MASTER

Value alignment in the Dutch bidirectional charging (V2G) ecosystem

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Master thesis project

Value alignment in the Dutch bidirectional charging (V2G) ecosystem

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Summary

Broader context and research objective

World-wide efforts to mitigate climate change result in a large transition of the current energy and mobility systems. Increased adoption of volatile renewable energy sources (e.g. solar PV and wind) and electric vehicles (EVs) contribute to reduced need for fossil fuels, but increase pressure on the electricity grid. In the Netherlands, grid capacity is already becoming scarce in almost every region, requiring grid operators to look for solutions.

Storage solutions could help intercept fluctuations in electricity supply and demand. Therefore, researchers and practitioners have frequently argued for the realization of a bidirectional vehicle-to-grid (V2G) connection via homes, buildings or public charge points, which enables EV batteries to act as a storage solution that reliefs the grid.

However, the use of bidirectional charging for grid purposes still experiences limited commercial application. Researchers dedicate this to the lack of a shared vision amongst key stakeholders and need for clearer insights into the bidirectional charging value propositions as well as the motivation of stakeholders to participate in system development for this technology. This asks for an investigation of the perspectives of stakeholders on their role in and individual motivations to contribute.

Theoretical embedding

This research introduced the “ecosystem” construct by Adner (2017) as an appropriate framework to guide this investigation, since it helps to deepen the understanding of such complex innovative transitions from a structural point of view. From this perspective, the ecosystem is viewed as ‘the alignment structure of a multilateral set of partners that need to interact in order for a focal value proposition to materialize’.

The development of a new ecosystem structure requires stakeholders to overcome an alignment challenge. This is explained as alignment in terms of their expectations and stakeholders’ ability and willingness to undertake the required activities. Other researchers emphasize on the importance of value discovery and negotiation among stakeholders for early stage ecosystem development.

Ecosystem theory suggests that for succesful ecosystem development, the ecosystem orchestrator will have to investigate what participant roles and individual value offerings are required for a newly developing alignment structure to be accepted by all stakeholders.

Research questions and methods

The main research question of this thesis is: "*What recommendations can be formed based on an analysis of value alignment in the Dutch bidirectional charging (V2G) ecosystem?*" This question is addressed by using various qualitative research methods, which are used throughout a case study - focused on the Dutch ecosystem for bidirectional charging.

A broad literature review was performed to identify the key stakeholders and the value - in terms of benefits and costs - mentioned througout bidirectional charging (V2G) literature. After this, 10 interviews took place with Dutch stakeholders and/or experts which are expected to play an important role in the (Dutch) bidirectional charging (V2G) ecosystem - to gain an understanding of how these stakeholder roles, benefits and costs are recognized and applied in practice. These interviews also provided further insights in the current topics of value negotiation. To substantiate and verify the previous outcomes, some additional qualitative research took place using data from a webinar, events and in-depth literature research.

The trustworthiness of the research - in terms of credibility, transferability, dependability and confirmability - was increased by amongst others the use of multiple qualitative data sources, the use of quotes from interviews throughout the results, interim discussions comparing the results of different methods and the provision of transcripts, summaries and main outcomes in Appendices.

Results - Key stakeholders

The literature review identified several stakeholder types. By combining these outcomes with results from interviews and additional research, key stakeholders in the bidirectional charging (V2G) ecosystem were found to be the TSO, DSO, energy supplier (or producer), aggregator, public / private EV owner or EV driver, OEM, CPO, the government and society. It was further discussed that the involved stakeholders largely differ depending on the use-case (i.e. whether V2G is performed via homes, buildings or public charge points) and that entities can take multiple stakeholder roles within the system.

Results - Value offerings

With the help of the literature review and interviews, key benefits of bidirectional charging (V2G) could be distinguished. The first and most mentioned benefit is revenue generation, which is performed through one of the following revenue models: self-consumption, peak shaving, DSO services, energy (SPOT) market trading and TSO services. Other benefits were the increased EV sales for OEMs, lower grid expansion costs, lower renewable electricity loss, security of power supply, lower CO_2 emissions and an overall decrease in electricity prices.

The expected costs are the EV hardware and software costs, charging infrastructure costs, open EMS/BMS system costs, optimization algorithm costs, control and measurement system costs, increased administrative or transaction costs, battery degradation costs, social costs of flexibility and range anxiety, and the regulatory costs. Based on these results, a value distribution was made, which could help to identify uncertainties with regards to the value distribution and individual value offerings.

Results - Value alignment challenges

Based on the uncertainties with regards to the value distribution and topics of discussion among stakeholders, some main alignment challenges have been identified. Discussions took place with regards to the size of generated revenues and the distribution of these revenues among stakeholders. This also large related to the control of charging behaviour, as multiple parties want to control the charging behaviour of the EV battery to offer services to the end customer.

Another large topic of discussion amongst stakeholders is the decision whether the inverter - that is required for the conversion from DC to AC - can be put either in the EV or charging point, increasing the costs of the EV or charging infrastructure.

Management implications/recommendations

Based on the results, several management implications and recommendations were provided for a potential ecosystem orchestrator, stakeholders and future research.

First of all, a focus on the implementation of V2B is suggested, mainly considering businesses and EV fleets, since bidirectional charging could provide large benefits to those stakeholders in terms of secured power supply. Secondly, it is expected that energy suppliers, OEMs and the DSO should stimulate the implementation of V2H and V2B by collaboratively offering an integrated bidirectional charging management system, EVs and charging stations. Thirdly, to solve the alignment challenge of the V2G revenue size and distribution, quantitative simulation models have to be created that consider dynamics in a future electricity market and account for various sensitivities. Fourthly, it is recommended that the impact of various bidirectional charging services on the local distribution grid should be examined. Fifthly, European standards need to be created to stimulate interoperability of different operators and enable implementation of V2G via V2P. Lastly, it is recommended to create an open data platform that regulates optimization of the different services for the electricity grid and creates transparency with regards to the EV battery control.

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Abbreviations

AC	alternating current
BSP	balancing service provider
BRP	balancing responsible party
BTM	behind the meter
CPM	charging point manufacturer
CPO	charging point operator
CP	charge point or charging station
DC	direct current
DSO	distribution system operator
e-MSP	e-mobility service provider
EV	electric vehicle
EVSE	electric vehicle supply equipment
FCR	frequency containment reserve (primary)
FRR	frequency restoration reserve (secondary)
FTM	in front of the meter
ISO	international standard organisation
OEM	original equipment manufacturer
OCPP	open charge point protocol
SOC	state of charge
V2B	bidirectional vehicle-to-building connection
V2H	bidirectional vehicle-to-home connection
V2P	bidirectional vehicle-to-public connection
V2G	bidirectional vehicle-to-grid connection
V2X	bidirectional vehicle-to-everything connection
VRES	variable renewable energy sources (i.e. solar PV or wind)
TSO	transmission system operator

1. Introduction

Climate change mitigation calls for decarbonization of all sectors (IPCC, 2022). Electric vehicles (EVs) are expected to play an important role to achieve the intended reduction in road transportation emissions (IPCC, 2022; IRENA, 2019). The rise in the adoption of EVs will be accompanied by a significant increase in electricity demand. In the Netherlands, the national government has set the ambition to have all newly sold cars emission-free in 2030 (Klimaatakkoord, 2019). In the same timeframe, variable renewable energy sources (VRES) such as solar PV and wind energy are expected to cover 70% of electricity production. Together with the utilization of VRES, EV adoption poses large grid congestion challenges for grid operators (Roos & Bolkesjo, 2017). Since grid congestion could impede local VRES projects and threaten power supply security, grid operators are forced to invest in expensive grid reinforcements or large batteries (Brinkel et al., 2020). Especially in the Netherlands, new grid solutions are critical, since grid capacity is already becoming scarce in almost every Dutch region (RVO, 2022).

While the "uncoordinated" charging of EVs has an additional destabilizing impact on the grid, "coordinated" or smart charging of EVs could help to address grid congestion problems (Van der Kam & Van Sark, 2015; Gschwendtner et al., 2021). As widely suggested throughout research and practice, bidirectional charging could take this one step further by enabling a two-way power exchange between the vehicle and the grid (V2G) (Tan et al, 2016; Pearre & Ribberink, 2019). It is argued that vehicles can be connected to the grid via homes (V2H), buildings (V2B) or through public charging stations (V2P). When a V2H or V2B connection is made, the EV battery could already act as local storage solution of excessive local renewable energy production, lower the building peak load or provide emergency backup for home or building owners (Noel et al., 2019). When connecting vehicles to the grid, additional services can be offered to energy suppliers or grid operators including local congestion management or balancing services (Noel et al., 2019).

Despite its potential advantages for grid relief, bidirectional charging still experiences limited commercial implementation (SCIS, 2020; Gschwendtner et al., 2021). Throughout literature, various reasons are given for this. Sovacool et al. (2017) argue that a shared vision among key stakeholders is lacking. In the two related industries - energy and transportation - and among individual stakeholders, different ideas exist about the likelihood of the technology being successful. Besides, bidirectional charging involves a highly complex system structure and the temporarily dynamic business models make value attribution to individual stakeholders hard to measure (Sovacool et al, 2020). Gschwendtner et al., 2021 argue that in order for bidirectional charging to move forward, clearer insights into the value propositions for different EV user segments as well as an examination of the various types of companies and their motivation to participate in bidirectional charging are required (Gschwentner et al., 2021).

This research takes the *ecosystem* construct by Adner (2017) as an appropriate structural framework to guide further understanding of the complex dynamics of bidirectional charging system development. The ecosystem is viewed as an alignment structure consisting of different actors, activities, positions and links. It helps to explain how the transition towards a new bidirectional charging ecosystem requires solving an alignment challenge (Adner, 2021). A shared vision needs to be formed amongst actors regarding the ecosystem value proposition and its corresponding alignment structure (Adner, 2017). Besides, new ecosystem development requires each participant to feel motivated by recognizing its individual value offering - the surplus of benefits and costs (Adner, 2013; Thomas et al, 2022). According to Thomas et al. (2022), value offerings are mainly identified during processes of value discovery and negotiation, which are considered of highest importance during early stage ecosystem development.

This research seeks to broaden the understanding of alignment challenges, and processes of value discovery and negotiation during early-stage ecosystem development by applying this to the case of bidirectional charging for the purpose of solving the described grid challenges. Throughout this research, the term *value alignment* is used to describe an agreement amongst ecosystem stakeholders regarding the individual value offerings in the ecosystem. It is expected that once value alignment is reached, value is distributed in such a way that each stakeholder feels incentivized to take its role in the ecosystem based on its individual value offering. Based on the above, a research approach was formed, comparing insights from broad literature research and interviews with stakeholders and experts in the context of the Dutch bidirectional charging (V2G) ecosystem. With the help of the ecosystem construct, a case study approach and various qualitative research methods, this research answers the following research question:

What recommendations can be formed based on an analysis of value alignment in the Dutch bidirectional charging (V2G) ecosystem?

In the following chapter, the theoretical framework used in this research is further clarified, explaining concepts such as ecosystem structure, alignment challenges and the process of value discovery and negotiation. In Chapter 2, the topic of bidirectional charging and the Dutch case study are further elaborated upon by explaining its applications, related protocols and the latest Dutch demonstration projects. In Chapter 3, it is further explained what the research design looks like. In Chapter 4, involved stakeholders within the ecosystem are discussed. In Chapter

5, the potential value offerings within the bidirectional charging ecosystem are identified through a discussion of benefits and costs. In Chapter 6, value alignment challenges are discussed based on the previous insights. In the last chapters, a conclusion is drawn, recommendations are provided and limitations of the research are discussed.

2. Theoretical Embedding

Throughout this chapter, the theoretical framework and concepts that underlie the proposed research question are further elaborated upon. The *ecosystem* construct is introduced to serve as an holistic framework by providing a structural, strategic, systemic and evolutionary perspective on how new innovations or value propositions emerge. Based on these insights, the importance of alignment with regards to stakeholders' roles and individual value offerings for early stage ecosystem development is recognized.

2.1 Introduction to ecosystems

Since Moore introduced the term "*ecosystem*" into the management literature in 1993, it has received large attention from both scholars and managers. Eversince, the term has been used throughout strategy research and practice to emphasize interdependence across organizations and activities. In general, ecosystem literature differentiates between different types of ecosystems, of which four types are most prominent; entrepreneurial, knowledge, business and innovation ecosystems (Cobben et al., 2022). These types of ecosystems for example differ in terms of purpose, perspective, structure and system boundaries. This research focuses on the innovation ecosystem, which has been defined by Autio and Thomas (2014) as:

> *"a network of interconnected organizations, organized around a focal firm or platform, incorporating both production and use side participants, and focusing on the development of new value through innovation".*

Through this definition, ecosystems are proposed to offer the complete system view. The concept moves beyond the traditional value chain, by not only considering linear buyer-supplier interactions, but suggesting an interdependent network of compatible modular offerings (Autio and Thomas, 2014). Furthermore, ecosystems distinguish themselves from clusters, innovation networks, industry networks and user networks by focusing on both the user and production sides. Besides, they broaden the view of value networks and constellations by including value appropriation and use (Autio and Thomas, 2014).

Whereas earlier research often viewed ecosystems as actor-centric "*networks of affiliated organizations*'', Adner (2017) suggests a structural view of the ecosystem. The actor-centric view can be useful to analyze network interactions between partners on a macro level but offers limited insights into value creation in more complex networks, platforms or multi-sided markets. The structural view focuses on the interdependent value creation among actors to serve a focal value proposition. Following this, Adner (2017) defines the ecosystem as:

> *"the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize*''

The 'focal value proposition' defines the boundaries of the ecosystem, usually from the perspective of one firm or platform (Adner, 2017). The 'multilateral set of partners' refers to the presence of multilateral interdependencies in the set of relationships between all actors on which the focal value proposition depends. The 'alignment structure' is used to describe the mutual agreement among the members regarding positions and activity flows. The alignment structure is often visualized in a value blueprint, which shows how value is (expected to be) created in the interdependent collaboration underlying the focal value proposition (Adner, 2017; Lingens et al, 2021).

