider this specific scenario.

For instance, an EV equipped with a 65 kWh battery connects to an 11 kW Bi-directional DC charger at 7:00 PM in the evening with a 70% SoC. It remains connected until 7:00 AM the following day, aiming for a 100% SoC. In a typical charging scenario, it would take 1.9 hours to achieve a full charge, consuming 19.855 kWh of energy. With V2G capabilities, the net energy balance at the end of the session should remain the same. Therefore, apart from the 1.9 hours needed for regular charging, the surplus available time can be employed for V2G operations to reducing the overall charging cost for this session for the CPO. Ideally, these 1.9 hours should be tried to be utilized during the off-peak hours to charge at the lowest price available among all the hourly blocks in the session.

As the vehicle is connected to the EVSE during a peak hour with an SoC higher than the lower limit, it allows the EV to discharge until the lower limit for the next two Time Blocks, with -1 and -0.865 values for 19 and 20 hours in the evening, with reference to the ascending order of EPEX pricing. However, it limits the SoC to 40% during discharging in the second Time Block. Following these Time Blocks, the subsequent ones have higher prices but no SoC left to discharge. Consequently, the EV remains idle without any activity until a suitable Time Block for charging becomes available.

Given that the EV initially required 1.9 hours of charge time to reach the targeted SoC and now an additional 1.865 hours (-1 and -0.865) are required to replenish the discharged energy back to the EV, totaling 3.765 hours of total charge time. The charging should be done with four Time Blocks, with 1 assigned to three blocks and 0.765 to one block, again with reference to the ascending order of EPEX pricing to use the lower-priced blocks. This ensures that by the end of the session, the EV is fully charged to the targeted SoC at the lowest cost possible for the CPO.

In the model, it's evident that the net energy used for charging the EV in both Regular and V2G charging scenarios is the same. However, the cost of electricity is significantly reduced in the V2G charging session, reducing it to 0.0003 €/kWh compared to 0.167 €/kWh in regular charging. This showcases the cost savings achieved through V2G charging for the CPO. The key difference lies in how the intervening time is utilized for arbitraging energy at the EPEX SPOT DAM market.

The results obtained from this base case charging session scenario for both types of charging technology will serve as inputs in the developed model used to assess the profitability of the CPO in the Public Charging Network business case in Session 4.2.

EV Data: 65 kWh Battery, SoC at arrival 70% Available Time: 7 PM to 7 AM	Initial to Target SoC: 70% to 100% 11 kW EVSE, 95% efficiency Time[5]: 1.9 hrs

Time	Price[1] (€/kWh)
4	0.079
2	0.084
3	0.084
1	0.086
24	0.089
5	0.092
23	0.096
22	0.108
6	0.115
21	0.122
20	0.154
19	0.179

V2G Charging					SoC	
Time	Price €/kWh	Time Block	Energy (kWh)	Cost (€)	SoC/Hr	70
19	0.179	-1.000	-10.45	-1.873	-16.07	53.93
20	0.154	-0.865	-9.039	-1.394	-13.9	40.029
21	0.122		0	0	0	40.029
22	0.108		0	0	0	40.029
23	0.096		0	0	0	40.029
24	0.089		0	0	0	40.029
1	0.086	0.765	7.9943	0.6837	12.294	52.323
2	0.084	1.000	10.45	0.8789	16.07	68.393
3	0.084	1.000	10.45	0.8798	16.07	84.463
4	0.079	1.000	10.45	0.8305	16.07	100.53
5	0.092		0	0	0	100.53
6	0.115		0	0	0	100.53
		Total[4]	19.855	0.0055	Cost/[2] kWh	0.0003
		Selling Price[3]		6.9493		

Regular Charging				
Time	Price €/kWh	Time Block	Energy (kWh)	Cost (€)
19	0.179	1.000	10.45	1.8728
20	0.154	0.900	9.405	1.4509
21	0.122		0	0
22	0.108		0	0
23	0.096		0	0
24	0.089		0	0
1	0.086		0	0
2	0.084		0	0
3	0.084		0	0
4	0.079		0	0
5	0.092		0	0
6	0.115		0	0
Cost/[2] kWh	0.1674	Total[4]	19.855	3.3238
		Selling Price[3]		6.9493

1. Ascending order of Price in DAM
2. Cost per kWh to CPO
3. Total selling price to Customer
4. Total Net Energy & Cost per session
5. Charging time from initial to target SoC

Table 4.2 Simulation Model for a Charging Session with V2G in the EPEX DAM & Corresponding Regular Charging Session

The cost reduction through V2G simulation model for a single charging session was conducted under specific conditions. In reality, there will be a multitude of scenarios with EVs connecting to the charging point at varying evening times, different initial State of Charge (SoC) levels, diverse battery capacities, and other factors like fluctuating charging power, the potential for injecting energy back into the grid, and load management considerations. To gain a more comprehensive understanding of V2G operation, cost reduction was performed for several additional scenarios with similar assumptions, grouped into two categories: one with consistent battery sizes but varying initial SoC levels and arrival times, and the other with consistent initial SoC levels and arrival times but different battery capacities. These scenarios offer insights into the influence of various parameters on V2G dynamics. Detailed descriptions of the scenarios from both categories can be found below, while the complete cost reduction simulation models with the end results for all other scenarios are available in the Appendix below. The results obtained from certain scenarios will be utilized as inputs in the CPO's Business Model for V2G profitability analysis, particularly during the sensitivity analysis conducted in Section 5.4.

Four Different Charging Scenarios with the Same Battery Capacities:

1. S 1, 65 kWh-7 PM-70% SoC: Scenario 1, which serves as the base case, involves an office worker with a 65 kWh EV battery. After completing some grocery shopping, the driver returns home with a 70% State of Charge (SoC) and connects the EV to the EVSE

at 7 PM. It's important to note that the EV had a full charge (100% SoC) when the driver left the office. The EV remains connected to the charging station until 7 AM the following morning.

2. S 2, 65 kWh-9 PM-50% SoC: Scenario 2 is essentially an extension of Scenario 1. In this case, the driver not only completes grocery shopping but also goes out for dinner. Consequently, the EV returns home at 9 PM with a lower State of Charge (SoC) of 50% when it's connected to the charging point.
3. S 3, 65 kWh-6 PM-85% SoC: Scenario 3 features a situation where the EV driver works relatively close to their home. Consequently, they are able to return home with a higher State of Charge (SoC) of 85% at 6 PM before connecting their EV to the home charging point.
4. S 4, 65 kWh-7 PM-30% SoC: In Scenario 4, the EV was not fully charged before departing from the office, leading to its arrival home at 7 PM with a significantly lower State of Charge (SoC) of 30%. This SoC falls below the threshold required for V2G operation..

Three Different Battery Capacities, with the Same SoC and Arrival Time:

In this category, the EV drivers arrive home at 7 PM with a 70% State of Charge (SoC) and connect their EVs to the charging station, maintaining the connection until the following morning at 7 AM. There are three scenarios within this category, each involving EVs with different battery capacities: 50 kWh, 65 kWh, and 100 kWh.

4.1.3 Battery Degradation

Battery degradation is a critical aspect of integrating Vehicle-to-Grid (V2G) technology into the operations of Charging Point Operators (CPOs). It directly impacts the lifespan and performance of the electric vehicle (EV) batteries that serve as the core energy storage units for V2G transactions. In this section, the complexities of battery degradation is explored, its implications for V2G integration, and how it should be thoughtfully factored into the CPO's business model, including customer compensation considerations where relevant.

Battery degradation is a natural process that occurs over time as a result of charge and discharge cycles. In the context of V2G, where EV batteries are frequently used to provide grid services, degradation can occur more rapidly compared to regular EV use. Factors such as depth of discharge, charging patterns, and temperature fluctuations play pivotal roles in determining the rate of degradation. It's crucial to acknowledge that battery degradation is an inevitable reality, and its management is central to sustaining V2G operations (Virta Global, 2023).

CPOs must approach battery degradation with a strategic perspective when integrating V2G into their business models. Firstly, an in-depth understanding of battery health is essential. Continuous monitoring and data analytics can provide insights into battery conditions, enabling proactive maintenance and replacement strategies. Incorporating this knowledge into the business model ensures optimal battery usage and longevity.

When contemplating customer compensation in the context of battery degradation, transparency, and fairness are paramount. CPOs should consider implementing clear policies regarding battery wear and tear due to V2G use. This may include offering compensation or incentives to EV owners for participating in V2G services while acknowledging that battery degradation is an inherent aspect of such services. Fair compensation models should be designed, taking into account factors such as the frequency and intensity of V2G usage. In this research, the base case scenario assumes a 10% discount on the charging fees for the V2G charging business model. This discount accounts for any potential battery degradation resulting from V2G operation, thereby ensuring a positive business outlook for the CPO.

4.2 CPO Business Model Profitability Analysis

In this section, the focus shifts towards evaluating the profitability within the Vehicle-to-Grid (V2G) business model for the CPO, particularly its interaction with the European Power Exchange Day-Ahead Market (EPEX DAM) while answering the third sub-research question. The financial intricacies are explored comprehensively to establish a profitability evaluation for V2G integration. Moreover, a comparative analysis is conducted, placing the V2G business model alongside conventional charging practices, thus shedding light on the financial landscape. Additionally, recommendations for enhancing the Charging Point Operator (CPO) business model within the V2G framework are presented, providing valuable insights for optimizing operations and profitability within the Dutch public charging network.

4.2.1 Business Case Model Formulization

To develop the financial business model conceptually for a Charging Point Operator (CPO) with Vehicle-to-Grid (V2G) integration, it's crucial to consider various cost components and revenue streams. The cost components comprise infrastructure investment, maintenance, electricity procurement, and operational expenses. Revenue streams include income from charging services, advertisement, and potential participation in energy markets through V2G. By comprehensively analyzing these elements, the profitability analysis aims to provide a holistic understanding of the financial dynamics, enabling strategic decision-making for an optimized and sustainable CPO business model within the V2G context.

The financial business model used for profitability analysis in the public charging network is quite similar for both Regular Charging and V2G Charging, with only a few additional cost and revenue components for V2G Charging. In this sub-section, the outline of all the components under cost and revenue used in the financial model for both types of charging will be presented, the difference in the components specific to the Charging technologies can be found in the Business Model conceptualization.

The values, figures, or any multiplication factors used in the model were sourced from past literature, governmental agencies' websites, journals, and analyses related to EVs from reliable sources like Statista, rvo.nl, reports by EVSE OEMs, and CPOs, among others. Additionally, a consultation was conducted with an expert from the Business Development Team at TotalEnergies, and a discussion was held with an expert from the Technical Service Team at a leading EVSE OEM. These consultations aimed to validate and acquire as realistic data as possible for use as input parameters in the model to ensure the output reflects real-world scenarios accurately.

The model is built upon several key assumptions that form the foundation of its calculations. These assumptions include a five-year evaluation period, with capital investment occurring in the first year, and constant costs and revenues every year, over the entire five-year period. While the typical lifecycle of an EVSE is considered to be 10 years after installation and initial use (Goncearuc et al., 2023), this is not factored into the model, which is designed for a five-year operational period.

Additionally, as mentioned in the previously, the assumption is made that the CPO procures 40% of the required electricity from the EPEX DAM, with the remaining electricity procured in bulk well in advance of delivery. The specific values for the cost of electricity procured from the EPEX DAM are derived from the base case scenario calculated for charging sessions in both regular and V2G charging, as outlined in the previous Section 4.1. These assumptions are essential for the model's calculations and provide a basis for its financial evaluations.

Let’s delve into the costs and revenue components of the Model:

The generalized can be defined as follows (Equation 2 & 3)

$$Total\ Costs\ = \quad Non-Recurring\ Costs + Recurring\ Costs \tag{2}$$

$$Total\ Benefits\ = \quad Total\ Revenues\ +\ Other\ Benefits \tag{3}$$

1. General Terms

Number of EVSE:

The total count of EVSE hardware installed in the CPO's public charging network. Denoted by N_y.

Charging Usage rate:

The charging usage rate represents the annual energy delivered by each EVSE for charging purposes. Various studies have estimated this rate differently, with some assuming it to be around 5-7% of the maximum yearly charging capacity (e.g., 8760 hours * 11 kW = 96,360 kWh), while others have calculated it based on factors like population density and city size, resulting in values ranging from 5,000 to 10,000 kWh per charge point annually (evdata, 2023; Goncearuc et al., 2023; Rivera et al., 2014).