The value blueprint is characterized by four elements: activities, actors, positions and links (Adner, 2017). The 'activities' are the discrete actions which need to be undertaken to create the value proposition, whereas 'actors' are the entities that undertake these activities. Following this, 'positions' are specified locations in the flow of activities across the system. These specify who hands off to whom. At last, the 'links' refer to the transfers across positions of various content e.g. data, materials, funds etc. (Adner, 2017).

2.2 Disruption and (re)alignment challenges

In line with evolutionary thinking, it should be noted that ecosystem structures are dynamic and subject to disruption. When Christensen (1997) introduced the concept of 'disruption', he meant the process where a new innovation initially serves a niche segment and then suddenly outperforms the firms in the mainstream market. From an ecosystems perspective, it is proposed that not the innovation on its own but the ecosystem as a whole is to be disrupted (Dedehayir et al., 2017; Oghazi et al., 2022). Following this, the disruption of an incumbent ecosystem by a new value proposition calls for a realignment of the ecosystem structure and its value blueprint (Dehehayir et al, 2017; Adner, 2017; Oghazi et al, 2022; Autio, 2022). This requires the focal firm to approach the alignment of partners and secure its role in the competitive ecosystem (Adner, 2017).

As shown in Figure 2.1, by moving from an emerging ecosystem to an established industry, an alignment challenge is to be overcome. This is described as "*the initial hurdle entails transitioning uncoordinated actors in an emerging ecosystem into stable, structurally embedded patterns*" (Adner, 2021). Following Adner (2017), the alignment challenge can be split into activity-based challenges and partner expectations. Activity-based challenges are categorized into co-innovation risks and adoption chain risks:

- The co-innovation risks refer to the stakeholders' ability to undertake new activities that underlie the planned contributions.
- The adoption chain risks are the partners' willingness to undertake the required activities, based on their priorities and incentives for participation in the ecosystem.

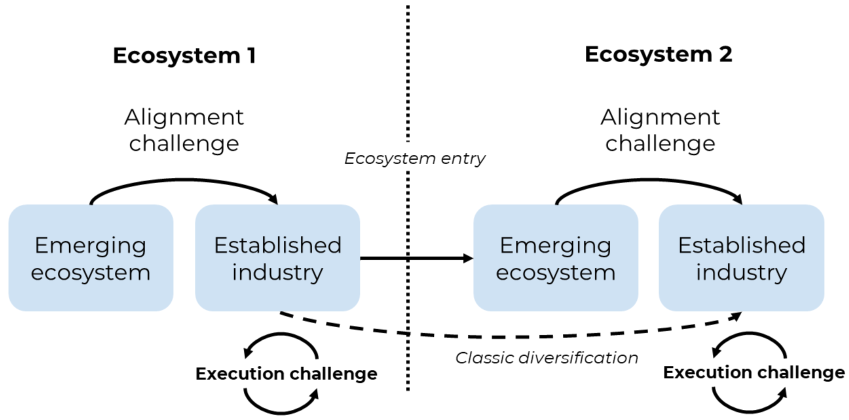


Figure 2.1. Ecosystem cycle of emergence and maturity (based on Adner, 2021).

2.2.1 The orchestration challenge

More recent research refers to the role of the orchestrator as a facilitator and designer of the ecosystem (Autio, 2021; Lingens et al, 2021; Thomas et al., 2022). The orchestrator is often characterized by its ability to assert control through resources, infrastructure or dynamic capabilities (Lingens et al., 2021). Most actors have to claim legitimacy for participation in the ecosystem - their contribution to value creation (Adner, 2021). However, since the ecosystem orchestrator leads the ecosystems' emergence, it often needs to motivate other system participants to follow the proposed value proposition (Autio, 2022). This requires finding the right balance between developing a shared vision and meeting the self-interests of involved actors that influence, facilitate and motivate their actions (Valkokari et al., 2017; Adner, 2006). From the orchestrator's perspective, the previously described alignment challenge comes down to an ecosystem orchestration challenge:

> *"How can ecosystem participants persuade others to behave in ways such that the value of the focal participant's offering increases in the eyes of the eventual recipient of the ecosystem's collectively generated value offering?" (Autio, 2022)*

To approach this challenge, it should be considered that different actors may have different views on the value proposition of the ecosystem (Adner, 2017; Valkokari et al, 2017). Based on this, an ecosystem analysis must account for the various interests of actors in terms of value capture and their divergence in perspectives around value creation and distribution. In his book, "Winning the Right Game", Adner (2021) also argues that succeeding in ecosystems requires participants to not only understand and strategize roles and structure for themselves, but also for partners on whom their success depends.

Because of the multilateral interdependency between partners, ecosystem emergence is often considered a highly interactive and multilateral process (Thomas et al., 2022). When designing a value blueprint, the orchestrator has to multilaterally negotiate what is "valuable" and investigate what participant roles and individual value offerings are required to deliver the ecosystem value proposition.

2.3 Value discovery, negotiation and alignment

In Figure 2.2, the three stages of three stages of ecosystem emergence identified by Thomas et al. (2022) are shown; the launch, expansion and established stage. Throughout these three stages, four distinct processes of collective negotiation and discovery take place. These processes include value discovery, collective governance, platform resourcing and contextual embedding and are described in table 2.1.

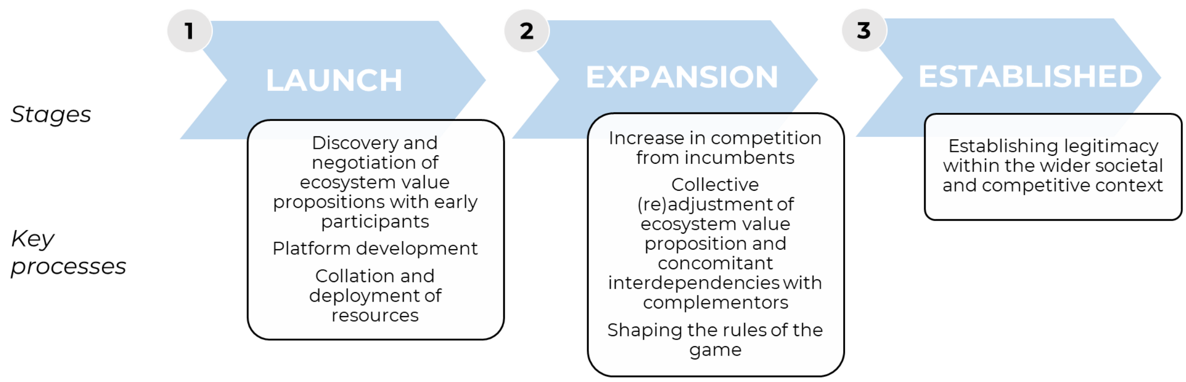


Figure 2.2. Ecosystem stages and their key processes (based on Thomas et al., 2022).

Table 2.1. Descripton of ecosystem development processes (based on Thomas et al., 2022).

Process	*Description*
Value discovery	Value discovery process consists of two main activities. First, the design and establishment of an overarching ecosystem value proposition with early participants, which also includes negotiation regarding the overall purpose of the ecosystem. After this, the individual value offerings should be identified - the benefits that contributing stakeholders may receive through the ecosystem value proposition.
Collective governance	Collective governance is the process of regulating participation in the ecosystem. It requires balancing the tensions between stakeholders' conflicting goals when forming a shared value proposition. Besides, it includes the negotiation process in which rules of participation are formed and roles are defined and assigned to stakeholders.
Platform resourcing	Platform resourcing considers the acquisition of financial resources and internal capabilities. Acquiring these can help to enable ecosystem emergence and further scale-up as it enables open-ended obligations for the ecosystem stakeholders which can be resolved through collective negotiation.
Contextual embedding	Contextual embedding refers to the creation of legitimacy in the wider societal and competitive context. Sometimes the value proposition of a new ecosystem threatens to substitute other value propositions that are already present in the competitive landscape. It is argued that activities of social embedding and regulatory processes can help towards legitimacy and cognitive acceptance of the new ecosystem.

Each of the four processes has a different contribution in different stages of ecosystem emergence (Thomas et al, 2022). From these findings, it becomes evident that in early-stage ecosystem emergence, the process of value discovery has the highest contribution (35%), followed by collective governance (33%) and platform resourcing (30%). In the second stage, the importance of contextual embedding grows. Throughout this research, each of the processes is considered, while the main focus remains on value discovery.

2.4. Relation to the research question

As explained, this research investigates *what recommendations can be formed based on an analysis of value alignment in the Dutch bidirectional charging (V2G) ecosystem.*

Whereas most of the described ecosystem theory is based on an ex-post investigation of ecosystems that are already in place, in this research the ecosystem construct is used to guide the development of a newly developing ecosystem for bidirectional charging in the context of grid relief. Rather than taking a view from one focal firm perspective, it takes the viewpoint of the ecosystem orchestrator by identifying all potential value offerings of ecosystem stakeholders from each of their perspectives. By focusing on the expected value among stakeholders, identification of alignment challenges takes place in terms of partner expectations and adoption chain risks, following Adner (2017).

As a result of this, and already explained in the Introduction, this research focuses on a distinct type of ecosystem alignment, which it calls value alignment due to its focus on value offerings. It is therefore considered a certain agreement amongst stakeholders regarding the individual value offerings as part of the overarching ecosystem value proposition. Reaching ecosystem value alignment would imply that no uncertainty exists concerning the way in which value is distributed over the ecosystem stakeholders. Besides, it is expected that based upon the agreed value distribution, each of the involved stakeholders would feel motivated or incentivized to contribute to the development or operation of the ecosystem.

3. Bidirectional charging

This chapter explains the difference and relationship between the concepts related to bidirectional charging, the required charging technologies and some of the key protocols related to the technology. Following this, the most relevant Dutch demonstration projects are briefly discussed.

3.1 Conceptualization

Bidirectional charging is often mentioned through or in combination with various concepts. Vehicle-to-everything (V2X) is the generic term which is often used to describe the application of EV batteries for other purposes than operating that vehicle (Pearre & Ribberink, 2019; Jones et al. 2021). More specific concepts mainly distinguish between the types of entities responsible for the energy dispatched from the vehicle (Tan et al., 2016; Pearre & Ribberink, 2019). Based on the literature, a list of the most common concepts related to bidirectional charging is provided (Pearre & Ribberink, 2019; Noel et al., 2019):

- Vehicle-to-load (V2L) refers to the connection between the EV and a single device, such as a cooler or stove;
- Vehicle-to-vehicle (V2V) refers to the connection between vehicles, which allows one vehicle to provide a load to another vehicle;
- Vehicle-to-home (V2H) refers to the exchange between the EV and home or non-commercial building) power network;
- Vehicle-to-building (V2B) explicitly refers to a commercial building that pays a demand charge to the electric utility;
- Vehicle-to-public (V2P) refers to the exchange between the vehicle and public charge points, or car sharing;
- Vehicle-to-grid (V2G) describes the exchange between the EV and grid through the control and management of a (local) aggregator.

This research leaves out V2L and V2V since these types of V2X connection are already commercialized and not connected to or expected to significantly relief the grid. Furthermore, the application of V2H/V2B behind-the-meter (BTM) is taken into account during this study. However, the main focus of this research is on in-front-of-the-meter (FTM) applications with V2G via V2H, V2B or V2P, since this has the highest potential for grid congestion relief (Noel et al., 2019). In Figure 3.1, a visualisation is provided of the bidirectional power exchange in V2H, V2B, V2P and V2G applications.

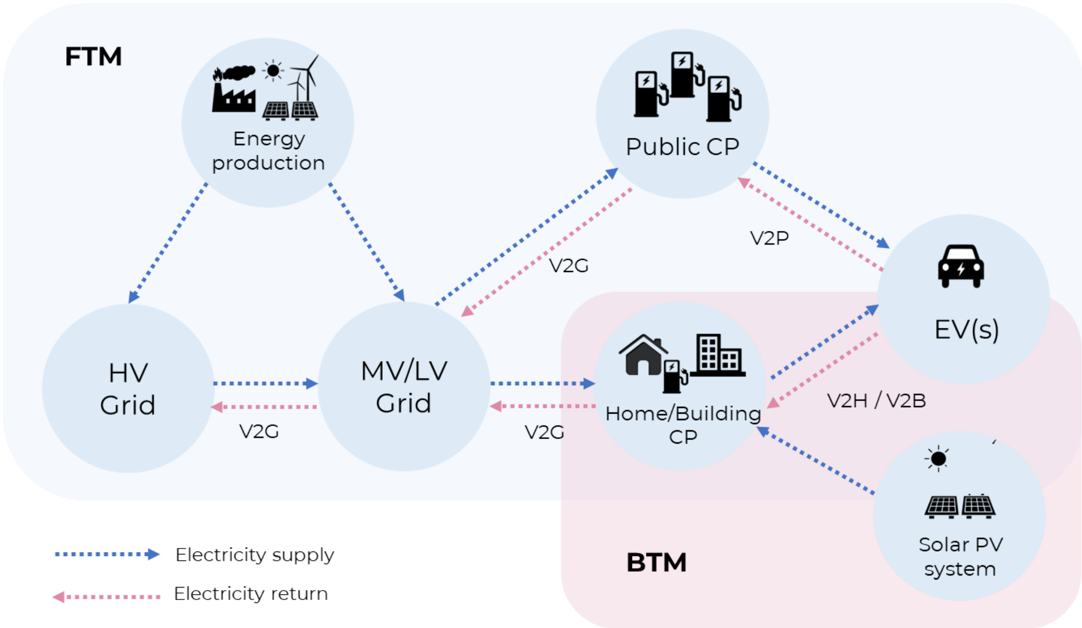


Figure 3.1. Visualisation of V2H, V2B, V2P and V2G based electricity exchange.

3.2 Charging technologies and protocols

Charging technologies

When charging an EV battery, the grid electricity is converted from alternate current (AC) to direct current (DC). Most EV batteries namely operate with DC, while the electricity in the grid uses AC (Kaufmann, 2019). Most of the charging stations in the Netherlands operate based on AC, which requires conversion to take place within the EV. Slowly, more fast charging stations are implemented, which operate based on DC. To enable a bidirectional power exchange between the car and the charging station, an additional inverter is required which can convert the electricity from DC back to AC power (IEA, 2019). The inverter can either be put into the charging station or integrated into the EV.

Communication protocols

Protocols are sets of rules and guidelines that certify smooth communication and data exchange between various entities. Two protocols are considered especially relevant in the case of bidirectional charging, the OCPP and ISO15118/20 protocols, visualised in Figure 3.2. The OCPP (Open Charge Point Protocol) is a global open communication protocol that allows for standardized communication between charging data from charging stations and back-end systems of charge point operators. ISO15118 is an international standard defining a data communication protocol between the charging station and the EV. This standard also enables bidirectional charging. The latest version of the standard is ISO15118/20.

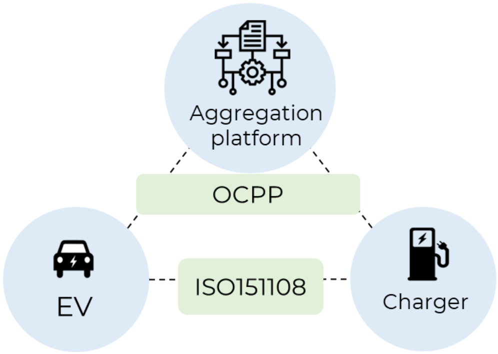


Figure 3.2. Visualisation of important V2G communication protocols.

3.3 Demonstration projects

Globally, more than 100 demonstration projects around V2G have been executed or started in over 25 countries (V2G-hub, n.d.). More than half of these projects took place in Europe, of which 14 in the Netherlands. In the Netherlands, most demonstration projects have been in the 'proof of concept trial' stage and did not include commercialization. A complete overview of Dutch demonstration projects is provided in Appendix I. From this, it can be seen that over the years, testing was focused mainly on small-scale implementation in a closed-off environment and a limited amount of involved stakeholders.

Most relevant demonstration projects in the Netherlands:

- *City-zen*. As part of the European program City-zen, several smart charging projects took place from 2014-2019 using a test side in Amsterdam. The V2G testing took place in collaboration with Alliander, Newmotion, Enervalis and Magnumcap. The project made use of 4 DC chargers and was mainly focused on pricing arbitrage and distribution services.
- *Smart Solar Charging*. The first SSC project took place between 2014-2019 and included testing with 22 public chargers connected to the grid in the Lombok neighbourhood in Utrecht by using EVs from Renault in a shared car scheme operated by WeDriveSolar. The key focus of this project was testing with AC charging standards for V2G. In the next stage, the project wants to scale up to 1000 chargers throughout the region of Utrecht.
- *SCALE*. As part of this Horizon Europe project, different V2X solutions and services are tested for different use cases, amongst others in three Dutch cities: Rotterdam, Utrecht and Eindhoven. The project has only started in June 2022, and will be led by Elaad, the Dutch knowledge and innovation centre for smart charging and charging infrastructure.

4. Methodology

This chapter further explains the research questions addressed in this research and the research methods that were used to examine these questions. Besides this, it is explained how trustworthiness of the research has been maintained throughout the research process.

4.1 Research concepts and questions

To substantiate ecosystem theory and provide a more concise methodology of identifying value offerings and alignment, the value case methodology (VCM) by Van Scheppingen (2012) and Dittrich et al. (2015) is used as an inspiration. The VCM also acknowledges that the motivation of stakeholders to contribute to realization of a common value proposition is based on benefits and costs. It offers a structured approach of identifying stakeholder value cases and value alignment.

By combining the ecosystem view and the value case methodology (VCM), four distinct sub-questions have been formulated which help to structure the process of answering the main research question. An overview of the sub-questions and research structure is provided in Figure 4.1.

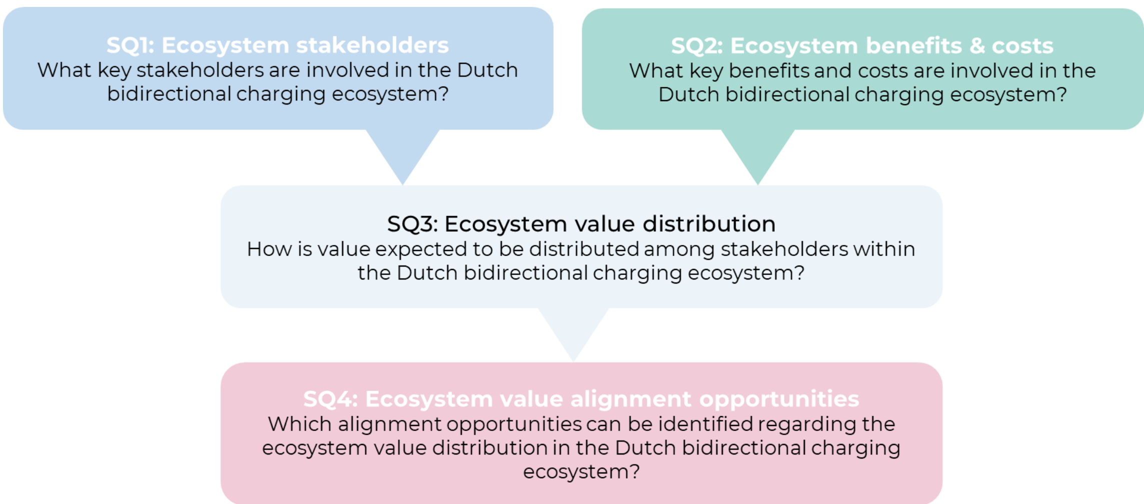


Figure 4.1. Structure of research questions.

SQ1: Ecosystem stakeholders.

Both ecosystem literature and the VCM emphasize on the importance of identifying key actors (Adner, 2017; Thomas et al., 2022) or key stakeholders (Van Scheppingen, 2017) for the identification of value offerings or cases and (ecosystem) alignment challenges. For this reason, the first sub-question is focused on the identification of the key stakeholders within the Dutch bidirectional charging ecosystem. The ecosystem construct connects the involved actors into a value blueprint through the expected activities, positions and links. These are also recognized, and discussed within Chapter 5.

SQ2: Ecosystem benefits and costs.

Both ecosystem theory and VCM assume the motivation of potential contributors to a collective value proposition to depend on their individual value offerings or cases, which can be derived from the benefits and costs (Adner; 2013; Van Scheppingen et al., 2012; Dittrich et al., 2015)[1]. The VCM does not only take monetary value into consideration but also identifies non-monetary value (e.g. social and ecological value). In their view, expanding beyond the financial namely increases the likelihood that all sorts of motivators or demotivators are identified. At the same time, this would further decrease the appearance of unexpected impacts, such as resistance to change (Van Scheppingen et al., 2012; Dittrich et al., 2015). The results are provided in Section 6.1 and 6.2, and discussed in 6.3. To illustrate the relative size of costs and benefits and inspire for future research, insights on the quantification of benefits and costs are provided in Boxes 6.1 to 6.9.

SQ3: Ecosystem value distribution.

Based on previous results, the distribution of value - in terms of benefits and costs - from SQ2 over the involved stakeholders from SQ1 is visualized in an ecosystem value distribution in Section 6.4. The presented value distribution provides an overview that allows for a comparison of the identified stakeholder value offerings or cases. It is expected that based on the uncertainties with regards to the overall value distribution, stakeholders could feel disincentivized or demotivated to contribute to ecosystem development.

SQ4: Value alignment challenges.

Since the concept of 'value alignment' is rather new, an exploratory approach was used to answer the question of value alignment challenges. It was expected that based upon the value distribution, certain unclarities would exist among stakeholders with regard to their individual value offerings. For example, the individual value offerings could be unclear as a result of different perspectives with regards to the activities assigned to certain stakeholder types. Another example would be the unclarity with regards to the size of benefits and costs, which could result in different sizes of value offerings.

[1] Unlike the value case methodology steps described by Dittrich et al. (2015), this research does not attempt to quantify value. However, quantitative findings from previous research were added to the results to provide the reader with some insights with regard to the sensitivities/factors these numbers depend on.

4.2 Research approach and methods

As explained in Chapter 1 and emphasized by Sovacool et al. (2021), the research topic of bidirectional charging - especially in the context of a V2G connection - is still in an early stage of development and considerd of high complexity. Besides, this research seeks for new insights with regards to ecosystem literature as it explores the processes of value discovery and negotiation through an analysis of value alignment. Due to the newness of the research topic, a qualitative - and more explorative - research approach is found to be most suitable. The approach uses a case study combining various qualitative data sources.

The research makes use of a combined inductive and deductive research approach. By applying the case study of bidirectional charging in the Netherlands to the theories on ecosystem development from amongst others Adner (2017) and Thomas et al. (2022), the applicability of these theories to practical use case are being tested. With the help of the value blueprint and VCM, it identifies stakeholder value offerings/cases. Furthermore, the research attempts to deepen the knowledge regarding stakeholder alignment within ecosystem development and build further on existing theory by deepening the knowledge on ecosystem orchestration through an analysis of value alignment.

4.2.1 Case study

One of the main methodologies used throughout the research is a case study, which focuses on the application of the explained theoretical concepts on bidirectional charging in the Netherlands. Case study research strategy is a widely adopted and appropriate method to gain an in-depth understanding of the dynamics present within a single setting (Eisenhardt, 1989). This case study did not only focus on bidirectional charging, but also specifically investigates this within the Dutch context to limit the research scope and leave out any country-specific differences. This was expected to complicate the interpretability of the results and decrease the credibility (internal validity) of the research.

The case study was performed through various research stages using different types of qualitative research methods, amongst which a literature review, interviews, webinars, events and additional in-depth literature research. By combining multiple, well-recognized sources of data collection the credibility of the research findings of the qualitative case study are increased (Eisenhardt, 1989; Kreuger & Casey 2009; Padgett, 2016). This namely reduces biases and helps to provide well-balanced empirical results (Eisenhardt, 1989). In Figure 4.2 the complete research process is shown, which visualises how the above explained research questions have been investigated througout the research in various research stages using different methods.

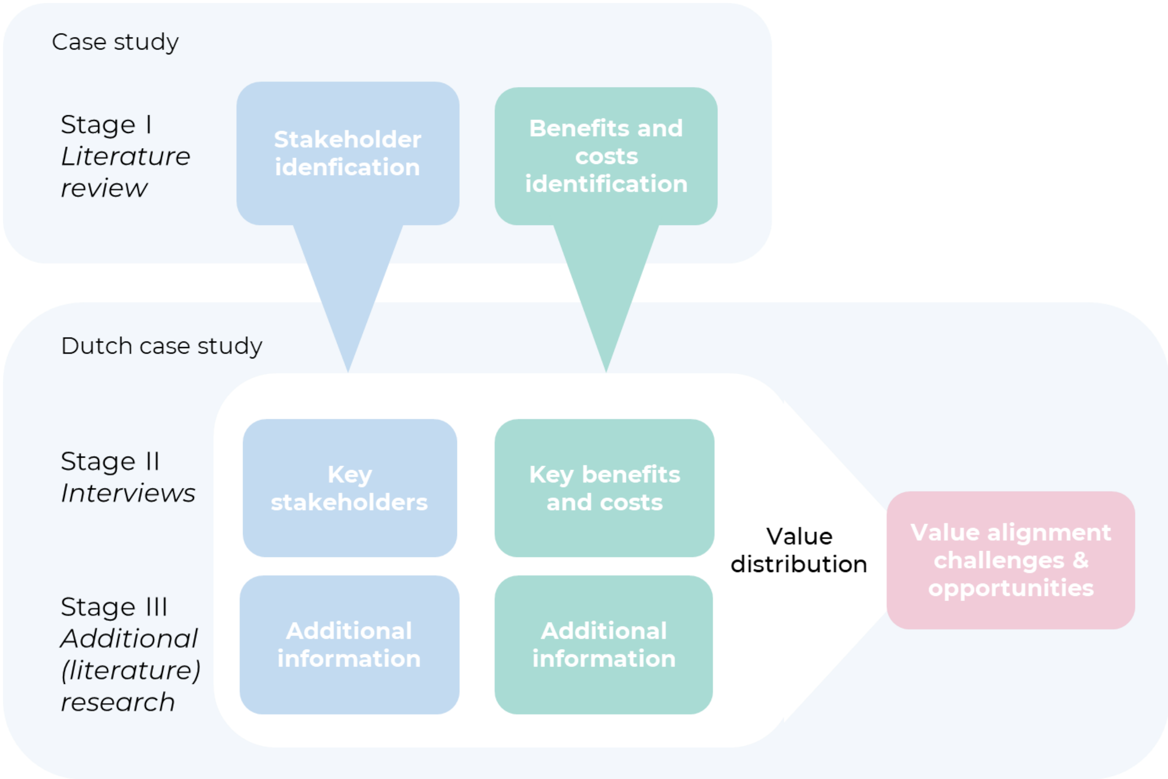


Figure 4.2. Research process and methods

Stage I: Literature review

In the first stage, an elaborative literature review is performed on the topic of bidirectional charging. The literature review has the purpose of identifying the main stakeholders (SQ1) and value in terms of costs and benefits (SQ2) addressed in the most recent literature on bidirectional charging. It enabled the researcher to obtain a certain level of knowledge with regards to the research topic to use througout the following research stages. Furthermore, it helped to identify of potential gaps in knowledge throughout literature and among the involved stakeholders. In addition, the review functioned as an extra validation method for the Dutch case results in following research stages.

The literature review combined various literature-based data sources, amongst which 20 scientific articles and (international) project reports. Scientific articles were mostly found in databases such as Google Scholar and Scopus, while searching for concepts related to the main research objects of the first two sub-questions, e.g. '*bidirectional charging*', '*V2G*', '*stakeholders*', '*actors*', '*value*', '*challenges*'. The project reports were mainly obtained by Google search, using the same type of search methods. Besides, the website of V2G-hub already gave an overview of the main reports on the topic of bidirectional charging in the context of V2G. In general, international studies were selected based on their relevance for the Dutch bidirectional charging (V2G) ecosystem development. The main results of the literature review are shown in Appendix II.