In the base case scenario, a charging usage rate of 5,000 kWh per charge point annually is assumed. However, values both higher and lower than this are explored in the sensitivity analysis in Section 5.4.

2. Non-recurring Costs

EVSE Cost:

EVSE cost refers to the expense associated with Electric Vehicle Supply Equipment, which includes the purchase and commissioning of charging stations for electric vehicles. These costs can vary based on factors such as the type of EVSE (level 1, level 2, or DC fast charger), location, and infrastructure requirements.

In this study, an 11 kW Bi-directional DC charger is considered for V2G operation. The cost typically varies depending on the location, brand of the EVSE, and power rating. The current cost of this EVSE is assumed to be €5000, based on (Goncearuc et al., 2023). However, for the base case scenario in the profitability evaluation, the cost is assumed to be €4000, which is derived as a break-even cost for this charger. In the same study, it is also anticipated that the cost could potentially decrease to €3500 or even less in the future as this technology becomes more widespread in the market. Different costs of EVSE assumed for different time periods can be seen in the Table 4.3. Other costs for EVSE are explored in the sensitivity analysis in Section 5.4.

For regular charging, the cost of an EVSE with the same power rating but unidirectional is assumed to be €3500.

11kW DC V2G Charger € in actual figures	
X = a,b,c	
a: DC (Present)	5000
b: DC (Break-Even)	4000
c: DC (Estimated)	3500

Table 4.3 Costs of 11 kW Bi-Directional DC Charger

Hardware cost:

This represents the aggregate cost of installing all the EVSE units within the public charging network. It's calculated by multiplying the cost of a single EVSE unit by the total number of units required.

Hardware Cost = N_y x EVSE Cost(€)

Installation Cost:

The installation cost covers the hardware setup at the site, insulation, protection against environmental conditions, potential foundation work, and all necessary measures to ensure the functionality of the EVSE. The cost is assumed to be consistent for both types of charging technology.

Installation Cost = €1000 x $N_{Y,}$ (Goncearuc et al., 2023)

Marketplace Cost:

These are expenses related to accessing the common, interoperable marketplace within the EV charging business ecosystem. This marketplace serves as a platform for transactions between the CPO and various entities, including the grid operator and energy service providers. The cost is assumed to be consistent for both types of charging technology.

Marketplace Cost = €15000, (Goncearuc et al., 2023)

Miscellaneous costs:

Miscellaneous costs incurred by a CPO depend on factors such as the network's scale, geographic locations, business strategies, and operational needs. These costs can encompass a wide range of expenses, including permitting and regulatory compliance, marketing and promotion, legal and compliance fees, and more. The cost is assumed to be consistent for both types of charging technology.

Miscellaneous costs = €100000, (Goncearuc et al., 2023)

3. Recurring Costs

Electricity Cost:

The procurement costs for electricity depend on both the quantity of electricity procured and the purchase price. Given the expected fluctuations in purchase prices, especially with the increasing demand for sustainable energy, this model accounts for an average purchase price. Currently, the average purchase price for the baseload electricity, constituting 60% of the total energy requirements, is assumed to be €0.07 (ECORYS, 2020). The cost is assumed to be consistent for both types of charging technology.

Electricity Baseload Cost = 0.6 x N_Y x Usage rate(kWh/CP/Year) x €0.07/kWh

The remaining 40% of peakload electricity is assumed to be procured from the EPEX SPOT DAM to fulfill the demand on the actual day of delivery. The specific values are derived from the V2G simulation model outlined in the previous Section 4.1.

Electricity Peakload Cost = 0.4 x N_Y x Usage rate(kWh/CP/Year) x EPEX DAM Price (€/kWh)

Management and Maintenance Cost:

Management and maintenance costs in a public charging network for electric vehicles encompass a range of expenses, including those related to personnel, routine upkeep, emergency repairs, utilities, software maintenance, compliance, and inspections. These costs are vital for ensuring the smooth operation and reliability of the network.

Maintenance costs = N_y x Maintenance costs/CP/Year

The assumed maintenance cost for Regular Charging is €100 annually, whereas for V2G, it's slightly higher at €150 per charge point. This increase in cost is due to the complex hardware required to handle the bi-directional flow of energy.

Grid Fees:

Grid fees are charges levied on entities, such as Charge Point Operators, for accessing and utilizing the electric power grid. These fees cover various expenses related to connecting facilities, ensuring capacity, and maintaining grid infrastructure. They play a crucial role in ensuring grid reliability and upkeep. The assumed cost for this is €175 per charger point annually, for both types of charging technology.

Grid Fees Cost = N_y x €175

HR Cost:

The Human Resources cost, associated with managing an organization's workforce, is assumed to be €1000 per charge point per annum for both types of charging technology.

HR Cost = N_y x €1000

Software cost:

The cost associated with developing and maintaining the software tool for V2G charging operation, which includes data exchange with the charge point and energy scheduling based on EPEX DAM pricing simulation tool, is assumed to be €90 per charge point annually for V2G charging. However, for regular charging, no such cost is considered as there is no load management or scheduling involved in conventional charging.

Software Cost = N_y x €90

4. Benefits/Revenue

Charging Fees:

Charging fees represent the charges imposed on EV owners for utilizing the charging infrastructure. The revenue generated from these fees depends on factors such as the pricing structure, utilization rates, and the total number of charging sessions conducted by users. Typically, CPOs charge users a fixed rate per kWh of energy consumed. In this study, it is assumed that the price charged to users is €0.35 per kWh, which aligns with the prevailing market trend (ECORYS, 2020; Goncearuc et al., 2023; Shellrecharge, 2023). Different pricing scenarios are examined in the sensitivity analysis outlined in Section 5.4. The fees are assumed to be the same for both types of charging technology.

Charging Fees revenue = €0.35 x N_y x Usage Rate(kWh/CP/Year)

Transaction Fees:

Transaction or Session fees refer to supplementary charges applied to users for each individual charging session. The precise fees can fluctuate based on the particular charging scenario, including whether it involves regular charging or V2G charging. It's a set fee that CPOs typically impose on users for each session, and in this model, it's assumed to be €0.35 per session (Shellrecharge, 2023). Additionally, it's assumed that 60% of non-premium members are required to pay this fee for their sessions. The assumed number of sessions per day for each charge point is 1.5 (Rivera et al., 2014). All of these assumptions are the same for both charge technologies models.

Transaction Fees Revenue = 0.6 x N_y x Session/CP/Day x 365 Days x €0.35

Premium Memberships:

Users have the option to subscribe to a premium membership with the CPO, which offers benefits like waived transaction fees for all sessions, priority charging, and enhanced usage data insights. The premium membership is assumed to cost €8 per month (Fastned, 2023), and 40% of the users are assumed to have this membership to access these advantages. The assumed number of users utilizing a specific charge point is 15 per year (evdata, 2023; Rivera et al., 2014). All of these assumptions are the same for both charge technologies models.

Premium Memberships Revenue = 0.4 x N_y x User/CP/Year x €8 x 12 Months

Advertisement Revenue:

This represents the income generated from selling advertising space on the EVSE infrastructure. Advertisers pay the CPO to display ads on charging stations, often considering factors like location and visibility. The advertising revenue is considered a potential income source for a CPO from a single charge point, annually. The actual revenue can vary based on factors such as location, target audience, and advertising strategies. For this model, an annual advertising revenue of €1000 per charge point is assumed.

Advertisement Revenue = N_y x €1000

Customer Compensation:

Customer benefit in this context represents a cost to the CPO or a negative benefit, as it entails compensating users for allowing their battery assets to participate in the V2G process. This compensation serves as a recognition of users' contribution to the CPO's ability to reduce the variable cost of electricity procured from the EPEX DAM. Additionally, it acknowledges potential battery degradation or lifespan impacts resulting from V2G operations.

This aspect can also be viewed as an intangible benefit for the CPO, as it may lead to increased usage rates and the addition of more users to their network by offering compensation, thus fostering sustainability. In this model, we assume the CPO will provide a 10% discount on user charging fees as compensation, while no compensation is offered for regular charging.

4.2.2 Cost-Benefit Analysis Simulation Model

Business Case Model for Regular Charging

The cost and revenue assumptions for the profitability analysis of the Business Case model in the context of regular or conventional charging methods are summarized in Table 4.4 and Table 4.5 below. The model utilizes these assumptions along with the formulas outlined earlier to calculate each of the cost and revenue components. Table 4.6 and Table 4.7 present the detailed breakdown of costs and revenue components in the Business Case model, respectively, that is used to evaluate the profitability by calculating NPV for five years of operation with regular charging for the CPO.

Cost Assumptions € in actual figures			
No of EVSE (N_y)	2000	Electricity Peakload (40%)	0.164
EVSE Cost (P_x)	3500	Electricity Baseload (60%)	0.07
Installation Cost (I_y)	1000	Maintenance costs/CP/Year	100
HR Cost (C_{HR})	1000	Grid Fees/CP/Year	175
kWh/Year/CP	5000	Software Tool/CP/Year	0

Table 4.4 Cost Assumptions for Regular Charging

Revenue Assumptions € in actual figures	
Charging Fees/kWh	0.35
Transaction Fees/Session (60% Users)	0.35
Premium Membership/month (40% Users)	8
Advertisements/CP/Year	1000
User/CP/Year	15
Session/CP/Day	1.5
Premium Members - No transaction Fees	

Table 4.5 Revenue Assumptions for Regular Charging

QUANTITATIVE COSTS **€ in actual figures**	**2023E**	**2024E**	**2025E**	**2026E**	**2027E**	**Total**
Non-Recurring Costs						
No of EVSE (N_y)	**2000**	**2000**	**2000**	**2000**	**2000**	**2000**
Hardware						
Total EVSE Cost ($P_y = P_x * N_y$)	7000000	0	0	0	0	7000000
Installation Cost (I_y)	2000000	0	0	0	0	2000000
Facilities						
Marketplace Cost	15000					15000
Other						
Miscellaneous Cost	100000	0	0	0	0	100000
Total Non-Recurring Costs	9115000	0	0	0	0	9115000
Recurring Costs						
Electricity						
Electricity Baseload (60%)	420000	420000	420000	420000	420000	2100000
Electricity Peakload (40%) in DAM	656000	656000	656000	656000	656000	3280000
Hardware/Software						
Management and Maintenance costs	200000	200000	200000	200000	200000	1000000
Grid Fees	350000	350000	350000	350000	350000	1750000
Labour						
HR Cost	2000000	2000000	2000000	2000000	2000000	10000000
Software (packaged or custom)						
Optimization Tool	0	0	0	0	0	0
Total Recurring Costs	3626000	3626000	3626000	3626000	3626000	18130000
Total Costs	12741000	3626000	3626000	3626000	3626000	27245000

Table 4.6 Cost Components of Regular Charging Business Model

QUANTITATIVE BENEFITS **€ in actual figures**	**2023E**	**2024E**	**2025E**	**2026E**	**2027E**	**Total**
Revenue Streams						
Revenues						
Charging Fees	3500000	3500000	3500000	3500000	3500000	17500000
Transaction Fees	229950	229950	229950	229950	229950	1149750
Premium Memberships	1152000	1152000	1152000	1152000	1152000	5760000
Advertisements	2000000	2000000	2000000	2000000	2000000	10000000
Total Revenues	6881950	6881950	6881950	6881950	6881950	34409750
Other Benefits						
Customer Compensation if any (-ve benefit)	0	0	0	0	0	0
Total Other Benefits	0	0	0	0	0	0
Total Benefits	6881950	6881950	6881950	6881950	6881950	34409750

Table 4.7 Revenue Components of Regular Charging Business Model

Business Case Model for V2G Charging

The cost and revenue assumptions for the profitability analysis of the Business Case model in the context of V2G charging are summarized in Table 4.8 and Table 4.9 below. The model utilizes these assumptions along with the formulas outlined earlier to calculate each of the cost and revenue components. Table 4.10 and Table 4.11 present the detailed breakdown of costs and revenue components in the Business Case model, respectively, that is used to evaluate the profitability by calculating NPV for five years of operation with V2G charging for the CPO.