Stage II: Interviews

In the second stage of the research, 10 semi-structured interviews took place with Dutch stakeholders and/or experts. These stakeholders and/or experts were selected and approached based on their contribution to demonstration projects, events or articles about bidirectional charging (V2G) and their expected role(s) in the new bidirectional charging (V2G) ecosystem - based on the results of the literature review. An overview of the interviewees and the (potential) stakeholder roles these reflect in the ecosystem is provided in Appendix III.

During the interviews, open-ended questions were used to obtain an understanding of their view on the key (future) ecosystem stakeholders - and get a first grasp on their activities, positions and links. By comparing the literature with the interview results, the key involved stakeholders could be selected. In the same way, the costs and benefits - which were identified in the literature review - were verified and/or added upon by asking open-ended questions about the potential value of and costs - also in the form of requirements or challenges. In Appendix III, both the interview protocol and the relation of certain interview questions to the research questions have been provided.

After each interview took place, the interview was transcribed and coded. The coding process existed of a combination of open, axial and selective coding as well as concept-driven coding - based on concepts derived from the literature review. Open codes were further organized and categorized through processes of axial and selective coding. After this, the concept-driven categories and new-found categories were allocated to the right subquestions. Throughout the coding and writing process, several quotes were selected to support the readers' comprehension of the interviewee's conception/intention and minimize the possibility of misinterpretation of the results. As shown in Figure 4.2, all of these insights were used to form the ecosystem value distribution.

Stage III: Additional (literature) research

In the third research stage, both during and after the interviews, more in-depth literature research took place in the form of scientific articles, as well as Dutch news articles and project reports. Additional information searched for to obtain a more complete understanding of statements and concepts mentioned during the interviews. Especially when the interviews pointed out new findings with regards to stakeholders, values or costs, this additional literature research could be used to verify these new results. The additional information was also searched for with the help of Google search, Google Scholar and Scopus. However, more specific keywords were used than throughout the literature review in stage I, such as 'balance responsible party', 'self-consumption' or 'congestion management'.

Besides this, some additional qualitative data sources were recommended by several interviewees. Therefore, aside from the literature research, some extra contextualinsights were obtained through a webinar by Ecomobiel (2022) and the attendance at two international conferences discussing the topic of bidirectional charging: "*The Road to Decarbonisation: Clean, Smart and Secure Solutions*" and "*Battery On Wheels*".

4.3. Validity and reliability

The validity and reliability of the research outcomes are reflected upon based on four criteria for trustworthiness of qualitative research introduced by Lincoln and Guba (1985). These criteria are credibility (internal validity), transferability (external validity/generalisation), dependability (reliability) and confimability (objectivity).

Credibility refers to the accuracy of findings, and the issue of whether consistency exists between the provided qualitative results and the researchers perception of these results (Shenton, 2004; Kalu & Bwalya, 2017). As explained the use of multiple data sources improved the credibility of the case study results (Eisenhardt, 1989). Furthermore, moderator bias was minimized by asking mainly open-ended questions to the interviewees and by including multiple interview quotes to the results. During the coding of the interview data, both audio files and transcripts were analyzed at the same time to ensure a more accurate interpretation of interviewees statements. The use of quotes was further expected to support the readers' comprehension of the interviewee's conception/intention and to minimize the possibility of misinterpretation of the results.

Transferability of findings means how well these fit outside of the study situation (Lincoln and Guba, 1985; Kalu & Bwalya, 2017). In this research, first, an extensive literature review is performed investigating stakeholders, benefits and costs associated with bidirectional charging in all types of cases. The comparison of these insights with the Dutch case study in sections 5.2 and 6.3 results shows how well literature is generalizable to such a case. Besides, this research further explored a new concept and methodology, of which the transferability to different cases requires more testing on different ecosystems within different countries.

Dependability implies reflection on the stability of research findings in changing conditions (Lincoln and Guba, 1985). This is also evaluated upon by comparing insights from literature with the case study results in Section 5.2 and 6.3 and by future research recommendations in Chapter 9. Lastly, confirmability refers to the demonstration how findings emerge from data instead of the researchers own predispositions (Lincoln and Guba, 1985). This has been ensured by providing the interview transcrips and summaries, using quotes, and showing the main outcomes of literature research in Appendix III.

5. Stakeholders

In section 5.1, the results regarding key stakeholders in the bidirectional charging (V2G) ecosystem are discussed. In section 5.2, a short discussion is provided on the observations throughout the research stages and corresponding data sources.

5.1 Stakeholders

Throughout V2G literature, the most commonly mentioned involved stakeholder types were grid operators (TSO and DSO), aggregators, OEMs, EV owners/ drivers, and energy suppliers/retailers. Less often mentioned were charge point operators (CPO), fleet owners, home owners, battery manufacturers, charging station manufacturers, renewable energy producers, energy management service providers (e-MSP), mobility as a service (MAAS) providers, public transit operators, data hubs, and national and European governments and society. Based on the discussions with interviewees on stakeholders and with the help of some additional (literature) research, the key stakeholders - for the purpose of this research - were determined and described below.

Transmission system operator (TSO). The TSO manages the high-voltage (HV) electricity grid (between 110 and 400 V) (Tennet, n.d.). The TSO is responsible for continuous monitoring and management of the grid balance, which also includes planning, maintenance and expansion of the grid (Tennet, n.d.). Maintaining the overall grid balance is facilitated by the energy markets (intraday market and day-ahead market) and balancing or 'frequency regulation and reserve' markets. Regarding its role in the V2G ecosystem, the TSO sees its role and responsibility in optimizing energy market functioning and facilitating data streams between different market parties (I1-TSO). In the Dutch ecosystem, TenneT takes the role of TSO, and on a European level, ENTSO-E is involved as a collaboration of TSOs.

Distribution system operator (DSO). The DSO manages the regional distribution network, which distributes the electricity from the HV grid via the middle voltage (MV) and low voltage (LV) grid towards the end user (Tennet, n.d.). Although the responsibility of maintaining the grid balance rests with the TSO, the DSO is responsible for preventing local network congestion. Therefore, DSOs should accommodate all needs of system users and requests for new connections (Brinkel et al., 2020). Besides, DSOs are responsible for the planning, maintenance and expansion of distribution networks and have to measure and report the electricity consumption to the supplier and TSO (Tennet, n.d.). Since V2G will largely impact the local grid balance, the DSO would have to start monitoring and controlling the grid in a more efficient and digital way (I4-DSO). In the Dutch ecosystem, Enexis, Stedin and Alliander are the main DSOs. Elaad is involved as a knowledge and innovation centre for the EV charging infrastructure led by Dutch grid operators.

Energy supplier (or producer). The energy producer generates electricity from fossil fuel-based energy sources such as coal and gas, or renewable energy sources such as solar PV, wind energy and hydropower. Usually, a separate entity takes the role of energy supplier/retailer, buying the produced electricity on the wholesale market and distributing it to its customers through fixed contracts (Tennet, n.d.). When suppliers or retailers trade large volumes of energy, they take an official role as a balancing responsible party (BRP). The BRP is responsible for maintaining an energy supply and demand balance within its own energy portfolio or E-program (Tennet, n.d.). When inconsistency occurs in the energy program, the BRP has to pay a fee to the TSO (Tennet, n.d.).

Aggregator. In general, the aggregator bundles the flexibility of multiple small users or producers to offer balancing services on the electricity market to TSOs and/or DSOs (de Brey, 2017; Tennet, n.d.). For example, aggregators can forecast the electricity consumption and production capacity of their own customers to contribute to day-ahead and intraday energy source scheduling (Inci et al., 2022). At this moment, the aggregator role is often taken by ICT-based companies (Noel et al., 2019). In the electricity system, the aggregator is officially considered a balancing service provider (BSP). The BSP offers balancing energy or power to the TSO, which can be used to eliminate unforeseen imbalances in the electricity grid (Tennet, n.d.). In the future, aggregators are also expected to provide congestion services via the CSP, which offers location-specific congestion management services to DSOs or TSOs (Tennet, n.d.).

Public/private EV owner and EV driver. Taking into account the variety of V2G applications, this research distinguishes between private and public EV owners. Private EV owners are considered EV drivers who charge their vehicles at home, work or use public charging networks (Jones, 2021). Public EV operators include fleet operators (charging fleets overnight), MaaS providers (E-car sharing relying on public charging networks); public charging infrastructure providers (offering flexible charging options to EV users); public transport providers (electric buses & taxi services) (Jones et al., 2021). In the latter case, the public EV owner and driver are usually separate entities.

Original Equipment Manufacturer (OEM). This refers to manufacturers of EVs, who are usually involved in the production of the EV battery as well. With regards to bidirectional charging (V2G), the OEM is considered responsible for the EV hardware and software that allows for bidirectional power flow to the battery. Besides, the OEM usually provides a guarantee on the battery, which now needs to be adjusted to allow for a bidirectional power flow. Some OEMs have already commercialized bidirectional charging for Dutch customers in the form of V2V or V2L, including Nissan (Leaf), Mitsubishi (Outlander PHEV) and Hyundai (IONIC 5). Other car manufacturers which are currently testing the technology are Volvo, Renault, Fiat, Mercedes, Volkswagen, BMW, Kia, Skoda and Audi (NetNL, 2022).

Charging point operator (CPO). The CPO is the operator of public charging stations. The CPO is therefore responsible for both technical and administrative aspects regarding the maintenance and exploitation of these charging stations (I9-MP). In the bidirectional charging (V2G) ecosystem, the CPO is expected to facilitate V2G by installing, maintaining and controlling the required hardware and software in the charging station. In a private situation, the charging station is often owned by a home or building owner and operated by an energy supplier or aggregator instead of a CPO. Some examples of CPOs in the Netherlands are Total Energies, EQUANS and Bluecurrent.

Government and society. Throughout the research, European, national and local governments are expected to play a highly important role in the bidirectional charging ecosystem. Here, the European and national governments are mainly responsible for the creation of the right policies, as well as new rules and regulations such as standards and protocols. In the Netherlands, three ministries are involved, the Ministry of Economic Affairs and Climate, the Ministry of Finance and the Ministry of Infrastructure and Water Management. Since the government considers the benefits and costs for society, this research takes these stakeholders together.

5.2 Discussion

The above overview is based on the combined insights from the literature review, interviews, and additional research in the form of literature, a webinar and events. Therefore, the considerations with regards to the inclusion or exclusion of certain stakeholders to this research are further discussed. Some stakeholder types were mentioned throughout the literature, but based on the interviews and additional research, not included as key stakeholders in the context of this research. For example, the role of the e-MSP often appears to be fulfilled by the aggregator and is therefore left out to simplify the results.

Besides this, several studies did not include each of the above key stakeholder types. For example, the research conducted by Sovacool (2020), the DSO and CPO were not considered. This can be explained by the fact that V2G is can be implemented through V2H, V2B and V2P and offer different types of services to either the TSO, DSO or energy market parties. From the interviews, it became clear that a public CPO is usually not involved in the case of V2H or V2B. Apart from this, it was recognized during the interviews that multiple actor roles can be taken by one entity. For example, as one of the interviewees mentioned, when producers, retailers and/or suppliers of VRES become an aggregator, they could use V2G to reduce their own inconsistencies (I7-MP).

An overview of the involved stakeholders in each situation is shown through Figure 5.1, 5.2 and 5.3. The relations among stakeholders are visualized by means of the energy flows and value delivery of V2G services. Based on this, is expected that the different structural configurations in these three types of V2G situations also affect the individual value offerings/cases and overall value distribution over each of these stakeholders. Besides, it is expected that the more stakeholder roles an entity takes, the more activities it is involved in or responsible for and the more of the related benefits or costs the entity will obtain.

Figure 5.1. Stakeholder network in situation 1.

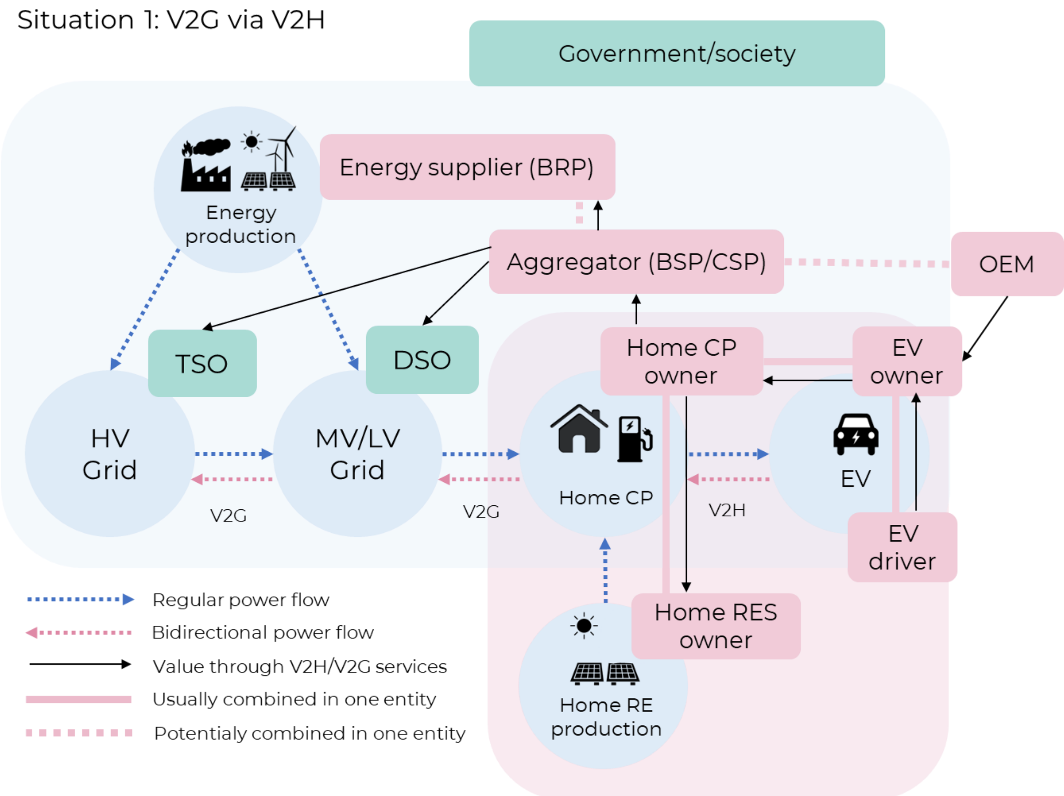


Figure 5.2. Stakeholder network in situation 2.