Cost Assumptions € in actual figures			
No of EVSE (N_y)	2000	Electricity Peakload (40%)	0.000279
EVSE Cost (P_x)	4000	Electricity Baseload (60%)	0.07
Installation Cost (I_y)	1000	Maintenance costs/CP/Year	150
HR Cost (C_{HR})	1000	Grid Fees/CP/Year	175
kWh/Year/CP	5000	Software Tool/CP/Year	90

Table 4.8 Cost Assumptions for V2G Charging

Revenue Assumptions € in actual figures	
Charging Fees/kWh	0.35
Transaction Fees/Session (60% Users)	0.35
Premium Membership/Month (40% Users)	8
Advertisements/CP/Year	1000
User/CP/Year	15
Session/CP/Day	1.5
Customer Compensation (Discount)	10%
Premium Members - No transaction Fees	

Table 4.9 Revenue Assumptions for V2Gharging

QUANTITATIVE COSTS € in actual figures	2023E	2024E	2025E	2026E	2027E	Total
Non-Recurring Costs						
No of EVSE (N_y)	2000	2000	2000	2000	2000	2000
Hardware						
Total EVSE Cost ($P_y = P_x * N_y$)	8000000	0	0	0	0	8000000
Installation Cost (I_y)	2000000	0	0	0	0	2000000
Facilities						
Marketplace Cost	15000					15000
Other						
Miscellaneous Cost	100000	0	0	0	0	100000
Total Non-Recurring Costs	10115000	0	0	0	0	10115000
Recurring Costs						
Electricity						
Electricity Baseload (60%)	420000	420000	420000	420000	420000	2100000
Electricity Peakload (40%) in DAM	1116	1116	1116	1116	1116	5580
Hardware/Software						
Management and Maintenance costs	300000	300000	300000	300000	300000	1500000
Grid Fees	350000	350000	350000	350000	350000	1750000
Labour						
HR Cost	2000000	2000000	2000000	2000000	2000000	10000000
Software (packaged or custom)						
Optimization Tool	180000	180000	180000	180000	180000	900000
Total Recurring Costs	3251116	3251116	3251116	3251116	3251116	16255580
Total Costs	13366116	3251116	3251116	3251116	3251116	26370580

Table 4.10 Cost Components of V2G Charging Business Model

QUANTITATIVE BENEFITS € in actual figures	2023E	2024E	2025E	2026E	2027E	Total
Revenue Streams						
Revenues						
Charging Fees	3500000	3500000	3500000	3500000	3500000	17500000
Transaction Fees	229950	229950	229950	229950	229950	1149750
Premium Memberships	1152000	1152000	1152000	1152000	1152000	5760000
Advertisements	2000000	2000000	2000000	2000000	2000000	10000000
Total Revenues	6881950	6881950	6881950	6881950	6881950	34409750
Other Benefits						
Customer Compensation if any (-ve benefit)	350000	350000	350000	350000	350000	1750000
Total Other Benefits	350000	350000	350000	350000	350000	1750000
Total Benefits	6531950	6531950	6531950	6531950	6531950	32659750

Table 4.11 Revenue Components of V2G Charging Business Model

5 Result

In this chapter, the actual findings from the research come to light. The study focuses into how Vehicle-to-Grid (V2G) technology might be revolutionary change for a Charging Point Operator's Business Case in the Public Charging Network in the Netherlands. This chapter reveals the facts and insights uncovered throughout the research. It presents a clear picture of the discoveries, answers the research questions, and emphasizes the practical significance of CPOs and the realm of electric mobility. This section provides essential data and insights that can aid in making well-informed decisions regarding sustainable electric mobility..

This chapter begins by examining the findings related to the current business model employed by Charge Point Operators (CPOs) within the public charging network in the Netherlands, addressing the first sub-research question. It then proceeds to evaluate the feasibility of integrating Vehicle-to-Grid (V2G) technology to enhance CPO operations, with a focus on reducing electricity costs in the EPEX SPOT DAM, thereby addressing the second sub-research question.

Furthermore, the chapter combines insights from these two investigations to formulate recommendations for modifying the business model, enabling the successful integration of V2G to reduce variable costs, particularly in the context of electricity procurement from the EPEX SPOT DAM, followed by profitability evaluation of the business model, thus, addressing the third sub-research question. Lastly, a sensitivity analysis is conducted to assess the responsiveness of various parameters and variables within the CPO's business model in the Dutch public charging network. Combinedly, will help to answer the main research question of this study.

5.1 CPOs Current Business Model

TotalEnergies serves as an example for understanding various elements in a business case that involve different charging technologies. This understanding spans from Regular Charging to a few pilot projects in Smart Charging and extends to Vehicle-to-Grid. To gather insights, the research involved consultation and engaged discussions with experts from TotalEnergies' Business Development Team, along with insights drawn from existing literature. These findings are compiled and briefed in Section 3.1 of the Conceptual Framework chapter, providing a deeper comprehension of the diverse factors that significantly shape the business model of a Charge Point Operator (CPO). These dynamics play a crucial role in a CPO's business model and influence both the costs and revenue structures within the business depending on the implemented charging technology.

In the research analysis using TotalEnergies as an example of a Charge Point Operator (CPO), it was evident that beyond the conventional practice of Normal Charging, other charging solutions such as Smart Charging and Vehicle-to-Grid offer opportunities for CPOs to maximize the utility of their assets, including EVSE and charging hardware, for their own business benefits. The study's findings indeed point to an opportunity for improving the business model of Charge Point Operators (CPOs) in the Dutch public charging network by conceptually adopting an advanced charging solution, Vehicle-to-Grid (V2G). Several aspects of the business case are believed to have the potential for improvement through V2G when compared to other charging solutions. These include the creation of additional revenue streams through various ancillary services such as FCR, grid balancing, and frequency regulations, as well as cost reduction in electricity procurement and support for load management or temporary energy storage using EV batteries to name some of the potential improvements in the business case.

However, this study particularly focuses on the results of an extensive examination of the potential for reducing electricity procurement costs for the peakload blocks or arbitraging electricity in the EPEX SPOT DAM, which can be found in Section 5.2. It explores how CPOs can harness the bidirectional capabilities of V2G charging technology to enhance profitability in their business by reducing the cost of procured electricity.

Nonetheless, CPOs must exercise caution and consider the dynamic factors that impact both costs and revenue streams. They might have to carefully weigh the advantages and disadvantages of integrating this technology into their business model. Further details regarding these quantitative findings of reduced EPEX SPOT DAM price through V2G followed by Developed Business Model integrated with V2G and their evaluations are discussed in-depth within this chapter, which might help the CPOs in their decision-making process.

5.2 EPEX DAM Integrated through V2G

In this section, the results of electricity procurement cost for the peakload blocks in the EPEX SPOT DAM using simulated charging/discharging via V2G are presented, which can be later analyzed in the next Section 5.3 by developing a business model for a CPO to check if it is profitable enough as compared to the Normal Charging. As previously mentioned in Section 4.1, V2G cost reduction simulation was conducted for four different scenarios involving EVs with identical battery sizes. However, these EVs arrived at the charging point at various times in the evening, each with a different State of Charge (SoC) for their batteries. Additionally, they remained connected until the following morning, departing at 7 AM with the aim of achieving a 100% SoC at the end of the session.

Subsequently, the electricity costs for each of these scenarios are calculated, both for V2G; by simulating the charging/discharging of the individual EV charging session, and Regular Charging; charging the EV at full capacity as soon as the EV gets connected to the charge point, and remains idle until the EV is disconnected. This allowed in approximating the cost per kWh in both cases and provided a rough estimate of the change in the cost of procured energy per kWh when utilizing V2G in comparison to Regular Charging in each scenario.

Below in Table 5.1, a detailed cost calculation model for reduced electricity expenses using V2G for a specific charging scenario can be found, and the comprehensive explanation of this model can be referred to in Section 4.1. In this scenario, an EV with a 65 kWh battery arrives at 7 PM with a 70% State of Charge (SoC) and departs the charging station at 7 AM the following morning, with a target State of Charge (SoC) of 100%. The corresponding cost calculation for Regular Charging in the same scenario is also included in the table. The green blocks indicate the charging blocks and the red ones show the discharging blocks, in the V2G charging scenario.

EV Data: 65 kWh Battery, SoC at arrival 70% Available Time: 7 PM to 7 AM	Initial to Target SoC: 70% to 100% 11 kW EVSE, 95% efficiency Time[5]: 1.9 hrs

Time	Price[1] (€/kWh)
4	0.079
2	0.084
3	0.084
1	0.086
24	0.089
5	0.092
23	0.096
22	0.108
6	0.115
21	0.122
20	0.154
19	0.179

1. Ascending order of Price in DAM
2. Cost per kWh to CPO
3. Total selling price to Customer
4. Total Net Energy & Cost per session
5. Charging time from initial to target SoC

V2G Charging					SoC	
Time	Price €/kWh	Time Block	Energy (kWh)	Cost (€)	SoC/Hr	70
19	0.179	-1.000	-10.45	-1.873	-16.07	53.93
20	0.154	-0.865	-9.039	-1.394	-13.9	40.029
21	0.122		0	0	0	40.029
22	0.108		0	0	0	40.029
23	0.096		0	0	0	40.029
24	0.089		0	0	0	40.029
1	0.086	0.765	7.9943	0.6837	12.294	52.323
2	0.084	1.000	10.45	0.8789	16.07	68.393
3	0.084	1.000	10.45	0.8798	16.07	84.463
4	0.079	1.000	10.45	0.8305	16.07	100.53
5	0.092		0	0	0	100.53
6	0.115		0	0	0	100.53
		Total[4]	19.855	0.0055	Cost/[2] kWh	0.0003
		Selling Price[3]		6.9493		

Regular Charging				
Time	Price €/kWh	Time Block	Energy (kWh)	Cost (€)
19	0.179	1.000	10.45	1.8728
20	0.154	0.900	9.405	1.4509
21	0.122		0	0
22	0.108		0	0
23	0.096		0	0
24	0.089		0	0
1	0.086		0	0
2	0.084		0	0
3	0.084		0	0
4	0.079		0	0
5	0.092		0	0
6	0.115		0	0
Cost/[2] kWh	0.1674	Total[4]	19.855	3.3238
		Selling Price[3]		6.9493

Table 5.1 V2G & Regular Charging Cost Calculation in the EPEX DAM

for S1: 65 kWh - 7 PM - 70% SoC (Base Scenario)

It's important to emphasize that the Scenario 1, with a 65 kWh battery arriving at 7 PM with 70 % SoC serves as the baseline scenario for the charging cost calculation, and the results from this scenario will be used for further profitability evaluation in the business model for Charge Point Operators (CPOs) in both charging technologies in Section 5.3. For all other scenarios, the calculation model and methodology remain consistent for both V2G and Regular Charging, and the detailed calculated results can be found in the Appendix below.

Table 5.2 below provides an overview of the cost of electricity per kWh procured from the EPEX SPOT DAM for V2G and Regular Charging across four different scenarios with different SoCs with different arrival times, and each EV equipped with a 65 kWh battery, concluding their charging sessions at 7 AM the following morning. After enhancing the charging sessions for all four scenarios, it becomes evident that V2G results in a substantial cost reduction when compared to Regular Charging in each case. This reduction can significantly assist CPOs in lowering their electricity procurement expenses from the EPEX DAM for the peakload blocks, consequently reducing the variable costs in the cost structure.

Scenario	Time	SoC	Regular Charging (€/kWh)	V2G (€/kWh)
S1	7:00 PM	70%	0.1674	0.0003
S2	9:00 PM	50%	0.1504	0.0750
S3	6:00 PM	85%	0.1290	-0.1430
S4	7:00 PM	30%	0.1367	0.0838

Table 5.2 EPEX DAM Cost, for 65 kWh Battery, with Different SoC & Arrival Time

Next, another evaluation assessed the cost of electricity using the same methodology. This evaluation involved different battery sizes, but the arrival and departure times were kept the same, i.e. arriving at 7 PM in the evening until 7 AM the next day morning, along with the same State of Charge (SoC) of 70 % at arrival. The results of this evaluation can be found in Table 5.3 below, clearly demonstrating a substantial reduction in the cost of procured energy from the EPEX DAM through V2G compared to Regular Charging, regardless of the EVs' battery sizes.

Battery Size (kWh)	Regular Charging (€/kWh)	V2G (€/kWh)
50	0.1721	-0.0050
65	0.1674	0.0003
100	0.1528	0.0197

Table 5.3 EPEX DAM Cost, for 70 % SoC & 7 PM Arrival, With Different Battery Sizes

These evaluations, one with the same battery size but different arrival conditions and another with different battery sizes but consistent arrival conditions, yielded a noteworthy finding illustrated in the graphs below in Figure 4.1 and Figure 4.2. The data clearly shows that when an EV connects to the charger early in the evening with a higher initial charge (SoC), there's a higher frequency of charging and discharging events through V2G, with the same battery size. A higher SoC enables the EV to have more room for such events, but crucially depending on the connection of the vehicle based on peak or off-peak hours.

This pattern is also observed with larger batteries compared to smaller ones when connected at the same time and with the same initial SoC scenario. However, it's crucial to highlight that this charging and discharging pattern is only noticeable if EVs are connected during peak hours with a certain SoC, ideally above 40% of the battery capacity, which is the lower threshold for V2G operations. In such cases, the energy discharged during peak hours is replenished during off-peak periods within the session. With larger batteries, which have a slower rate of SoC change per hour compared to smaller batteries, this charging/discharging pattern becomes more pronounced in scenarios with the same initial SoC and arrival time.

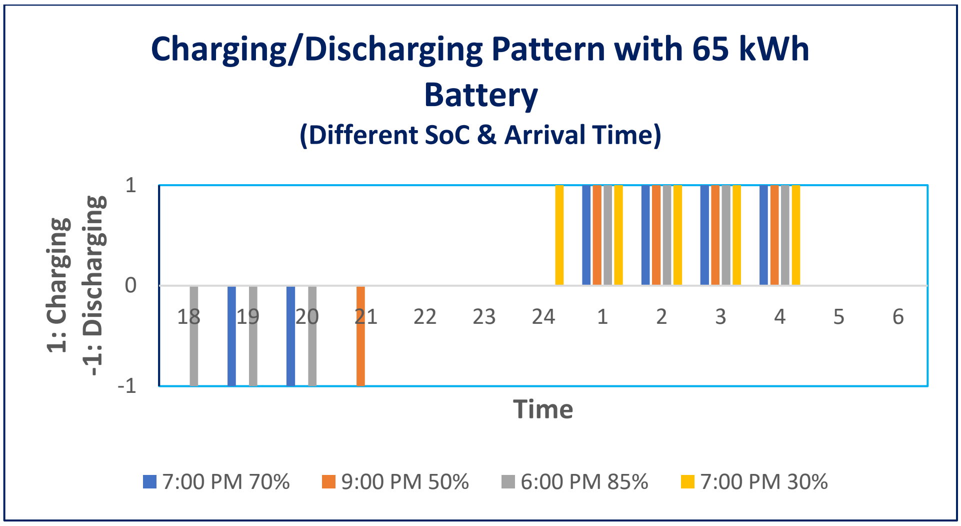


Figure 5.1 Charging/Discharging Pattern, with 65 kWh Battery, Different SoC & Arrival Time

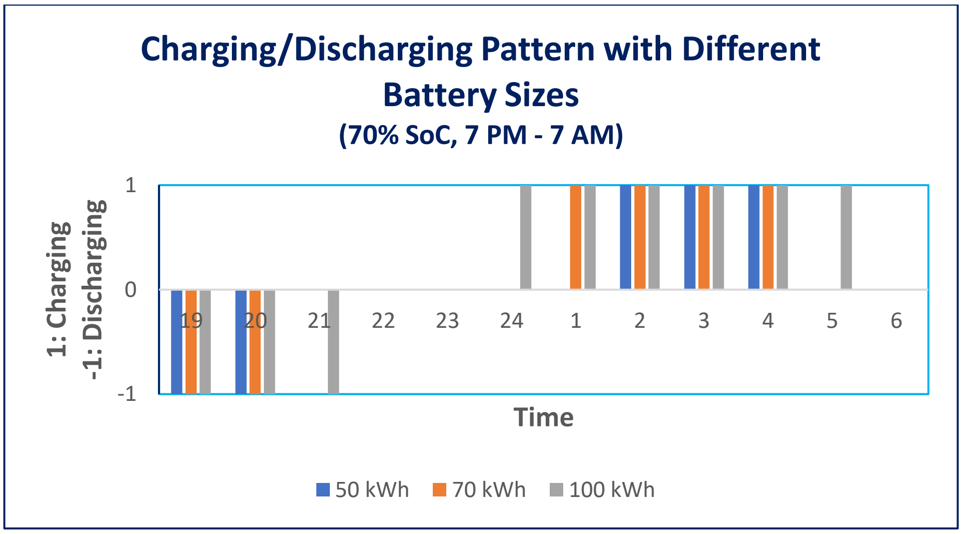


Figure 5.2 Charging/Discharging Pattern, 70 % SoC & 7 PM Arrival, Different Battery Sizes

The next evaluation analyzed cost per kWh of electricity for both Regular Charging and V2G, considering scenarios with the same battery size but different arrival conditions, and scenarios with different battery sizes but consistent arrival conditions.

For scenarios with the same battery size but different arrival conditions, it's evident that the cost per kWh decreases as the State of Charge (SoC) of the battery at arrival increases, especially when the EV connects early in the evening, as seen in Figure 5.3. The cost reduction is more substantial during peak hours when electricity costs are higher. Discharging the EV and injecting energy into the grid during this time, followed by recharging at lower off-peak rates early in the morning, results in a net cost reduction.

In these scenarios, there's a greater potential for cost savings when an EV with a higher SoC at arrival is connected to the charging point, provided the battery size is the same. However, as previously mentioned, larger batteries have a slower rate of SoC change per hour compared to smaller ones. Consequently, the cost per kWh is lower for smaller batteries with the same arrival conditions, as compared to higher costs for bigger batteries, as can be seen in Figure 5.4. This difference in charging times explains the variation in the cost of electricity per kWh for different battery sizes in these conditions.

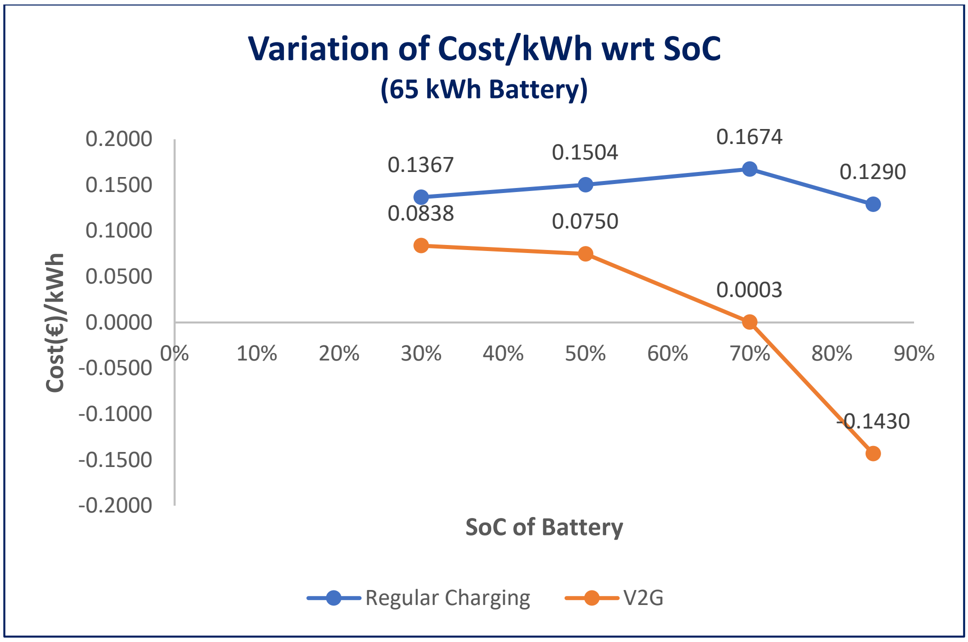


Figure 5.3 Variation of Cost/kWh w.r.t SoC

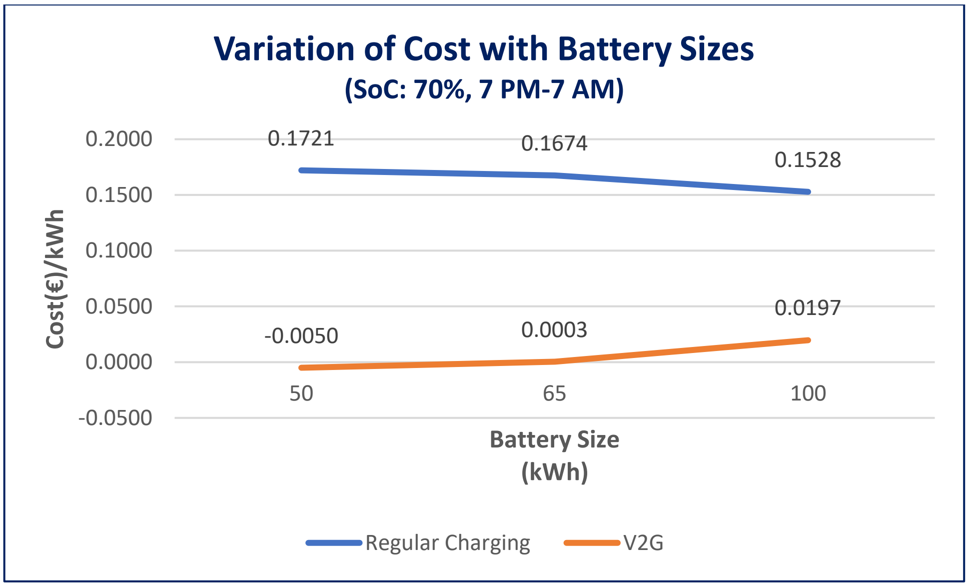


Figure 5.4 Variation of Cost with Battery Sizes

5.3 Profitability Evaluation for V2G Integrated Business Model

In this section, the core focus is into the heart of the study by evaluating the business model of Charging Point Operators (CPOs) in the context of the Dutch public charging network, with a particular emphasis on profitability. The aim is to evaluate how the integration of Vehicle-to-Grid (V2G) technology, using the quantitative findings of the reduced EPEX SPOT DAM price from the preceding section 5.2, and the dynamics of the financial aspects of CPOs' business operations. The analysis aims to identify the breakeven point in the business at which V2G integration becomes a pivotal factor. This assessment provides a comparative view of the business model with V2G integration and conventional charging, shedding light on the financial dynamics of electric mobility in the Public Charging Network in the Netherlands.

With Regular Charging

As mentioned earlier in Section 2.1.1, the traditional approach to charging, known as Regular Charging, involves charging an EV at its maximum power capacity as soon as it's connected to the charger. This continues until the EV is fully charged or disconnected from the charging point.

Following this concept, the cost of electricity procurement by a CPO from the EPEX SPOT DAM was calculated for a base case charging session scenario. This scenario involves an EV with a 70% State of Charge (SoC) connecting to the charge point at 7 PM and departing at 7 AM the following day. The EV in this scenario has a 65 kWh battery capacity. The outcomes of this calculation are showcased in Table 5.1. These results will play a pivotal role in the calculations associated with the base case scenario in the Business Model for Regular Charging.

The Regular Charging Business Model encompasses both non-recurring costs, such as hardware and installation expenses, and recurring costs like electricity procurement, maintenance, and more. Additionally, it includes revenues from various sources, all extensively explained in the profitability evaluation in the business case model detailed in Section 4.2.

The overview of the combined non-recurring, recurring costs and combined revenue/benefits within the Business Model for Regular Charging is summarized in Table 5.4, which serves as the base case scenario. In this base case, some fundamental assumptions are considered: the CPO manages 2000 EVSEs, each with an annual energy usage of 5000 kWh. The cost per EVSE is 3500 Euros, with a baseload electricity procurement cost of 0.07 Euros/kWh and a peakload electricity cost procured at the EPEX SPOT DAM market at 0.164 Euros/kWh, as detailed in Table 5.1. Revenue assumptions include selling electricity to EV drivers at 0.35 Euros per kWh and charging 0.35 Euros per session as transaction fees. When all these assumptions are accounted for, the business model for the base scenario for regular charging reveals a net present value of five million euros over five years of operation, as presented in Table 5.4.