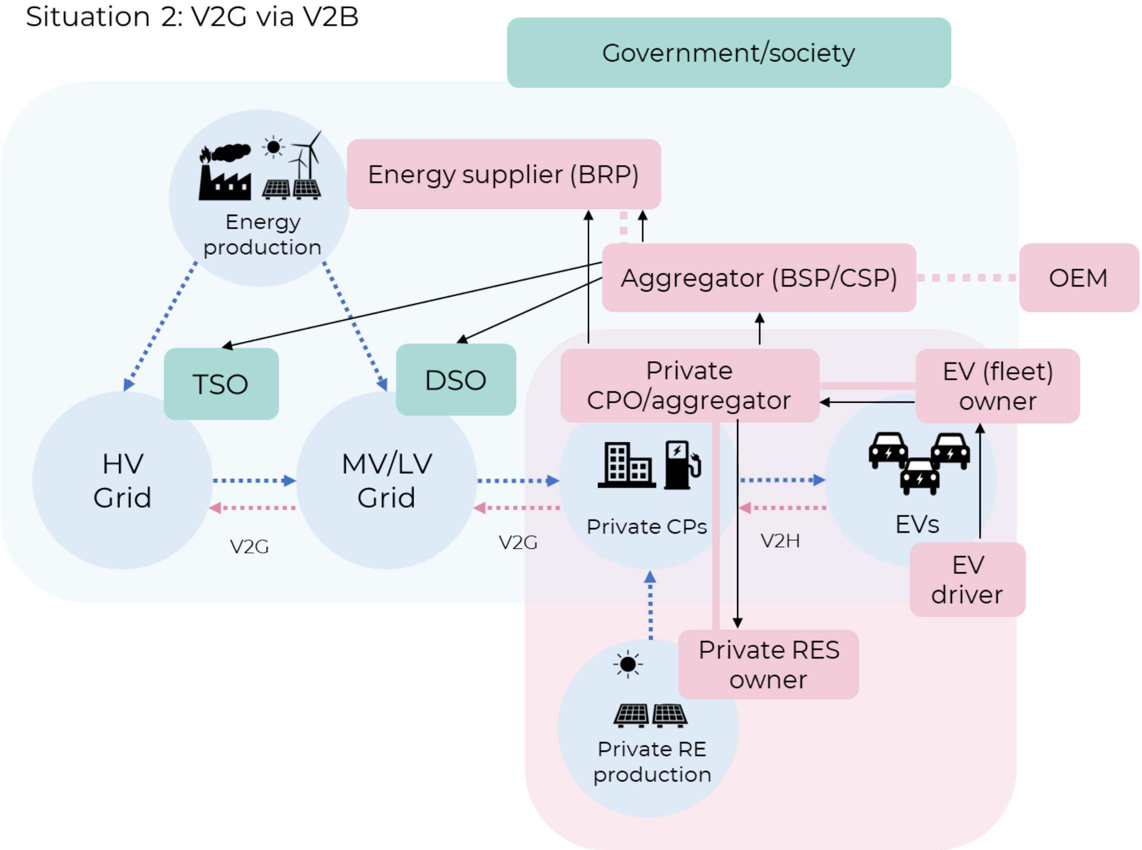
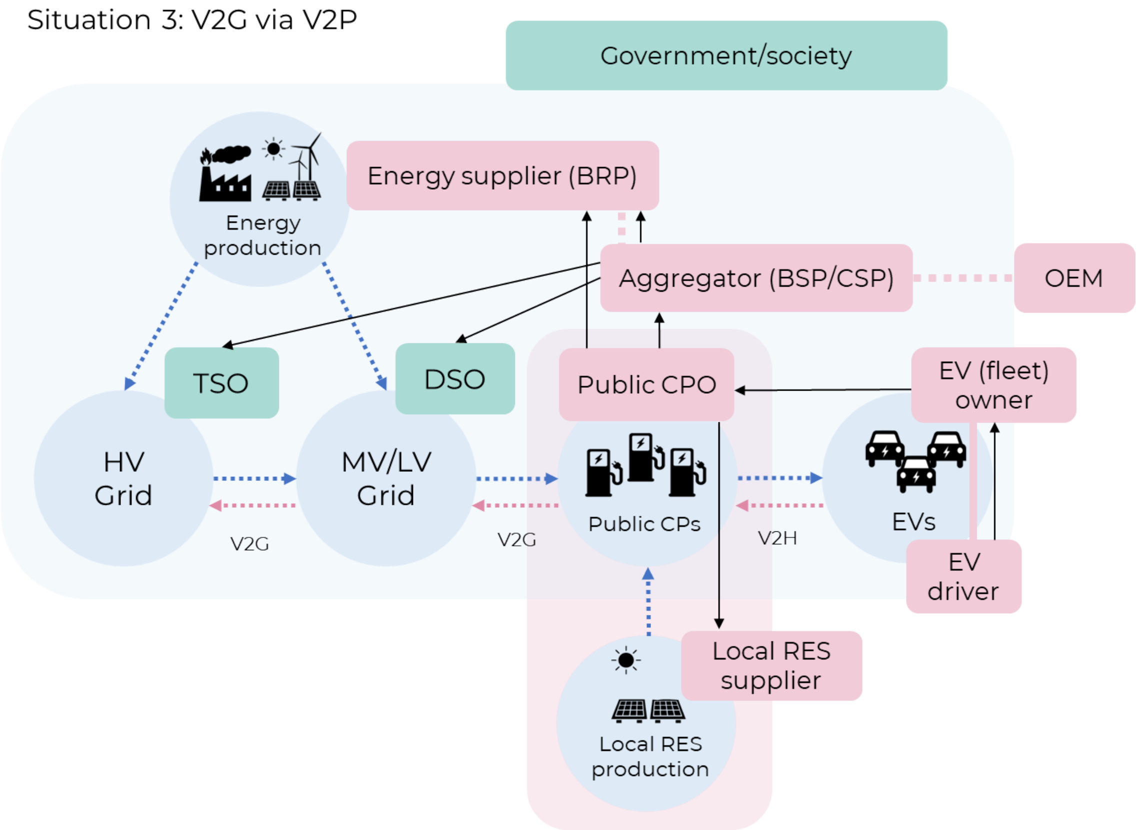


Figure 5.3. Stakeholder network in situation 3.



6. Value offerings: benefits and costs

This chapter further discusses the insights regarding SQ2 and SQ3. Section 6.1 and 6.2 elaborate upon the expected benefits and costs for all types of stakeholders. In 6.3, a short discussion is provided comparing the insights from different research methods. Based on previous results, 6.4 gives an overview of the individual value offerings by showing the distribution of the discussed benefits and costs over the previously identified stakeholders.

6.1 Benefits

6.1.1 Revenue generation

One of the most discussed value propositions identified for bidirectional charging is enabling the generation of revenues (Cenex, 2019; IREC, 2019; Cenex, 2020; Sovacool et al., 2020; Jones et al., 2021; PWC, 2021; Energinet, 2022). Some of the interviewees mentioned the potential revenue earnings to be the main benefit of bidirectional charging for the EV owner, which increases with high electricity prices (I3-MP; I6-OEM). However, the expected revenues have to be distributed amongst several stakeholders and depend on several factors. Not only to the EV owner, but also to other market parties such as the CPO, aggregator, energy supplier and OEM are expecting to take part of these revenues (I1-TSO; I4-DSO; I6-OEM; I7-MP; I10-OEM). The discussion with regards to the revenue generation and distribution is one of the identified alignment challenges which is further elaborated upon in Chapter 7.

During the research, several revenue models were distinguished that could enable market parties to generate revenues from bidirectional charging. First of all, the value of non-V2G revenue models such as maximizing self-consumption and peak shaving is evaluated. After this, some of the key V2G revenue models are discussed, amongst which local congestion management, energy market trading and grid balancing services. These were selected based on the outcomes of literature research and interviews.

6.1.1.1 Revenue model 1: Maximizing self-consumption (V2H/V2B)

When the EV owner is a prosumer (i.e. producing its own electricity - usually through a solar PV system), it can use the battery storage of its EV to increase self-consumption (Cenex, 2019; Cenex, 2020; ENTSO-E, 2021; Englberger et al., 2021; Kern et al., 2022). Self-consumption is also referred to as behind-the-meter (BTM) optimization and usually applies to the V2H and V2B use cases (Englberger et al., 2021; Kern et al., 2022). Since this revenue model does not use V2G connection, it is not as often mentioned in V2G-focused literature as other revenue models.

According to several interviewees, this revenue model is the easiest to implement (I5-DSO; I9-MP; I10-OEM). As long as electricity is stored and used behind the same meter, no regulatory issues - such as double taxation - arise yet (I5-DSO; I10-OEM). Besides, it does not require the implementation of a DSO data and measurement system on the cable level (I4-DSO). However, this revenue model is expected to have the lowest impact on grid congestion issues (I5-DSO). Besides, it is of the least interest to involved market parties (I6-OEM; I7-MP; I8-MP). Since this model mainly considers storing the peaks of local solar PV, revenues are mostly generated during the summer period (I2-DSO).

As shown in Box 6.1, the research by Kern et al. (2022) states that the self-consumption revenues largely differ and depend upon several factors, with the most important being the availability of the EV, PV peak power and feed-in tariffs. Interviewees also mentioned that the phasing out of the Dutch netting arrangement for feed-in tariffs and other proposed changes in the tariff system could enhance the value of storage systems such as V2G (I4-DSO; I6-OEM). Besides, the rising electricity prices further intensify the need for self-optimization through such storage solutions (I1-TSO).

Box 6.1. Insights regarding quantification of self-consumption revenues.

Recent research by Kern et al. (2022) used mixed-integer linear programming to model and compare the revenues of increased self-consumption through smart charging and bidirectional charging. Results show that the revenues of a non-commuter household using bidirectional charging for self-consumption are around €310 per EV per year, which is €100 higher than the revenues they identified for smart charging. When considering a higher EV battery capacity of 100 kWh, larger household demand of 5900 kWh, a larger PV system of 9.5 kWp and a lower feed-in tariff of 3.6 ct/kWh, the expected revenues could become €390 for smart charging and €835 for bidirectional charging.

6.1.1.2 Revenue model 2: Peak shaving (V2B)

Larger energy consumers pay significant fees for causing peak load on the local grid (Aasbøe, 2021; Englberger et al, 2021). Throughout literature, it is argued that bidirectional charging can contribute to lowering such peaks behind the meter and thereby reduce the energy bill of large energy consumers (Tchagang and Yoo 2020; Aasbøe, 2021; Englberger et al., 2021; Kriekinge et al. 2021)). Peak shaving can be very energy intensive and only required during demand peaks, which makes it easy to combine with other services. Research by Tchagang and Yoo (2020) found that peak shaving would result in less reduction in energy bill than offering of frequency services to the TSO. In contrast, it was found by Englberger et al. (2021) that in case of high building energy demand or peak load, peak shaving behind-the-meter offered relatively high profits compared to self-consumption, energy market trading or frequency services to the TSO.

None of the interviewees mentioned this revenue model explicitly. This could be partly explained by the fact that the main interested stakeholders such as businesses or other types of building owners were not involved in this research.

Box 6.2. Insights regarding quantification of peak shaving revenues.

First of all, Tchagang and Yoo (2020) found that peak shaving could reduce the electricity bill of the building owner with about 5% when using V2B through 5 EVs with an average battery storage capacity of 24 kWh in a building with 70 kWh consumption and 10 kW peak power. Since peak shaving is highly sensitive to tariffs, these results might not be transferable to the Dutch context. In the analysis of Englberger et al. (2021), in a multi-use strategy, peak shaving could result in a 956 euro annual cash flow. Research by Van Krieginge et al. (2021) tested the use of a model predictive control (MPC) algorithm for peak shaving on bill minimization of buildings, comparing the differences for smart charging and bidirectional charging algorithms. It is found that for bidirectional charging, the morning peak can be reduced by 34% (compared to 14% for smart charging) and peak-to-valley height can be reduced by 84% (compared to 31% for smart charging). Besides, larger building PV systems and higher minimum SOC result in the highest cost savings.

6.1.1.3 Revenue model 3: DSO services (V2G)

In many cases, literature mentions the offering of distribution system services as one of the revenue models of V2G (Reynolds et al., 2018; Arias, 2019; Borne, 2019; Cenex, 2019; SCIS, 2019; ENTSO-E, 2021; Jones et al., 2021). DSO services mentioned are for example congestion management, load shifting, peak shaving, valley filling and voltage drop. During the literature research, no previous studies were found that performed an analysis of the potential revenues that could be created through distribution system services.

Interviewees mentioned that testing with bidirectional charging for the purpose to offer local congestion management services to the DSO has only started recently (I8-MP; I5-DSO). Since the additional value V2G could have for the DSO depends highly on local conditions, the same applies to the potential revenues of this revenue model for the EV owner. However, it is expected that the DSO will pay revenues to the customers for their services in some way. "*If we need*

V2G for grid operation, the network operator will likely also pay money to the consumer" (I2-DSO). The compensation for the EV owner could for example be based on the prevented costs for transformer replacement (including the workforce and licenses) (I5-DSO). In general, interviewed market parties did not recognize the business case for V2G in congestion management at this moment. For example, a car sharing fleet owner stated "*We work a lot with grid operators - to prevent congestion - but we do not see the real business there*" (I3-MP).

6.1.1.4 Revenue model 4: Energy (SPOT) market trading (V2G)

In literature, it was recognized that energy market players can also participate in price arbitrage on the energy market through V2G (Reynolds et al, 2018; Cenex, 2019; Cenex, 2020; Sovacool, 2020; Jones et al., 2021; Energinet, 2022). Energy arbitrage through V2G is considered mainly relevant in the so-called SPOT energy markets; the day-ahead and intra-day energy markets. Throughout V2G literature, numerous studies have investigated the revenue that could be gained in these SPOT markets (Illing et al. 2016). Eventhough SPOT market trading has not been attractive in the past, the decreasing FCR remunerations and increase in price spreads - as a result of renewable electricity introduction and dynamic pricing - are creating new opportunities in this market (Englberger et al., 2021).