Quantitative Analysis € in actual figures	2023E	2024E	2025E	2026E	2027E	Total
BENEFITS						
Revenues	6881950	6881950	6881950	6881950	6881950	34409750
Other Benefits	0	0	0	0	0	0
Total Benefits	**6881950**	**6881950**	**6881950**	**6881950**	**6881950**	**34409750**
COSTS						
Non-Recurring	9115000	0	0	0	0	9115000
Recurring	3626000	3626000	3626000	3626000	3626000	18130000
Total Costs	**12741000**	**3626000**	**3626000**	**3626000**	**3626000**	**27245000**
Net Benefit or Cost	**-5859050**	**3255950**	**3255950**	**3255950**	**3255950**	**7164750**
Present Value of Total Benefits M (€):						30
Present Value of Total Costs M (€):						24
Net Present Value M (€)						**5**
Regular Charging Business Case Cost-Benefit						

Table 5.4 Regular Charging Business Case Cost-Benefit Analysis (Base-Scenario)

The accompanying graphs in Figure 5.5 Break-Even Points for Business Case in Regular Charging illustrate the break-even point for the Business Case with Regular Charging, which is the juncture at which the CPO begins generating a net positive cash flow or turns a profit in its business. The first graph clearly indicates that, in the base case scenario, the CPO starts earning positively from the third year onward, considering 2000 EVSEs, each with a charging load of 5000 kWh per year. The second graph highlights that a higher usage rate, such as 10000 kWh per charge point per year, accelerates the break-even point, allowing the CPO to start making a profit nearly in a year time, thereby increasing the net present value.

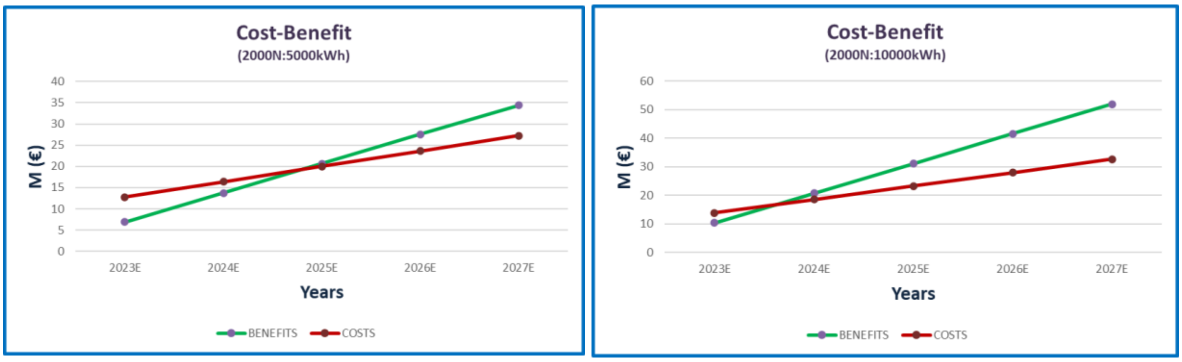


Figure 5.5 Break-Even Points for Business Case in Regular Charging

With V2G Charging

In Section 2.1.3, as discussed Vehicle-to-Grid (V2G) charging, which is a bi-directional charging technology. It not only charges the EV when connected to the charge point but also has the capability to inject surplus energy back into the grid when needed to maintain grid stability and balance. V2G technology plays a significant role in optimizing sustainable energy consumption, essentially turning EVs into grid assets. This supports grid stability during peak demand and facilitates the integration of renewable energy sources.

Building upon the previous discussion of how Charge Point Operators (CPOs) can leverage their charge point assets to reduce variable costs through strategically procuring electricity, V2G technology plays a pivotal role in the evaluation of business model profitability. The values derived from the reduced electricity cost procured from the EPEX DAM market through V2G for a base case charging scenario are detailed in Table 5.1. In this scenario, an EV with a 70% State of Charge (SoC) connects to the charge point at 7 PM and departs at 7 AM the following day, with a 65 kWh battery capacity. These results are crucial for calculations within the base case scenario of the Business Model for V2G Charging.

Much like Regular Charging, the V2G charging business model for CPOs encompasses non-recurring costs like hardware and installation, along with recurring expenses including software tools for enhancing V2G charging sessions, electricity procurement, maintenance, grid fees, and more. In terms of revenue, aside from the standard revenue streams generated through charging fees from EV customers, session fees, and premium membership fees, there's an additional cost or an intangible benefit to the company. This cost involves compensating EV users for utilizing their battery assets for successful V2G operations. This compensation should be a necessary part of the business model, as CPOs utilize end-users' assets for their benefit, and this process may contribute to battery degradation, which might affect the EV battery's lifespan, a topic explored in detail in Section 4.1.3. The comprehensive Business Model for V2G Charging for CPOs is extensively discussed in Section 4.2, providing a conceptual analysis of the profitability of this business model.

Table 5.5 summarizes the combined non-recurring, recurring costs and combined revenue/benefits within the Business Model for V2G Charging, serving as the base case scenario. In this base case, the considered key assumption: the CPO manages 2000 EVSEs, each with an annual energy usage of 5000 kWh. The cost per Bi-Directional EVSE is 4000 Euros, with a baseload electricity procurement cost of 0.07 Euros/kWh and a peakload electricity cost reduced through V2G at 0.0003 Euros/kWh, as detailed in Table 5.1. Revenue assumptions include selling electricity to EV drivers at 0.35 Euros per kWh, charging 0.35 Euros per session as transaction fees, and a negative benefit of compensating EV users with a 10% discount on the charging fees. When all these assumptions are considered, the business model for the base scenario for V2G also reveals a net present value of five million euros over five years of operation, as presented in Table 5.5.

Quantitative Analysis € in actual figures	2023E	2024E	2025E	2026E	2027E	Total
BENEFITS						
Revenues	6881950	6881950	6881950	6881950	6881950	34409750
Other Benefits	-350000	-350000	-350000	-350000	-350000	-1750000
Total Benefits	**6531950**	**6531950**	**6531950**	**6531950**	**6531950**	**32659750**
COSTS						
Non-Recurring	10115000	0	0	0	0	10115000
Recurring	3251116	3251116	3251116	3251116	3251116	16255580
Total Costs	**13366116**	**3251116**	**3251116**	**3251116**	**3251116**	**26370580**
Net Benefit or Cost	**-6834166**	**3280834**	**3280834**	**3280834**	**3280834**	**6289170**
Present Value of Total Benefits M (€):						28
Present Value of Total Costs M (€):						24
Net Present Value M (€)						**5**
V2G Business Case Cost-Benefit						

Table 5.5 V2G Charging Business Case Cost-Benefit Analysis (Base-Scenario)

The outcomes from the Business Model are instrumental in generating Break-Even graphs for the Base Scenario and several other cases with varying annual energy usage rates per EVSE system. These graphs indicate the point at which CPOs achieve a net positive cash flow in their business for different usage rates. In the base case scenario with an annual usage rate of 5000 kWh per EVSE, the CPO turns a profit from the third year onwards. With increased usage rates, the business can break even and become profitable much earlier, as demonstrated in the last two graphs in Figure 4.6. Conversely, with a lower usage rate of 3000 kWh annually, the CPO takes longer, until the middle of the fourth year, to achieve a break-even point and begin making a profit, as shown in the first graph. The impact of the usage rate on CPO business profits and reaching the break-even point is clear.

For both types of charging, the NPV for the base case scenario is the same. From a business perspective, this might not appear as an incentive for CPOs to invest more in V2G. However, from a societal standpoint, it might remain a promising investment. Even with additional investments, CPOs can achieve the same level of profit as regular charging. To gain insight into how other parameters influence the profitability in the Business Model, a sensitivity analysis for Business Case for V2G Charging is conducted, that might provide the parameters that can influence the revenue and, consequently, profits for V2G, detailed in the following section, 5.4.

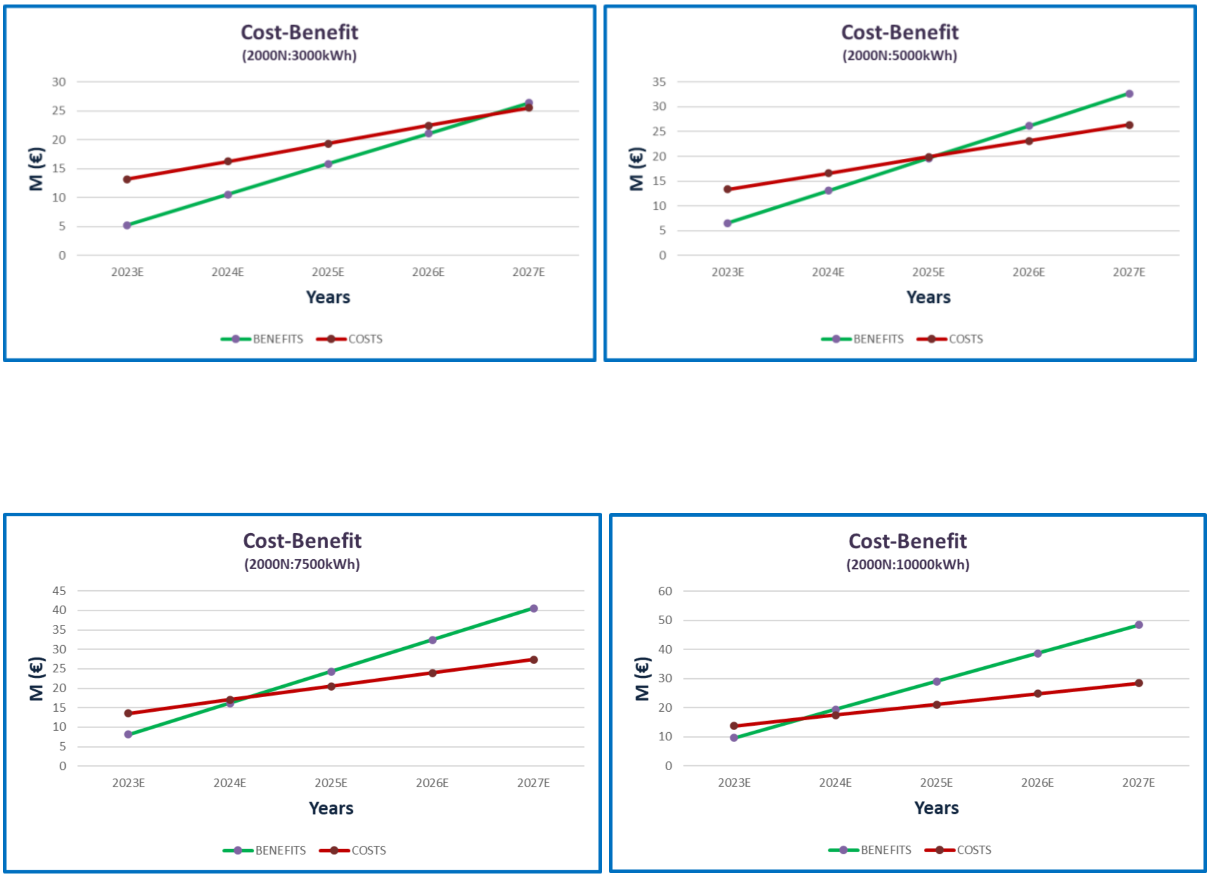


Figure 5.6 Break-Even Points for Business Case in V2G Charging

5.4 Sensitivity Analysis of V2G Business Model

This section entails a sensitivity analysis aimed at examining how various parameters influence the profitability dynamics of the Business Model for V2G Charging for a CPO. Figure 5.7, presents a detailed analysis of various variables that impact the Net Present Value (NPV) of the CPO's business case over five years of operation. NPV represents the sum of all future cash flows discounted to their present value. A positive NPV indicates that the business is feasible and would generate profits for the CPO during the operational period.

The parameters for the base case scenario of the Business Case for V2G Charging are fixed and can be referenced in Table 5.6. These values are chosen based on realistic figures obtained through literature and market research, as discussed in Section 4.2.1. The minimum and maximum values for these parameters are derived from relevant sources and governmental agencies, which have projected data based on real usage patterns in specific locations or areas. For instance, a city like Amsterdam, with numerous EVSE installations in the Public Charging Network, would likely have a higher usage rate and more charging sessions compared to a smaller city like Delft, where these parameters would be lower, possibly even lower than the base case parameters.

The cost of Bi-directional EVSE is estimated to decrease in the future due to technological advancements, hence the lower value of 3500 Euros per EVSE. However, as V2G becomes more widespread and demand increases, prices may further decrease. The cost of reduced electricity procured from the EPEX DAM is obtained from various scenarios in which the net cost per kWh was calculated, as shown in Table 5.2. This helps to understand how different V2G charging scenarios influence the Business Case through DAM costs.

Similarly, baseload electricity costs are considered with a higher value, anticipating potential price increases in the future due to increased demand driven by the aim for complete electrification in all sectors. Conversely, the lower value accounts for factors like the integration of more renewable energy into the system, which could lead to lower electricity prices.