The value of this revenue model was explicitly recognized by OEMs and energy suppliers (I6-OEM; I7-MP; I8-MP). I6-OEM investigated the revenues that can be found in the future energy market, as shown in table 6.3. One of the electricity suppliers expects to combine V2G with a regular battery to help rectify their own imbalance on the SPOT market (I7-MP). Another electricity supplier had some issues regarding this model: "*That's exactly the model we did first, only our pool was too small. It was quite a difficult product to sell. Besides this, energy prices went in all directions…*". It was also mentioned that on the intra-day market, the expected revenues are larger than on the day-ahead market (I8-MP).

Box 6.3. Insights regarding quantification of SPOT market revenues.

Tepe et al. (2022) found in their research that currently, annual revenues on the intra-day market can vary from €76 to €203, while revenues on the day-ahead market vary from €4 to €28. However, these do not take into account future market prices. In October 2022, the primary results of an ongoing study were presented at the "*Battery on Wheels*" conference (Thewessen, 2022). In his study, Thewessen (2022) investigates the revenue potential for offering V2G services on the SPOT market in 2030 based on a simulation model. Depending on the amount of participating EVs, the total revenues are expected to lay between €200 and €600 per year. The study made use of public charging data from Elaad and assumed a 30% availability of EVs for V2G services. Revenues were found highly dependent on market saturation and charging behaviour.

6.1.1.4 Revenue model 5: TSO services (V2G)

Another V2G revenue model includes the aggregation of large amounts of EV batteries to offer balancing or frequency services to the TSO. Whereas the SPOT markets trade capacity (MWh), the frequency market is based on the amount of power (MW) that can be delivered on short notice. It was found that these margins provide sufficient incentives for aggregators to develop and maintain a V2G algorithm (SCIS, 2020). However, concerns are raised with regard to the future value of these services, since the market will saturated and revenues will drop (Cenex, 2019; Hoogvliet et al., 2017; Englberger et al., 2021).

Stakeholders also often mentioned the frequency market as one of the most important applications of V2G (I2-DSO; I3-MP; I8-MP; I10-OEM). As of the grid operator: "*For high-voltage lines and connections with other countries, we look at frequency control. The market is looking at this in order to maintain that 50 Hz*" (I2-DSO). One of the energy suppliers stated "*I do not necessarily see value on the intra-day market, but rather on the reserve markets*" (I8-MP). Within the frequency market, a distinction can be made between primary and secondary reserve market. Corresponding to research (e.g. Tepe et al., 2022), stakeholders expect the highest revenues for V2G in the FCR market (I8-MP; I10-OEM).

Primary reserve, or frequency containment reserve (FCR), requires the fastest response of the different frequency reserve markets (Tepe et al., 2022). With the penetration of VRES and fewer traditional synchronous generators, the need for FCR through storage systems is growing significantly (Englberger et al., 2021). However, based on a Dutch study by Hoogvliet et al. (2017), it is argued that the most value could be delivered when using V2G in the secondary reserve market, called frequency restoration reserve power (FRR / RRP). This is contracted through market bids that apply for 15-minute blocks, which can be submitted one hour before dispatch. They argue that primary reserve only takes into account the capacity price, and does not remunerate for the volume of the delivered energy.

Box 6.4. Insights regarding quantification of FFR revenues.

Tepe et al. (2022) have analyzed the revenues of bidirectional charging (V2G) on the primary reserve (FCR) market when optimizing the use of EV pools. Based on this research, depending on the number of EVs, bidirectional charging (V2G) could create an annual revenue of €220 - €380 euro at the Central European FCR market. Tepe et al. (2022) saw that revenues can be generated from a number of 115 EVs. The optimal amount of 243 EVs resulted in revenues of approximately €380 per EV per year. For secondary reserve, a Dutch study by Hoogvliet et al. (2017) found that the provision of FRR power to the TSO could result in revenues of between €120 - €750 per EV per year. These results were based on 2014-2015 market prices. The revenues within the given range depended on the size of the EV battery (capacity 12-85 kWh) and the EV availability (resident, commuter or resident-commuter). The value of FRR also highly depends on the future market size. The volume of the FRR market would already be saturated if all current Dutch EV drivers provide FRR services. When including 2 million participants, revenues could even decline by 66%.

6.1.1.5. Reflection on revenue models

The findings from previous research on revenue models are hard to compare, since revenues in these studies largely depended on various context-specific sensitivities including control algorithms, energy and feed-in tariffs, market penetration, PV system size, home or building energy usage and more.

During the interviews, it was further recognized that several V2G revenue models could be combined (I6-OEM). Most studies on V2H, V2B or V2G services have only investigated individual revenue models, such as self-optimization at home, or frequency regulation and reserve. Only some researchers have investigated the interaction effects of different types of revenue models and grid services. For example, in their research, Millner et al. (2014) suggested the primary use-case of bidirectional charging to be peak load reduction in the V2B context, while its second use-case could be frequency regulation services. Gough et al. (2017) combined the use of self-consumption, peak shaving and trading on the reserve, wholesale energy and capacity markets. Another study by Englberger et al. (2021) used mixed linear programming to investigate a commercial multi-use operation strategy for bidirectional charging. They examined the effect of including multiple value streams for users of bidirectional charging; including self-consumption increase (SCI), peak shaving (PS), frequency containment reserve (FCR) and spot market trading (SMT).

6.1.2 Increased EV sales

Throughout some literature and interviews, bidirectional charging is expected to have a positive impact on EV sales by OEMs. Kaufmann (2019) and Kern et al. (2022) argue if the generated revenues are high enough, this will become an attractive option OEMs could offer to customers. It could provide an additional incentive for citizens to purchase EVs. Besides the monetary benefits, Jones et al. (2021) mentioned that this service could deliver a green status to the EV owner.

During the interviews, it was also acknowledged that expect bidirectional charging could increase EV sales (I1-TSO; I2-DSO). For example: "*Once they are finally available, you can buy a car which you can make money with, so I think they will become very popular*" (I2-DSO). Interviewed OEMs agreed that especially V2G services could be a potential new business model for them since customers could receive revenues from these services (I6-OEM; I10-OEM). Hyundai already made V2L technology available and sees an onboard charger as an extra service to the customer (I10-OEM). OEMs are also considering to act as an aggregator and take a part of these revenues, in case they need to compensate for the large investment costs of hardware and software (I6-OEM; I10-OEM). However, to know whether offering V2G services fits into the existing business model of the OEM, more testing is required. The value that could be captured would largely depend on the value of previously described revenue models.

6.1.3 Lower grid expansion costs

As earlier addressed, the use of EVs is going to increase grid congestion issues to a large extent (Roos & Bolkesjo, 2017). In one one of the largest V2G trials, it was found that transformer capacity was already exceeded with 40% EV penetration (Quirós-Tortós, 2018). This was also acknowledged during the interviews, for example by I8-MP: "*Anyone who has an electric car will use about twice as much energy. This causes tensions on the grid, which lead to local congestion at certain times.*". Throughout the literature, it is argued that V2G could offer particular value at a local/distribution level by lowering the need for grid expansion and corresponding costs (Quirós-Tortós, 2018; Pearre & Ribberink, 2019; Cenex, 2020; ENTSO-E, 2021; Jones et al., 2021; PWC, 2021). The replacement and upgrading of generation, transmission and distribution equipment (stations and cables) requires high capital costs (Pearre & Ribberink, 2019; PWC, 2021).

Delaying grid expenditures not only represents a cost saving for the utility in terms of time and money, but also saves money for all ratepayers of the electricity grid - thus save costs for society (Pearre & Ribberink, 2019). Besides, the prevention of grid expansion reduces the need for manpower in the case of manufacturing and installing grid assets (Brinkel et al., 2020). This was further acknowledged by I5-DSO: "*If you don't have to replace a certain transformer, because you can use flexibility there, then less manpower is needed to upgrade the transformer.*".

The impact of bidirectional charging services on the grid upgrading costs requires further investigation (I4-DSO). Self-consumption in the form of V2H or V2B enables the EV owner or prosumer to directly use the electricity produced through its own system, therefore reducing its use of grid-produced electricity. Self-consumption is therefore expected to lower peaks on the electricity grid to some extent. However, I5-DSO does not expect the effects of (unregulated) self-consumption to make a large difference. "*Everything we do not have to supply as a network operator makes us happy, but self-consumption is not helping to the extend we need since it does not take grid balance into account*".

According to the I2-DSO, peak shaving through V2G has a large potential to lower the peaks on the low-voltage network. For example "*If you have an office area that is not able to connect to the grid because their grid capacity is too high, you could think of smart solutions to reduce the peak load at a certain area*" (I1-TSO). Still, the exact contribution peak shaving could deliver to the congestion (and voltage) problems compared to smart charging in the LV and MV grid still needs to be examined by the grid operator itself (I4-DSO). The value of the various services to the DSO largely depends on the conditions of the geographical location, since congestion problems can vary largely per electricity cable and transformer station (I4-DSO; I5-DSO).

For the HV network, the congestion problem is viewed differently. *"It is less of our problem with respect to congestion issues. We can make use of personal cars distributed through the country, but especially for balancing". (I1-TSO).* The TSO really views this as a market force. Regarding the services that V2G could offer to the grid, it was said: *"It is not a service we offer, it is a service the market will offer to us" (I1-TSO).* Besides, the use of V2G for grid balancing could even increase congestion problems on the lower grid (I1-TSO; I4-DSO). *"For coordinated congestion management, so TSO and DSO congestion management, it would really help to have EVs being able to do biddings" (I1-TSO).* In the UK, already an online market platform has been developed that centralizes the needs of several DSOs (Weiller et al., 2020).

Box 6.5. Insights regarding quantification of grid congestion benefits.

Van Kriekinge et al. (2021) found two bidirectional charging strategies that reduce peak power on the grid lower levels than prior to the introduction of the EV to the local grid. Lowering the minimum state-of-charge (SoC) of the EV would significantly improve the potential contribution of bidirectional charging to peak load reduction on the distribution grid. Brinkel et al. (2020) show that bidirectional charging can achieve cost savings of up to 32.4% compared to uncontrolled charging. The IEA (2011) found a similar result, concluding that bidirectional charging is expected to save the upgrading and replacement of transmission and distribution grid 30% in costs. A recent demonstration project on bidirectional charging in Rotterdam, part of the SCALE V2X/V2G program, has shown that the use of 66 EVs with a storage of 400 kWh and power of 10 kW could lower the peak usage of the grid by 14% (Automotive-Online.nl, 2022).

6.1.4 Lower (renewable) electricity loss

In the next decade, over-generation and curtailment of green energy is expected to become an issue as a result of the increased uptake of volatile VRES-based electricity generation (Kaufmann, 2017; Arias et al., 2019; Noel et al., 2019; ENTSO-E, 2021). This has a financial and environmental impact for both the individual energy producers and society as a whole. The societal impact is further explained in section 6.1.6 regarding CO^2 emissions and in section 6.1.7 the effect on electricity prices is considered. The potential loss reduction for energy producers or suppliers is not often mentioned throughout literature.

In interviews, the distinction was made between local RES production and large-scale operations based on the use-case: only V2H and V2B or V2G. On a local or distributed level, prosumers could lose home-produced electricity once the local grid (transformer) reaches its maximum capacity. "*For example, if both EV and solar panels would deliver electricity back to the grid at the same time, the voltage level of the cable could exceed the maximum value, making the solar panels switch off*" (I4-DSO). The costs of lost electricity go to the owner of the solar PV system, who is not compensated for this by the DSO.

For large-scale operations, the same problem occurs for producers of variable renewable electricity. For example, I2-DSO mentioned that "*producers are afraid that their wind parks or solar PV systems have to be switched off if there is a sudden overproduction*". When prosumers or producers of electricity are able to store the overproduction in their own EV or a fleet of EVs, the overproduced (cheap) renewable energy does not get lost (I7-MP). This also means that when using this technology on large scale, more solar panels and wind turbines can be implemented (I3-MP).

Besides, bidirectional charging reduces the need to transfer electricity over large distances. As explained by Kaufmann (2019), energy losses from high to low-voltage grids can be lowered by increasing the use of distributed generation locations (close to consumption). Since bidirectional charging of EVs will facilitate distributed electricity storage, electricity can be stored closer to consumption, which reduces these long-distance energy losses (Kaufmann, 2019).

6.1.5 Security of power supply

The security of power supply or the value of bidirectional charging to allow for power supply backup is only recognized throughout some of the reviewed literature (Gough et al., 2017; Cenex, 2020; Jones et al., 2021). The voltality of VRES electricity production could namely also increases times of underproduction of electricity, resulting in (local) power outages. Local storage solutions such as V2G could enhance resilience to power outages (Gough et al., 2017; Cenex, 2020; Jones et al., 2021). From a social point of view, engagement in the electricity market via V2G may help reverse the legacy trust deficit many people have in the reliability of the energy system (Jones et al. 2021).

In one of the interviews, it was mentioned that Dutch grid operators are obliged to provide security of supply for home owners (I8-MP). However, without large-scale grid expansion and increased adoption of variabile renewable energy technologies and EVs, security of power supply will be hard to maintain. In some countries, the EV is already placed outside of this security of supply. An example of this was given by I8-MP: *"In the UK, EVs are no longer allowed to be charged between 4:00 PM and 10:00 PM."*. In the Netherlands, businesses are no part of this security of supply, which could make the adoption of V2B or V2G highly interesting for businesses to maintain power security in the future (I8-MP).

6.1.6 Lower CO^2 emissions

Several reports mention the environmental benefits of bidirectional charging, often in terms of reduced CO^2 emissions (Noel et al., 2019; SCIS, 2019; Cenex, 2020; Jones et al., 2021; PWC, 2022). As already explained in Section 6.1.3, storage through bidirectional charging could lower the need for grid reinforcements and the costs that come with this. Brinkel et al. (2020) found that V2G making use of an emission minimization algorithm could reduce emissions by 23.6% while simultaneously reducing EV charging costs by 13.2%. In most cases, V2G cost or emission benefits outweigh the cost and emissions of upgrading that transformer (Brinkel et al, 2020). Furthermore, Noel et al., (2019) and Jones et al. (2021) also associate the lower use of fossil fuels with a decrease in societal health damages.