Charging fees and session fees are determined by comparing current CPO pricing for their customers. This helps assess how changes in fees, whether increases or decreases, impact CPO profits. Customer compensation for using their assets i.e., battery, is assumed to be 10% discount on the charging fees, ensuring the company maintains a positive business outlook. However, the CPO can adjust this rate based on margin percentages or customer usage rates for V2G charging. Regarding advertisements, CPOs have substantial potential to increase revenue through advertising in cities with larger populations compared to smaller ones.

Variables	Minimum	Base	Maximum
No of EVSE (Ny)	1000	2000	5000
Charging Fees/kWh (€/kWh)	0.3	0.35	0.4
User/CP/Year	10	15	25
Discount Rate (%)	10	5	15
Transaction Fees/Session (€)	0.3	0.35	0.4
Session/CP/Day	1	1.5	3
Customer Compensation (%)	8	10	15
EVSE Cost (Px) (€)	3500	4000	5000
Electricity Baseload Price (60%) (€)	0.03	0.07	0.09
Electricity Peakload Price (40%) (€)	-0.143	0.000279	0.075
Usage Rate (kWh/Year/CP)	7500	5000	10000
Advertisement/CP/Year (€)	2000	1000	3500

Table 5.6 Different Variables Used in the Sensitivity Analysis

The sensitivity analysis plot in Figure 5.7 underscores the significant sensitivity of the NPV of the Business Case for CPOs in V2G Charging to the usage rate. It's crucial for CPOs to strategically plan their charging network implementation, with a focus on larger cities where higher usage rates and a greater number of required EVSE installations can substantially boost business profitability. Additionally, the increased number of sessions in these areas contributes further to overall profitability.

Leveraging advertisements on EVSE systems represents a potential game-changer for CPOs' business prospects, provided this opportunity is exploited effectively.

The cost of electricity procurement in the EPEX DAM through V2G enhancement is another influential factor. Lower costs per kWh translate to significantly increased profits, as demonstrated by the sensitivity analysis.

Certain parameters, such as EVSE costs and electricity baseload costs, directly influence business dynamics but are not under the CPO's control; they are more reactive to market changes. Charging fees and transaction fees per session also impact profitability, but CPOs must align their pricing with market trends to remain competitive.

Customer compensation is a variable that can be strategically adjusted to pass on more benefits to users with high V2G usage rates. This strategy can motivate users to maintain high usage rates, benefiting both the users and the CPO, as the latter can maximize the use of their assets.

In conclusion, the sensitivity analysis highlights the importance of considering usage rates, cost reduction, and strategic pricing decisions to enhance the profitability of V2G Charging for CPOs.

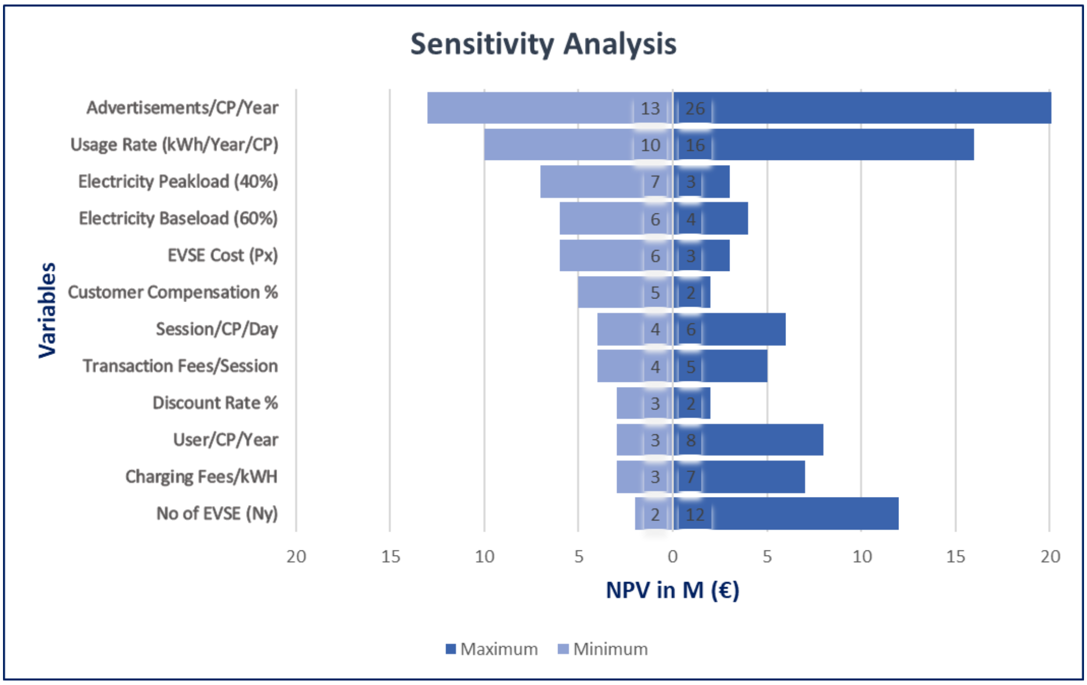


Figure 5.7 Sensitivity Analysis Graph For V2G Business Case

6 Conclusion and Discussion

6.1 Conclusion

In the pursuit of understanding the evolving landscape of electric mobility, this study comprehensively explored the dynamics within the Charge Point Operator (CPO) business model in the Public Charging Network in the Netherlands, specifically focusing on Vehicle-to-Grid (V2G) Charging. Through an extensive analysis of various charging technologies, operational strategies, and their financial implications, this study has illuminated several critical facets that bear significant implications for the future of sustainable electric mobility.

Diverse Charging Technologies: The investigation recognized the diversity of charging technologies available to CPOs. Beyond conventional Normal Charging, we delved into the potential of Smart Charging and, more profoundly, Vehicle-to-Grid (V2G) Charging as transformative options. These technologies empower CPOs to leverage their assets, such as Electric Vehicle Supply Equipment (EVSE), in novel ways to enhance their business models.

V2G Charging: A Game Changer: V2G Charging emerged as a game-changer, presenting the capability to not only charge electric vehicles but also inject surplus energy back into the grid. This bi-directional capability opens doors to numerous benefits, including grid stability maintenance during peak demand and the integration of renewable energy sources.

Business Model Profits: Central to the exploration was the assessment of how V2G technology impacts the financial aspects of CPO operations. Through meticulous analysis, it was revealed that profitability hinges on various factors, most notably the usage rate. Larger cities, with higher usage rates and a greater need for EVSE installations, offer fertile ground for profitability. The potential for advertising on EVSE systems adds another layer of opportunity. Furthermore, reduced electricity procurement costs through V2G can significantly augment profits.

Sensitivity Analysis Insights: The sensitivity analysis reinforced the pivotal role of the usage rate, emphasizing the strategic importance of network implementation in high-demand areas. Factors such as EVSE hardware and electricity costs, while not within the CPO's direct control, remain influential. Charging fees should align with market trends for competitiveness, and customer compensation can be leveraged strategically to motivate high V2G usage.

Net Present Value (NPV): For both types of charging, the NPV for the base case scenario is the same. From a business perspective, this might not appear as an incentive for CPOs to invest more in V2G. However, from a societal standpoint, it remains a promising investment. Even with additional investments, CPOs can achieve the same level of profit as regular charging. The sensitivity analysis underscores the importance of usage rates and the number of EVSEs, providing strategic insights for CPOs to focus on densely populated cities to maximize revenue and, consequently, profits.

Additional Conclusions:

1. The conceptual analysis affirmed the potential of V2G to enhance profits or reduce costs for the electricity procured in the EPEX market.
2. To maximize V2G potential, EVs should connect for longer durations and at higher State of Charge (SoC) levels, notably at peak hours.
3. Charging and discharging patterns occur more frequently when EVs with smaller batteries and higher State of Charge (SoC) levels connect, leading to shorter charging and discharging times and thus, greater V2G advantages.
4. V2G potential will only be able to realized when SoC exceeds the 40% lower threshold and when EVs connect during peak hours.
5. Although the Net Present Value (NPV) for both types of charging is initially the same in the base case scenario, considering factors like societal benefits, technological maturity, and market share, V2G remains an attractive investment.
6. Sensitivity analysis highlights the significance of usage rates and the number of EVSEs, providing strategic guidance for CPOs to focus on densely populated cities to maximize revenue and, subsequently, profits.

Path Forward: In closing, this study paints a compelling picture of the potential for CPOs to thrive in the electric mobility ecosystem by embracing V2G Charging. To do so successfully, CPOs must carefully consider factors such as location, cost reduction at EPEX, pricing strategies, and customer engagement. By navigating this evolving landscape with insight and adaptability, CPOs can foster profitable business models and contribute significantly to the advancement of sustainable electric mobility.

In a world where the demand for clean and sustainable transportation solutions is ever-growing, CPOs equipped with the knowledge and insights uncovered here stand poised to drive the future of electric mobility toward a brighter, more sustainable horizon.

This study has laid the groundwork, but the journey towards an electrified, sustainable future is far from over. The road ahead is illuminated, and it beckons with endless possibilities.

As the electric mobility landscape continues to evolve, embracing V2G Charging opens doors to innovation and sustainability, ultimately driving us toward a cleaner, more efficient future.

6.2 Discussion

Unravelling the Business Model for Charge Point Operators

This study introduces a quantitative framework to scrutinize the business model of Charge Point Operators (CPOs) within public and semi-public charging points. Here, the broader implications of the findings and their relevance beyond the Dutch electric vehicle charging landscape are discussed.

1. A Quantitative Framework for Business Analysis: This research provides a structured approach to assess the profitability of CPOs, offering valuable insights into various charging technologies. This framework serves as a practical tool for CPOs navigating the evolving electric mobility sector, facilitating a thorough understanding of costs, revenues, and profitability.

2. Applicability Across the EV Ecosystem: The insights and models developed in this study can extend to other players in the electric vehicle charging ecosystem. The actors that perform similar functions, involved in charging infrastructure can adapt this framework with minor adjustments. The core cost and revenue model remains applicable, making it versatile for a variety of stakeholders.

3. V2G's Path to Maturity: This study echoes the industry sentiment that Vehicle-to-Grid (V2G) technology is still in its nascent stages. This presents an opportunity for collective action among industry stakeholders. Collaboration can expedite the maturity of V2G, leading to quicker realization of benefits like grid stability, renewable energy integration, and cost reduction.

4. Global Applicability in Similar Markets: While the focus is on the Dutch EV charging landscape, the findings are relevant to regions with similar demographics and energy market dynamics. Comparable characteristics make the business model adaptable globally, contributing to the sustainable growth of electric mobility.

In summary, this research advances the understanding of CPO business models, offering a practical framework for analysis. Its potential applications extend beyond CPOs, benefiting various participants in the electric vehicle charging ecosystem. As V2G technology matures, industry-wide collaboration is key. The model can guide regions with similar profiles towards a greener and more sustainable electric mobility future.

6.3 Limitations & Recommendations

This study, while providing valuable insights into the business dynamics of Charge Point Operators (CPOs) in the realm of electric vehicle charging, encounters several limitations that point toward avenues for future research. One significant limitation lies in the qualitative examination of battery degradation, prompting the need for quantitative studies that offer a more precise understanding of how V2G operations impact battery health, and the business model for a CPO. Additionally, this research draws on daily data from EPEX SPOT DAM for a single day, warranting future investigations with broader datasets, such as yearly or seasonal averages, to better capture market fluctuations. Another limitation arises from the focus on enhancing a single EV charging session, suggesting future research should explore the complexities of multiple EV interactions in real-time scenarios. Moreover, the reliance on assumptions and literature-based parameters for costs and revenues underscores the importance of future studies incorporating real-world market data to enhance model accuracy. The oversimplification of charging/discharging at full capacity could also be addressed in future research by considering average power charging (Smart Charging) for a more realistic representation. Lastly, the static nature of the business case, assuming constant usage rates and prices over the years of operation, calls for future investigations encompassing scenarios with dynamic rates and pricing to accommodate evolving market dynamics.

In light of these limitations, recommendations for future research naturally emerge. Researchers can venture into quantifying battery degradation in V2G scenarios, offering a more comprehensive perspective on the trade-offs between profitability and battery lifespan. Expanding the analysis to encompass various EPEX markets, including intraday markets with varying time intervals, would provide a more thorough understanding of market dynamics. Beyond charging, future studies could explore broader applications of V2G for CPOs, such as providing frequency regulation services to the grid, thereby diversifying revenue streams. Developing business models that consider CPOs offering V2G services to fleets, characterized by predictable arrival and departure times, presents another avenue for research. Simulating a more complex and realistic environment involving multiple EVs with distinct arrival and departure times and varying battery sizes is also an area ripe for exploration. Finally, investigating the expansion of grid availability for V2G, including complex grid interactions beyond simple energy injection, can yield valuable insights. These combined limitations and future research recommendations collectively illuminate the path toward more comprehensive and accurate analyses in the evolving landscape of electric mobility.

Recommendations for Charge Point Operators (CPOs)

Based on the study's insights, here are concise recommendations for CPOs to enhance profitability and promote sustainable electric mobility:

1. Embrace V2G Technology: Invest in Vehicle-to-Grid (V2G) technology to optimize energy usage and explore new revenue streams.
2. Strategic Location Selection: Focus on densely populated areas to maximize usage rates and profitability.
3. Compensate Customers: Strategically compensate EV owners for participating in V2G programs to encourage longer vehicle connections.
4. Explore Marketplace Models: Investigate innovative marketplace models that create value for all stakeholders in the EV ecosystem.
5. Leverage Advertising Revenue: Diversify income streams by collaborating with advertisers for charging station ad placements.

By incorporating these recommendations, CPOs can thrive in the evolving electric mobility landscape while contributing to sustainable transportation solutions.

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Appendix A

A.1 Charge Stations

Charging Pool

A charging pool is made up of one or more charging stations as well as parking lots. The charging pool is managed by a single charge point operator (CPO) at a single address and GPS coordinates. The charging pool is an object that is relevant for the "cartographic view", guiding tools, and any elements that represent a charging infrastructure element on a map.

Connector

A connector is the physical interface that allows electric energy to be transmitted between the charging station and the electric car. The number of charging points and connectors are usually equal, but not always. There are charging stations, for example, that have two charging points and three plugs. In that situation, no more than two connectors may be utilized, and no more than two vehicles may be charged at the same time (one AC and one DC).

A.2 Connector Types

Type 1 / Yazaki (SAE J1772, IEC 62196-1)

This is the standard Japanese connector for alternating current electric vehicle charging (also used by North American countries and accepted by the EU). It can charge electric vehicles such as the Opel Ampera (prior model), Nissan Leaf, Nissan E-NV200, Mitsubishi Outlander, Mitsubishi iMiev, Peugeot iON, Citröen C-Zero, Renault Kangoo ZE (type 1), Ford Focus Electric, Toyota Prius Plug-in, and KIA SOUL.

Type 2 (IEC 62196-2)

The European Union Commission has designated this connector type as the norm for regular (22 kW) charging of electric vehicles. It can charge electric vehicles such as the Opel Ampera (current version), the BMW i3, the i8, the BYD E6, the Renault Zoe, the Volvo V60 plug-in hybrid, the VW Golf plug-in hybrid, the VW E-up, the Audi A3 E-tron, the Mercedes S500 plug-in, the Porsche Panamera, and the Renault Kangoo ZE.

Combined Charging System (CCS Combo 1)

The CCS connector incorporates the J1772 charging input as well as two additional pins below. It gets its name from the fact that it "combines" the J1772 connector with the high speed charging pins. The Society of Automotive Engineers (SAE) established and adopted CCS, which is the recognised standard in North America. General Motors (all divisions), Ford, Chrysler, Dodge, Jeep, BMW, Mercedes, Volkswagen, Audi, Porsche, Honda, Kia, Fiat, Hyundai, Volvo, smart, MINI, Jaguar Land Rover, Bentley, Rolls Royce, and others have all consented to implement the CCS standard in North America.

Combined Charging System (CCS Combo 2)

This connector is an improved version of the type 2 connector, having additional power contacts for quick charging. CCS is AC and DC compatible, and it has been the European fast-charging standard since 2017. This type of connector is used by manufacturers such as Audi, BMW, Porsche, and Volkswagen.

GB/T

The GB/T charging standard is a set of GB/T standards, notably in the GB/T 20234 family, that are used in China for electric vehicle AC and DC rapid charging. The Chinese Standardization Administration most recently amended and updated the standards in 2015.

Type 4 / CHAdeMO

CHAdeMO is a DC-only charging system that can be utilized for fast charging. It may be used to charge Nissan Leaf, Nissan E-NV200, Mitsubishi Outlander, Mitsubishi iMiev, Peugeot iON, Citröen C-Zero, and KIA SOUL electric vehicles.

Tesla Supercharger

Designed just for Tesla. The Tesla supercharger has the same layout as the type 2 connector, however it has been significantly changed to fit in the conventional type 2 outlet. The Tesla Model 3 in Europe, on the other hand, has a CCS inlet.

Various Connectors across the Globe (enelxway, 2023)

A.3 Charging Power and Types

The charging time is determined by several factors, including the capacity of the car battery and the power and settings of the charging station. In the coming years, charging time is projected to decrease dramatically.

Regular Power Charging Point

A charging station that permits electricity to be transferred to an electric car with a power of less than or equal to 22 kW.

High Power Charging Point

A charging port that permits electricity to be transferred to an electric car with a power of more than 22 kW. A typical fast charger offers 50 kW. Fast charging technology is always evolving, and today there are fast chargers capable of giving 175 kW or more, as well as superchargers capable of supplying 350 kWh of power (for heavy-duty motor vehicles, there are chargers capable of delivering 450 kW of power).

The power system provides alternating current (AC), but an electric vehicle's battery requires direct current (DC). AC to DC conversion can occur in a vehicle or at a charging EVSE.

A.4 Accessibility

Private charging points / Home charger

Private charging stations are located on private property and are linked to a private electrical supply. These charging outlets are frequently inaccessible to electric vehicles other than those belonging to the charging point's owner.

Charging at workplaces/Business

This is referred to as private charging, and it occurs when businesses install charging stations on business premises for the use of staff (and clients).

A.5 Charging Protocol

Open ADR – Open Automated Demand Response Standard

The protocol is intended to automate demand response communication; it allows a system and/or device to modify power consumption or demand-side resource output. This can be done, for example, based on grid needs, using tariffs, incentives, or emergency alerts to balance demand with sustainable supply.

OSCP - Open Smart Charging Protocol

The Open Smart Charging Protocol provides forecasts of the energy grid's available capacity to other systems. The protocol is built on a budgetary system in which client systems can signal their demands to a central system, which protects the grid from overuse by allocating budgets per cable.

IEC 61850

The IEC 61850-90-8 specification is not a protocol in and of itself. It's a technical report outlining an object model for electric mobility. According to the paradigms established in IEC 61850, it models Electric Vehicles as a special type of Distributed Energy Resource.

EV ROAMING

EV Roaming allows EV drivers to charge at any charging station and administers the charging action's billing to the driver. The state of the charging infrastructure for electric vehicles is open. It entails a shared usage of charging infrastructure that is independent of technology and is free of budgetary and legal constraints.

OCHP - Open Clearing House Protocol

The Open Clearing House Protocol (OCHP) is a protocol used to exchange authorization data, charging transaction data, and charge point information data for roaming over the e-clearing.net platform.

OCPI - Open Charge Point Interface protocol/ NKL Nederland

OCPI is an independent roaming protocol that facilitates data interchange. It can be utilized by businesses (peer-to-peer) as well as through a roaming hub or platform. The protocol has international backing. OCPI provides EV drivers with information on charging point availability and costs.

IEC 63119

IEC 63119 is a current standard for information sharing for electric vehicle charging roaming services. It is divided into four sections: Part 1: General, Use Cases, Part 2, and Part 3 is about message structure, while Part 4 is about cybersecurity and information privacy.

A.6 Energy Market

ICE ENDEX - Forward and Futures Market

ICE ENDEX, also known as Forward Market, or Futures market, is a prominent energy exchange that plays a pivotal role in the European energy market. Specializing in the trading of natural gas and electricity contracts, it provides a robust and transparent platform for energy market participants to conduct transactions (ICE Endex, 20223).

As a major player in the energy sector, ICE ENDEX contributes to the establishment of fair market prices and the efficient allocation of energy resources. Market participants, including producers, utilities, and traders, rely on ICE ENDEX for price discovery, risk management, and portfolio optimization.

In the ICE ENDEX, the energy is traded for years up to weeks preceding the day of supply. However, trading relatively substantial volumes of energy far in advance of the trading day necessitates strong supply confidence. CPOs may use futures to obtain a baseline average energy amount in order to hedge against higher volatility or price increases in short-term markets as the CPO's exposure to short-term energy prices is decreased. The units for energy procurement are too large to be called flexible because energy procurement in the futures or forwards market consists of acquiring blocks of energy demand for a minimum of weeks. The difference between the baseline produced by these procured blocks of energy and the predicted energy demand at the time of delivery is then either secured or sold through the EPEX SPOT DAM in hourly blocks.

EPEX SPOT - Intra-Day Market (IDM)

The EPEX SPOT provides intraday trading in addition to day-ahead trading. The energy and energy are exchanged on the Intra-Day Market (IDM), which is similar to the DAM. Unlike the DAM, which shuts at 12:00 the day before the trading day, the IDM opens and closes at 15:00 the day before delivery. The IDM is divided into three market time intervals, each of which allows bids to be entered 1 hour, 30 minutes, and 15 minutes before the time of delivery. CPOs can bid on and procure energy in the IDM in the same way that they can in the DAM. However, when the market shifts to shorter delivery times, estimates become more certain, and bids can be presented more aggressively. However, the volume of energy traded through the IDM in the Netherlands is rather limited. As a result, the market is illiquid and the earning potential is poor. Thus, while the market is considered a potential integration for CPOs, its value is much smaller than that of the EPEX SPOT DAM.

Appendix B

1. Four Different Scenarios with the Same Battery Capacity, Different SoC & Arrival Time

EV Data: 65 kWh Battery, SoC at arrival 70% Available Time: 7 PM to 7 AM	Initial to Target SoC: 70% to 100% 11 kW EVSE, 95% efficiency Time[5]: 1.9 hrs

Time	Price[1] (€/kWh)
4	0.079
2	0.084
3	0.084
1	0.086
24	0.089
5	0.092
23	0.096
22	0.108
6	0.115
21	0.122
20	0.154
19	0.179

V2G Charging					SoC	
Time	Price €/kWh	Time Block	Energy (kWh)	Cost (€)	SoC/Hr	70
19	0.179	-1.000	-10.45	-1.873	-16.07	53.93
20	0.154	-0.865	-9.039	-1.394	-13.9	40.029
21	0.122		0	0	0	40.029
22	0.108		0	0	0	40.029
23	0.096		0	0	0	40.029
24	0.089		0	0	0	40.029
1	0.086	0.765	7.9943	0.6837	12.294	52.323
2	0.084	1.000	10.45	0.8789	16.07	68.393
3	0.084	1.000	10.45	0.8798	16.07	84.463
4	0.079	1.000	10.45	0.8305	16.07	100.53
5	0.092		0	0	0	100.53
6	0.115		0	0	0	100.53
		Total[4]	19.855	0.0055	Cost/[2] kWh	0.0003
		Selling Price[3]		6.9493		

Regular Charging				
Time	Price €/kWh	Time Block	Energy (kWh)	Cost (€)
19	0.179	1.000	10.45	1.8728
20	0.154	0.900	9.405	1.4509
21	0.122		0	0
22	0.108		0	0
23	0.096		0	0
24	0.089		0	0
1	0.086		0	0
2	0.084		0	0
3	0.084		0	0
4	0.079		0	0
5	0.092		0	0
6	0.115		0	0
Cost/[2] kWh	0.1674	Total[4]	19.855	3.3238
		Selling Price[3]		6.9493

1. Ascending order of Price in DAM
2. Cost per kWh to CPO
3. Total selling price to Customer
4. Total Net Energy & Cost per session
5. Charging time from initial to target SoC

S1: 65kWh-7PM-70%SoC

EV Data: 65 kWh Battery, SoC at arrival 50% Available Time: 9 PM to 7 AM	Initial to Target SoC: 50% to 100% 11 kW EVSE, 95% efficiency Time[5]: 3.1 hrs

Time	Price[1] (€/kWh)
4	0.079
2	0.084
3	0.084
1	0.086
24	0.089
5	0.092
23	0.096
22	0.108
6	0.115
21	0.122
20	0.154
19	0.179