Although literature emphasizes that the reduction in CO^2 emissions due to bidirectional charging could be highly relevant for society, only few interviewees mentioned this benefit explicitly. For example, I4-DSO stated that overall CO^2 emission would be lowered due to the increased potential for renewable energy production. I6-OEM further clarified that the increased utilisation of renewable electricity production can often prevent CO^2-intensive, fossil-fuel-based backup production.

Box 6.6. Insights regarding quantification of grid congestion benefits.

A study by Aunedi and Strbac (2020) looked into the CO^2 emission reduction of unmanaged, smart and bidirectional (V2G) charging of fleets for the UK power system for 2025 and 2030. Based on the scenario's, it was found that the use of V2G leads to a country-level reduction of CO^2 emissions of in between 1.8 to 5.2

mt/year compared to only 0.1 to 0.2 in case of smart charging scenario. Per vehicle, overall cost would be reduced by 243 gCO^2 per km driven.

6.1.7 Decrease in electricity prices

Througout literature, is expected that bidirectional charging will not only reduce the energy bill of EV owners but could also lower electricity prices in general (Hanemann & Brucker, 2018; Englberger et al., 2021; ENTSO-E, 2021; Jones et al., 2021; PWC, 2021). This benefits not only applies to V2G users, but to all energy consumers in our society. As explained earlier, renewable energy storage through V2G reduces the need for expensive backup power from fossil fuel-based sources and increases the use of cheaper renewable electricity (Jones et al., 2021). V2G lowers power prices the most on weekend days, since these days are usually characterized by low power demand (Jones et al., 2021).

The postive effect of V2G (and other storage solutions) on electricity price was also mentioned by I6-OEM, as this interviewee studied the effect of V2G on the (future) SPOT market. However, both literature and I6-OEM address that these price effects are accompanied by a saturation effect. For example, Hanemann & Brucker (2018) found that market saturation is already noticeable in the German case at two million vehicles.

6.2 Expected costs

6.2.1 EV hardware and software costs

The costs of EV hardware and software development were not often mentioned throughout literature. Studies by Kaufman (2017), Aasbøe (2021) and PWC (2021) took this into account as one of the cost components of V2G. The availability of (commercialized) EVs with bidirectional charging capability is often mentioned by stakeholders and experts as the largest barrier for large-scale testing and commercialization at this moment (I2-DSO; I3-MP; I7-MP).

According to I3-MP, this mainly has to do with the approval of the standard ISO15118 for bidirectional charging in EVs. In the case of DC charging, it is argued that the additional costs of a V2G compared to a non-V2G EV can be neglected (PWC, 2021). I6-OEM also mentioned that these costs are not significant since it only requires replacing the diodes in the car for active components. However, when using DC charging, the inverter should be put into the charging pole, which increases charging pole costs (see section 4.2.2).

When choosing AC charging, the inverter is put into the car. In this case, the software and control logic required in the EV is expected to be the largest cost component (I6-OEM). Besides, the technology has to comply with net codes, which should be legally tested and differ per country (I6-OEM; I10-OEM). "*We need to prepare the next version of our cars with the right hardware (onboard inverter), and this is bound to the ISO5118/20 certification*" (I10-OEM). About the hardware costs of the onboard inverter, I10-OEM stated: "*It is a little bit more expensive having the onboard charger in the car, but in the end, we have more control and more possibilities.*".

Box 6.7. Insights regarding quantication of additional EV costs.

> As stated above, the hardware costs for enabling DC bidirectional charging in the EV are not significant (PWC, 2021). It was estimated that enabling V2G for DC charging poles would only cost around €100 of hardware to the OEM (I6-OEM). When considering AC charging, an inverter should be put into the EV, which could make car manufacturers hesitant to enable bidirectional V2G. The costs of a bidirectional inverter for the car are relatively high (ca. €1000 more in case of mass production) (Tweakers.net, 2020). Besides, software and control logic, and compliance with net codes could require fixed investment costs of around €5 to 7 million, which the OEM would have to cover (I6-OEM).

6.2.2 Charging infrastructure costs

The existing literature recognizes that implementation of bidirectional chargers requires extra investments compared to monodirectional chargers (Noel et al., 2019; SCIS, 2019; Aasbøe, 2021; PWC, 2021). In several stakeholder conversations, the high charging infrastructure costs were mentioned as one of the largest barriers to the adoption of bidirectional charging (I8-MP; I5-DSO). However, the choice of an AC or DC charging standard could largely affect the charger cost.

Stakeholders often mentioned that DC charging stations are much more expensive than AC charging stations (I5-DSO). For example I5-DSO: "*If you do DC-based V2G, you need a very large charging station that is much more expensive, because the conversion will take place in the charging station itself.*" One of the main reasons given is *"You will need to add an extra cooling component inside the charging station. The car already has a cooling (fan), but it is not usually available in a charging station*". Besides this, safety must be built into the charger that prevents the car to be discharged (I5-DSO).

In box 6.8, it is shown that the additional costs for AC or DC charging are expected to become lower in the future. The potential future cost reduction is acknowledged by stakeholders (I4-DSO; I5-DSO). For example "*the technology is becoming more optimized and costs of the AC-DC converter are becoming lower*" (I4-DSO). Reducing the purchase price of charging stations could have a large effect on the adoption. "*If a charger that can do something in the future that is now twice as expensive, people will not buy it [...] right now it already costs a lot of money to get a charger at home*" (I8-MP). Also one of the stakeholders mentioned, "*the charging poles are much more expensive, but it is not significant compared to the revenues you could make*" (I3-MP).

Box 6.8. Insights regarding quantification of additional charging pole costs.

The costs of charging poles depend on the choice of AC or DC charging. This is further elaborated in Chapter 7. Interviewees expect the current costs for a charging pole would be increased 6 to 8 times to make it DC bidirectional, going from €1000 to about €6000 - 8000 (I4-DSO; I6-OEM). PWC (2021) expects the cost of the charger to become lower by 2030 since economies of scale will allow for large cost reductions. Based on numbers from a case study by Nissan and Enel and several expert interviews, costs per charging station would become around €1300 - 1400 (PWC, 2021). The costs to make the charge pole AC bidirectional are lower, since the costly inverter is put into the car. The research by PWC (2021) predicts the costs in 2030 to be around €400 per charging station when extrapolating the costs from the WeDriveSolar project. It

should be noted that this creates additional EV hardware and software costs (as shown in section 6.2.1).

6.2.3 Open EMS/BMS system costs

Using V2G in front of the meter requires connectivity between stakeholders. Data exchange between the CPO, OEM, aggregator energy suppliers, grid operators and others is needed (I1-TSO; 13-DSO). The need for a smart data management system that connects all stakeholders is highly important. *"Smart charging solutions - amongst which V2G - require communication between the car and the grid, which says 'charge now, now not'." (I3-MP).* Technical aggregators and a back-end system are required, including software which gives insights into the speed and level of charging of the EV (I1-TSO). For example, an open EMS or BMS (energy or battery management system) would enable everyone to connect (I1-TSO). To stimulate this data exchange, Elaad has developed the Open Charge Point Protocol (OCPP), which now has become a world standard (I3-MP).

The grid operator needs transparency regarding the payments allocated to V2G offering grid services. "*If tax money is spent for grid services, a data management system should be in place that can verify these payments*" (I2-DSO). On the TSO level, the Equigy data platform is a collaboration of TSOs which could offer verification of smart charging payment data. V2G is no part of this platform, but could be added to this in the future (I4-DSO).

6.2.4 Optimization algorithm costs

Only some studies mention the development of control algorithms as one of the important costs that are usually covered by V2G aggregators (Borne, 2019; Noel et al., 2019; SCIS, 2019). The aggregator (or service provider) will need to develop a control strategy that balances energy flows between drivers needs (Noel et al., 2019). Such algorithms could learn from previous V2G charging behaviour and predict the availability of V2G resources during future market opportunities. Here, a tradeoff exists for aggregators between computation time and accuracy of the optimization (Borne, 2019). Besides, algorithms could focus on minimizing an economic or technical cost function, for even environmental optimization (Borne, 2019; Brinkel et al., 2020). It could also happen that different objectives (e.g. TSO and DSO markets) might conflict with one another.

The responsibility for charging optimization algorithms is often expected to lay by the aggregator, but can also be fulfilled by the CPO, electricity supplier, or OEM, depending on who controls the EV's charging behaviour (I9-MP: I8-MP; I10-OEM). The additional adjustments for smart charging service providers

(SCSPs) in control algorithms and protocols for bidirectional charging compared to smart charging are expected to be negligible (I8-MP).

6.2.4 Control and measurement system costs

Literature does not often mention the need for a control and measurement system for the DSO. Only SCIS (2019) acknowledged the need for utility-grade settlement meters. From the interviews, the need for such a system was mainly recognized by I4-DSO. To enable the use of bidirectional charging for local congestion services, the DSO needs to develop a measurement and regulation system that operates on a cable level (I4-DSO). It is currently possible to check manually whether a transformer has reached its full capacity in the past, but this needs to become digitalized when implementing V2G (I5-DSO; I4-DSO). "It *[V2G] is not something we are used to as a grid operator. We can already dampen the electricity consumption pattern through smart charging, but V2G requires more steering, fine-grained measurements and insights on cable level*" (I4-DSO). Based on this information, the CPO or OEM can check whether they could activate vehicle-to-grid (I4-DSO).

Also, the analysis by Hoogvliet et al. (2017) pointed out that the offering of frequency response and reserve services to the TSO could contribute to existing peak loads in local distribution grids. This problem was also pointed out by several stakeholders (I4-DSO; I1-TSO). "*If you activate V2G on a cable where solar panels are already delivering electricity back to the grid, the voltage will become too high*". (I4-DSO). A control and measurement system is expected to help regulate this, but in the short term, an emergency measure should be implemented that controls peaks on the lower grid (I4-DSO; I1-TSO).

6.2.5 Increased administrative/transaction cost

Throughout literature, the increase in administrative or transaction costs as a result of V2G is not often mentioned (Borne, 2019; IREC, 2019). According to interviewees, the TSO namely sets a minimum of 1 MW for BSPs to operate in the market to reduce the administrative and/or transaction costs (I6-OEM; I7-MP). Once the minimum capacity and duration of bids get reduced, the TSO will increase the contract number and associated transactional/administrative costs would increase (IREC, 2019). Since individual EVs offer relatively low amounts of energy to the market, aggregators have to bundle the battery capacity to enable EVs to offer V2G services to the different markets.

To enable V2G services, data exchange is required between the aggregator, EV driver, CPO and OEM etc. (I1-TSO). From the interviews, it was stated that administrative costs increase once the roles of CPO and OEM are taken by separate parties (I7-MP; I8-MP). Besides, it was argued that the role of energy supplier, aggregator (optimizing battery usage) and CPO are preferably combined into one organisation to lower these administrative costs (I8-MP). In case a (variable) renewable energy supplier takes the role of BSP, it could balance its own production through V2G, further reducing transactional costs (I7-MP).

6.2.6 Battery degradation costs

The potential cost of battery degradation when using bidirectional charging is a widely discussed topic. Both the user and social acceptance of the technology by EV drivers could be low due to their association with battery degradation (Geske et al, 2018; Ghotge et al., 2022). In the research by van Heuveln et al. (2022), battery degradation was even found to be one of the main concerns of Dutch EV drivers. They expect battery degradation costs to be covered or somehow compensated. This is also considered by stakeholders, for example: "*It could be argued that the battery owner should be compensated for the costs of battery degradation when using bidirectional charging*" (I5-DSO).

The exact costs of battery degradation largely differ for different case studies, since it highly depends on the control algorithms used in the battery (Tepe et al., 2022). In some research, for example, Uddin et al. (2017) and Cenex (2020) it was argued that bidirectional charging could also extend the lifetime of the battery once "intelligent battery management" control algorithms are used. Besides, battery degradation does not have to be a problem when the OEM chooses a battery with a longer lifetime (Noel et al., 2019). This was acknowledged by one of the OEMs as well: "*It is best to choose a battery with the lowest amount of cycles, from an environmental and cost-efficient aspect. These batteries experience a longer lifetime and do not limit the deployment of bidirectional charging.*" (I6-OEM). Currently, the only downside of this is that such batteries slightly increase the weight of the EV, which makes them unattractive.

Box 6.9. Insights regarding quantification of battery degradation costs.

Tepe et al. (2022) studied the cost of battery degradation when comparing the application of the battery for smart charging, and in different V2G revenue models. In their simulation, they found that smart charging leads to the largest increase in battery lifetime from 7.7 to 12.8 years. Using the battery for intraday market trading did almost not affect the battery life while using bidirectional charging on the FCR and day-ahead markets would increase the battery lifetime to 11.8 and 10.4 years.

6.2.7 Social costs of flexibility and range anxiety

Although this research suggests the EV battery to be highly relevant for grid purposes, the main purpose of the EV remains mobility (Kaufman, 2017; Englberger et al., 2021). One of the main concerns of EV drivers with regard to bidirectional charging is their loss of freedom, in terms of flexibility and range anxiety (Geske & Schumann, 2018; Englberger et al., 2021; Ghotge et al, 2022). The loss of freedom in terms of operating hour flexibility was mentioned by several stakeholders as one of the main costs for the EV driver. "*You need to know when the battery is going to be used when it is needed again for driving purposes and how large the next ride will be*" (I5-DSO). This does not only require planning ahead but also plugging in the charger at any time. "*People need to see the value of plugging in their charger, even at times it would not necessarily deliver them anything*" (I6-OEM).

The aforementioned problem of battery degradation also relates to another problem, that of range anxiety (Yuan et al., 2015; Geske & Schumann, 2018). "*OEMs are currently focusing on fast charging and improving the range. They are not focusing on the bidirectional charging yet*" (I4-DSO). I4-DSO agrees that the larger the range of the battery, the more capacity will be available for bidirectional charging. Also I6-OEM acknowledged that the implementation of bidirectional charging makes it even more important to increase the battery capacity.

6.2.8 Regulatory costs

Literature does not often mention regulatory costs for the development of V2G. Kaufman (2017) only mentions the lack of standardistion, while Noel et al. (2019) explain that storage solutions such as V2G require new regulatory frameworks, for which new taxation and tariff schemes need to be designed.