V2G Charging					SoC	
Time	Price €/kWh	Time Block	Energy (kWh)	Cost (€)	SoC/Hr	50
19	0.179	0.000	0	0	0	50
20	0.154	0.000	0	0	0	50
21	0.122	-0.620	-6.479	-0.79	-9.963	40.037
22	0.108		0	0	0	40.037
23	0.096		0	0	0	40.037
24	0.089		0	0	0	40.037
1	0.086	0.720	7.524	0.6435	11.57	51.607
2	0.084	1.000	10.45	0.8789	16.07	67.677
3	0.084	1.000	10.45	0.8798	16.07	83.747
4	0.079	1.000	10.45	0.8305	16.07	99.817
5	0.092		0	0	0	99.817
6	0.115		0	0	0	99.817
		Total[4]	32.395	2.4425	Cost/[2] kWh	0.0754
		Selling Price[3]		11.338		

Regular Charging				
Time	Price €/kWh	Time Block	Energy (kWh)	Cost (€)
19	0.179	1.000	10.45	1.8728
20	0.154	1.000	10.45	1.6121
21	0.122	1.000	10.45	1.2744
22	0.108	0.100	1.045	0.1125
23	0.096		0	0
24	0.089		0	0
1	0.086		0	0
2	0.084		0	0
3	0.084		0	0
4	0.079		0	0
5	0.092		0	0
6	0.115		0	0
Cost/[2] kWh	0.1504	Total[4]	32.395	4.8718
		Selling Price[3]		11.338

1. Ascending order of Price in DAM
2. Cost per kWh to CPO
3. Total selling price to Customer
4. Total Net Energy & Cost per session
5. Charging time from initial to target SoC

S2: 65kWh-9PM-50%SoC

EV Data: 65 kWh Battery, SoC at arrival 85% Available Time: 6 PM to 7 AM	Initial to Target SoC: 85% to 100% 11 kW EVSE, 95% efficiency Time[5]: 0.9 hrs

Time	Price[1] (€/kWh)
4	0.079
2	0.084
3	0.084
1	0.086
24	0.089
5	0.092
23	0.096
22	0.108
6	0.115
21	0.122
18	0.129
20	0.154
19	0.179

V2G Charging					SoC	
Time	Price €/kWh	Time Block	Energy (kWh)	Cost (€)	SoC/Hr	85
18	0.129	-0.800	-8.36	-1.078	-12.86	72.144
19	0.179	-1.000	-10.45	-1.873	-16.07	56.074
20	0.154	-1.000	-10.45	-1.612	-16.07	40.004
21	0.122		0	0	0	40.004
22	0.108		0	0	0	40.004
23	0.096		0	0	0	40.004
24	0.089		0	0	0	40.004
1	0.086	0.700	7.315	0.6256	11.249	51.253
2	0.084	1.000	10.45	0.8789	16.07	67.323
3	0.084	1.000	10.45	0.8798	16.07	83.393
4	0.079	1.000	10.45	0.8305	16.07	99.463
5	0.092		0	0	0	99.463
6	0.115		0	0	0	99.463
		Total[4]	9.405	-1.349	Cost/[2] kWh	-0.143
		Selling Price[3]		3.2918		

Regular Charging				
Time	Price €/kWh	Time Block	Energy (kWh)	Cost (€)
18	0.129	0.900	9.405	1.2132
19	0.179		0	0
20	0.154		0	0
21	0.122		0	0
22	0.108		0	0
23	0.096		0	0
24	0.089		0	0
1	0.086		0	0
2	0.084		0	0
3	0.084		0	0
4	0.079		0	0
5	0.092		0	0
6	0.115		0	0
Cost/[2] kWh	0.129	Total[4]	9.405	1.2132
		Selling Price[3]		3.2918

1. Ascending order of Price in DAM
2. Cost per kWh to CPO
3. Total selling price to Customer
4. Total Net Energy & Cost per session
5. Charging time from initial to target SoC

S3: 65kWh-6PM-85%SoC

EV Data: 65 kWh Battery, SoC at arrival 30% Available Time: 7 PM to 7 AM	Initial to Target SoC: 30% to 100% 11 kW EVSE, 95% efficiency Time[5]: 4.4 hrs

Time	Price[1] (€/kWh)
4	0.079
2	0.084
3	0.084
1	0.086
24	0.089
5	0.092
23	0.096
22	0.108
6	0.115
21	0.122
20	0.154
19	0.179

1. Ascending order of Price in DAM
2. Cost per kWh to CPO
3. Total selling price to Customer
4. Total Net Energy & Cost per session
5. Charging time from initial to target SoC

V2G Charging					SoC	
Time	Price €/kWh	Time Block	Energy (kWh)	Cost (€)	SoC/Hr	30
19	0.179		0	0	0	30
20	0.154		0	0	0	30
21	0.122		0	0	0	30
22	0.108		0	0	0	30
23	0.096		0	0	0	30
24	0.089	0.400	4.18	0.3716	6.428	36.428
1	0.086	1.000	10.45	0.8937	16.07	52.498
2	0.084	1.000	10.45	0.8789	16.07	68.568
3	0.084	1.000	10.45	0.8798	16.07	84.638
4	0.079	1.000	10.45	0.8305	16.07	100.71
5	0.092		0	0	0	100.71
6	0.115		0	0	0	100.71
		Total[4]	45.98	3.8544	Cost/[2] kWh	0.0838
		Selling Price[3]		16.093		

Regular Charging				
Time	Price €/kWh	Time Block	Energy (kWh)	Cost (€)
19	0.179	1.000	10.45	1.8728
20	0.154	1.000	10.45	1.6121
21	0.122	1.000	10.45	1.2744
22	0.108	1.000	10.45	1.1245
23	0.096	0.400	4.18	0.4014
24	0.089		0	0
1	0.086		0	0
2	0.084		0	0
3	0.084		0	0
4	0.079		0	0
5	0.092		0	0
6	0.115		0	0
Cost/[2] kWh	0.1367	Total[4]	45.98	6.2853
		Selling Price[3]		16.093

S4: 65kWh-7PM-30%SoC

2. Three Different Battery Capacities, with the Same SoC & Arrival Time

EV Data: 50 kWh Battery, SoC at arrival 70% Available Time: 7 PM to 7 AM	Initial to Target SoC: 70% to 100% 11 kW EVSE, 95% efficiency Time[5]: 1.4 hrs

Time	Price[1] (€/kWh)
4	0.079
2	0.084
3	0.084
1	0.086
24	0.089
5	0.092
23	0.096
22	0.108
6	0.115
21	0.122
20	0.154
19	0.179

1. Ascending order of Price in DAM
2. Cost per kWh to CPO
3. Total selling price to Customer
4. Total Net Energy & Cost per session
5. Charging time from initial to target SoC

V2G Charging					SoC	
Time	Price €/kWh	Time Block	Energy (kWh)	Cost (€)	SoC/Hr	70
19	0.179	-1.000	-10.45	-1.873	-21.9	48.1
20	0.154	-0.360	-3.762	-0.58	-7.884	40.216
21	0.122		0	0	0	40.216
22	0.108		0	0	0	40.216
23	0.096		0	0	0	40.216
24	0.089		0	0	0	40.216
1	0.086		0	0	0	40.216
2	0.084	1.000	10.45	0.8789	21.9	62.116
3	0.084	0.760	7.942	0.6686	16.644	78.76
4	0.079	1.000	10.45	0.8305	21.9	100.66
5	0.092		0	0	0	100.66
6	0.115		0	0	0	100.66
		Total[4]	14.63	-0.075	Cost/[2] kWh	-0.005
		Selling Price[3]		5.1205		

Regular Charging				
Time	Price €/kWh	Time Block	Energy (kWh)	Cost (€)
19	0.179	1.000	10.45	1.8728
20	0.154	0.400	4.18	0.6448
21	0.122		0	0
22	0.108		0	0
23	0.096		0	0
24	0.089		0	0
1	0.086		0	0
2	0.084		0	0
3	0.084		0	0
4	0.079		0	0
5	0.092		0	0
6	0.115		0	0
Cost/[2] kWh	0.1721	Total[4]	14.63	2.5177
		Selling Price[3]		5.1205

S1: 50kWh-7PM-70%SoC

EV Data: 65 kWh Battery, SoC at arrival 70% Available Time: 7 PM to 7 AM	Initial to Target SoC: 70% to 100% 11 kW EVSE, 95% efficiency Time[5]: 1.9 hrs

Time	Price[1] (€/kWh)
4	0.079
2	0.084
3	0.084
1	0.086
24	0.089
5	0.092
23	0.096
22	0.108
6	0.115
21	0.122
20	0.154
19	0.179

V2G Charging					SoC	
Time	Price €/kWh	Time Block	Energy (kWh)	Cost (€)	SoC/Hr	70
19	0.179	-1.000	-10.45	-1.873	-16.07	53.93
20	0.154	-0.865	-9.039	-1.394	-13.9	40.029
21	0.122		0	0	0	40.029
22	0.108		0	0	0	40.029
23	0.096		0	0	0	40.029
24	0.089		0	0	0	40.029
1	0.086	0.765	7.9943	0.6837	12.294	52.323
2	0.084	1.000	10.45	0.8789	16.07	68.393
3	0.084	1.000	10.45	0.8798	16.07	84.463
4	0.079	1.000	10.45	0.8305	16.07	100.53
5	0.092		0	0	0	100.53
6	0.115		0	0	0	100.53
		Total[4]	19.855	0.0055	Cost[2]/kWh	0.0003
		Selling Price[3]		6.9493		

Regular Charging				
Time	Price €/kWh	Time Block	Energy (kWh)	Cost (€)
19	0.179	1.000	10.45	1.8728
20	0.154	0.900	9.405	1.4509
21	0.122		0	0
22	0.108		0	0
23	0.096		0	0
24	0.089		0	0
1	0.086		0	0
2	0.084		0	0
3	0.084		0	0
4	0.079		0	0
5	0.092		0	0
6	0.115		0	0
Cost[2]/kWh	0.1674	Total[4]	19.855	3.3238
		Selling Price[3]		6.9493

1. Ascending order of Price in DAM
2. Cost per kWh to CPO
3. Total selling price to Customer
4. Total Net Energy & Cost per session
5. Charging time from initial to target SoC

S2: 65kWh-7PM-70%SoC

EV Data: 100 kWh Battery, SoC at arrival 70% Available Time: 7 PM to 7 AM	Initial to Target SoC: 70% to 100% 11 kW EVSE, 95% efficiency Time[5]: 2.9 hrs

Time	Price[1] (€/kWh)
4	0.079
2	0.084
3	0.084
1	0.086
24	0.089
5	0.092
23	0.096
22	0.108
6	0.115
21	0.122
20	0.154
19	0.179

V2G Charging					SoC	
Time	Price €/kWh	Time Block	Energy (kWh)	Cost (€)	SoC/Hr	70
19	0.179	-1.000	-10.45	-1.873	-10.9	59.1
20	0.154	-1.000	-10.45	-1.612	-10.9	48.2
21	0.122	-0.750	-7.838	-0.956	-8.175	40.025
22	0.108		0	0	0	40.025
23	0.096		0	0	0	40.025
24	0.089	1.000	10.45	0.9289	10.9	50.925
1	0.086	1.000	10.45	0.8937	10.9	61.825
2	0.084	1.000	10.45	0.8789	10.9	72.725
3	0.084	1.000	10.45	0.8798	10.9	83.625
4	0.079	1.000	10.45	0.8305	10.9	94.525
5	0.092	0.650	6.7925	0.6265	5.85	100.38
6	0.115		0	0	0	100.38
		Total[4]	30.305	0.5976	Cost[2]/kWh	0.0197
		Selling Price[3]		10.607		

Regular Charging				
Time	Price €/kWh	Time Block	Energy (kWh)	Cost (€)
19	0.179	1.000	10.45	1.8728
20	0.154	1.000	10.45	1.6121
21	0.122	0.900	9.405	1.1469
22	0.108		0	0
23	0.096		0	0
24	0.089		0	0
1	0.086		0	0
2	0.084		0	0
3	0.084		0	0
4	0.079		0	0
5	0.092		0	0
6	0.115		0	0
Cost[2]/kWh	0.1528	Total[4]	30.305	4.6319
		Selling Price[3]		10.607

1. Ascending order of Price in DAM
2. Cost per kWh to CPO
3. Total selling price to Customer
4. Total Net Energy & Cost per session
5. Charging time from initial to target SoC

S3: 100kWh-7PM-70%SoC