Among stakeholders, the regulatory environment was a main topic of discussion, emphasized by both grid operators and market parties (I1-TSO; I5-DSO; I8-MP). Rules and regulations need to change to enable the scaling up of V2G (I1-TSO). As long as energy arbitration behind the meter is done by one person, the tax authorities will not make a problem (I5-DSO). However, when using bidirectional charging in front of the meter (FTM) and for larger aggregation purposes, an amendment of legislation for energy taxation is required (I8-MP). Currently, exchanging energy in front of the meter is seen as 'money laundering' or 'wages in kind'. *(I8-MP).* "*If you charge for free at the office, or discharge at home, that is not going to be a desired result of vehicle-to-grid*" (I1-TSO). In the Netherlands, a working group by the Ministry of Economic Affairs and Climate and the Ministry of Finance is currently working on this (I8-MP).

6.3 Discussion on benefits and costs

Table 6.1 summarizes how often benefits and costs were mentioned in the literature review and interviews. When comparing the results from the literature review and interviews, several differences were observed. Both literature and interviewees underscore the benefits of bidirectional charging rather than the costs. Especially benefits of revenue generation were a largely discussed topic. More specifically, the most often mentioned revenue model was the offering of V2G services on the TSO market. During the interviews, an important point of discussion was the uncertainty with regards to size of these revenues and the potential distribution over the involved stakeholders.

The costs that were most often mentioned throughout the literature were that of battery degradation, social costs and charging infrastructrure. Interviews mainly emphasized the charging infrastructure costs, EV hardware/software, the data infrastructure, social costs and regulatory costs.

Table 6.1. Mentioning of benefits and costs throughout literature review and interviews.

	Literature review (20)	*Interviews (10)*
Benefits		
Revenues	18	10
Increased EV sales	2	4
Lower grid expansion costs	6	4
Lower renewable energy loss	4	4
Reduced power outages	3	1
Lower CO2 emissions	5	2
Decrease in electricity prices	5	1
Costs		
EV hardware/ software	3	5
Charging infrastructure	4	4
Open EMS/BSM system	2	4
Optimisation algorithm	3	5
Control/measurement system	1	1
Administrative/ transaction costs	2	4
Battery degradation	6	2
Social costs of flexibility and range anxiety	4	3
Regulatory costs	2	3

6.4 Value distribution

Based on the previously discussion on costs and benefits, a potential overarching ecosystem value distribution is created. In Table 6.2, this value distribution is provided, allocating the costs and benefits from previous sections to the types of stakeholders introduced in Chapter 5. The + and ++ indicate the relative size of these benefits, which are still topic of discussion and require further investigation.

Table 6.2 Potential value distribution among stakeholders.

	EV driver	EV owner	Home/ building owner	OEM	CPO	Aggregator	Energy supplier	DSO	TSO	Government / society
Benefits										
Revenues	++	++		+		++				
Increased EV sales				++						
Lower grid expansion costs								++	+	++
Lower renewable energy loss			++				++			++
Reduced power outages			+					++	+	++
Lower CO2 emissions								++	+	++
Decrease in electricity prices										++
Costs										
EV hardware/ software		+		+						
Charging infrastructure			+		+					++
Open EMS/BSM system				+				+	++	
Optimisation algorithm						+				
Control/measurement system								++		
Administrative/ transaction costs			+			+				
Battery degradation		+		+						
Social costs of flexibility and range anxiety	++									
Regulatory costs										++

In this research, it has been argued that the motivation of each stakeholder to contribute to ecosystem development depends on their expected value offering, which further depends on whether the benefits outweigh the costs. Based on this, for each stakeholder type, the potential value offering is discussed.

EV driver/owner. The EV driver and EV owner could receive part of the generated revenues, for example by offering services in one or multiple of the five explained revenue models. In return, the driver pays social costs in terms of flexibility and range anxiety. The owner pays costs for the EV and battery degradation.

Home/building owner. The owner of a home or building with a solar PV system is assumed to receive the benefits of lower renewable energy losses and could use V2G as a backup for local power outages.

OEM. The OEM could benefit from bidirectional charging by selling more EVs due to the additional value they add to the EV. The costs for the OEM are mainly present in terms of EV hardware and software. Besides, they might need to compensate the EV owner for battery degradation.

CPO. The CPO only has to make some additional costs with regard to the charging infrastructure. The CPO might need the incentive to include V2G hardware and software in charge points. This could either be obligated by the government or compensated through part of the revenue from the aggregator.

Aggregator. The aggregator is expecting to generate revenues through the three V2G revenue models. When bringing together the individual EV owners, the aggregator makes certain transaction costs. Besides, it makes costs for the creation and operation of optimization algorithms that are required for managing the battery charging behaviour.

(Renewable) energy supplier. Renewable energy suppliers mainly benefit as they could use V2G services to lower their imbalance and decrease renewable energy losses.

DSO. The DSO has lower costs of grid expansion (also including social costs and subsequent CO^2 emissions). Besides, the DSO experiences fewer problems with regard to providing energy security - e.g. compensating for power outages. The costs would mainly lie with the creation of a data platform and a control and measurement system on the cable level.

TSO. The benefits for the TSO in terms of grid expansion and power outages are expected to be lower than for the DSO. For the TSO, V2G could offer balancing services at a lower price than other balancing options. The TSO makes certain costs for facilitating the market and open data platform.

Government/society. The main societal benefits are lower grid expansion costs - since the grid infrastructure is paid for through the government, lower losses of (renewable) energy, energy security due to lower chances of power outages, lower environmental costs in the form of CO^2 emissions and an overall decrease in electricity price. Costs are mainly present in the form of charging infrastructure and regulatory costs.

7. Value alignment challenges

In Chapter 6, the main benefits and costs of bidirectional charging were identified, perspectives of stakeholders regarding these benefits and costs were discussed and a potential value distribution was provided to compare the individual value offerings of stakeholders. As expected, ongoing uncertainty and negotiation exists throughout literature and among the interviewees about the size and distribution of the identified benefits and costs. Since revenue size and distribution and the inverter costs were the largest topic of discussion amongst the interviewees, these are further elaborated upon below.

7.1 Revenue size and distribution

The size and distribution of revenues among involved stakeholders appeared to be a large topic of discussion throughout literature and among interviewees. As discussed elaboratively in section 6.1.1, bidirectional charging revenues could be generated through various revenue models, which all largely depend on many sensitivities. During the research, it became clear that the electricity price could largely impact the revenue generation. As mentioned by I1-TSO: "*With these electricity prices, it is really speeding up and accelerating*" and I3-MP: "*At this moment, the incentive for using V2G is high. A year ago, the energy prices were too low, which made it look financially unfeasible to roll this out*". It was also argued that dynamic electricity prices are required to allow for revenue generation (I6-OEM). In the V2H/V2B situation, these need to be offered by the energy supplier of the house or building. In the case of public charge points, the CPO needs to offer dynamic prices to EV drivers.

Uncertainty regarding the distribution of revenues was emphasised by several stakeholders, for example by the I1-TSO: "*That's interesting, because who's got what, who's going to benefit*?". In one of the interviews, 16-OEM mentions the following distribution: "*For example, 20% OEM, 10% for the CPO and a part goes to the tax authority*". At the same time, the I1-TSO stated the following: "*We will benefit. If the market is functioning correctly, the aggregator will also benefit. I don't see the OEM benefit from this technology. Maybe they will sell more cars, but as long as there is not an incentive, it will not fly*". What becomes clear from the results is that the more roles one party takes, the higher the revenues it could receive. From theory and previous results, it became clear that the benefits stakeholders will receive also largely depend on the roles they take in the ecosystem, the costs they pay and the compensation which is available for this.

7.1.1 Control of charging behaviour

The distribution of generated revenues also largely depends on the use-case and corresponding value chain in between the EV owner/driver and the grid operator or energy supplier to whom the services are provided. Also with regards to the stakeholder that controls the charging behaviour and the one who aggregates these EVs, some unclarity exists. "*What is required is clarity for all market parties. For instance, charging pole operators can switch it on and off and even change the power coming out of the charging, but a car can also do it to itself.*" (I1-TSO). Or as stated by the DSO: "*In the end, the customer, who is the owner of the car, should decide. Yet, the system for charging or discharging can be initiated by either the car manufacturer or the charge point operator*" (I4-DSO).

Currently, many OEMs are implementing their own app, platform, or web portal. "*All these personal apps, for instance Tesla, want to create their own business case in the end, so they make a reservation on the asset. This makes using a different charge pole less easy*". (I1-TSO) However, an open energy or battery management system would make it easier for the aggregator to offer their services (I1-TSO). The OEM wants to control the charging behaviour since it could lead to battery degradation (I10-OEM). In a study by Van Heuveln et al. (2022), it was found that occasional control - or at least transparency - is required for the OEM regarding the use of the battery (van Heuveln et al., 2022)).

7.2 Inverter costs and AC/DC charging

Another largely discussed topic during the interviews was the uncertainty among stakeholders with regards to the inverter costs. They explicitly mention the current indecisiveness of whether bidirectional charging should take place via AC or DC (I2-DSO; I4-DSO; I5-DSO; I6-OEM). As explained in Section 3.1, there are two technological options that could enable bidirectional charging. The inverter, that is required for AC-DC conversion of the bidirectional power flow will increase either the EV hardware and software costs (Section 6.2.1) in case of AC charging or the charging infrastructure costs (Section 6.2.2) in case of DC charging. Due to this indecisiveness, it remains unclear whether the charge pole operator or OEM is responsible for installing the inverter.

On the one side, stakeholders expect the standard to become DC charging. "*Especiallly German OEMs advocate for having the inverter in the charging station. Putting this into the EV would increase the costs of the EV to much. Besides, every country had different net codes, which makes it hard for EV to be used in different countries*" (I4-DSO). At the same time, it was argued that "*CPOs would consider putting the inverter into the charging stations*". However, the

CPO is currently not considering this, since using public charging will become very hard (I9-MP).

On the other hand, several stakeholders in the Netherlands - amongst which Elaad, WeDriveSolar and Renault - have been testing with a bidirectional AC technology. Car manufacturers currently testing with AC technology are Hyundai, KIA, Volvo and Renault. Most of the interviewed Dutch stakeholders and experts seem to advocate for AC charging for several reasons. First, of all, the current Dutch charging system is largely based on AC charging (I5-DSO). De Brey (2017) argued for the use of AC-based charging stations based on the Smart Solar Charging project. AC charging would namely increase the interoperability among stations and stimulate customer adoption. Another reason for OEMs to put an onboard inverter in the EV, is that it could deliver vehicle-to-load (V2L) services to the customer (I10-OEM). This does not allow for a connection to a grid, but will allow for charging of other types of appliances.

However, AC charging still needs the adoption of a new communication protocol for V2G (I5-DSO). One of the stakeholders expected the costs of the inverter to be the same when implemented in the EV as in the charging station (I4-DSO). However, as shown in Sections 6.1.1. and 6.1.2, this is not necessarily the case. Based on the cost analysis, it could be cheaper to put the inverter in the EV due to reuse of the cooling components, but require more software investment costs for the OEM.

When it comes to roles and responsibilities for the decision regarding AC or DC charging, I4-DSO expects that "*OEMs have the biggest say in this, they need to come to an agreement within their branche organisation. Then, other stakeholders who have an interest in V2G would have to make sure that the inverter is build into the charging stations*". For grid operators, the AC or DC discussion is less relevant: *"For the DSO, the whole AC-DC discussion is not that important. It is only if you want to do it via V2G, then the inverter must either be in the car or in the pole, and then it is up to the market parties to sort that out together." (I4-DSO).* The DSO will probably also pay for the inverter in some way. This depends on whether they will use bidirectional charging services or stick to smart charging (I4-DSO).

8.Conclusion

In this study, it was investigated what recommendations can be formed based on an analysis of value alignment in the Dutch bidirectional charging (V2G) ecosystem. This question has been answered through four sub-questions, focusing on the identification of stakeholders, benefits and costs, and resulting in an ecosystem value distribution, which further allowed to identify new challenges (and opportunities) for ecosystem value alignment. The questions were examined with the help of a case study approach and through three main research stages, using different types of qualitative methods and data sources. First, an elaborative literature review was performed, after which interviews took place with several stakeholder and/or experts. Lastly, some additional qualitative research was done using data from literature, webinar and events.

Based on combined insights from these methods, some key stakeholder types in the (Dutch) bidirectional charging ecosystem (V2G) were identified. Key stakeholders that are receiving or creating the key benefits and costs within the ecosystem are the TSO, DSO, energy supplier, aggregator, EV owner or driver, OEM, CPO, the government and society. These stakeholders could exist in different ecosystem configurations depending on the use-case: V2G via V2H, V2B or V2P. For example, the CPO is only included when considering V2G via V2P. Besides, it could happen that multiple stakeholder roles are taken by one entity. Furthermore, in many use-cases the aggregator role is taken by either the energy supplier, OEM or CPO.

To answer the second sub-question, the expected benefits and costs in the Dutch bidirectional charging (V2G) ecosystem were identified. By combining the insights from different methods, the main benefits of bidirectional charging are determined to be revenue generation, increased EV sales, lower grid congestion costs, lower renewable energy loss, reduced power outages, lower CO^2 emissions and decreased electricity prices. On the other side, the main costs that come with the creation of a bidirectional charging ecosystem are expected to be the EV hardware/software costs, the charging infrastructure costs, open EMS or BMS system costs, optimization algorithm costs, control/measurement system costs, administrative/transaction costs, battery degradation costs, social costs of flexibility and range anxiety and regulatory costs.

Based on the discussion and expectations regarding mentioned costs and benefits in literature and during interviews, an overarching value distribution was created and the individual value offerings for each stakeholder were shortly discussed. From the analysis, it became clear that the value distribution could largely vary depending the relative size of benefits and costs, and the exact distribution among stakeholders. Considering previous findings on the value distribution and by noting the main topics of discussion among interviewees, the most important value alignment challenges were identified that would currently stagnate stakeholder alignment concerning the value distribution and individual value offerings in the bidirectional charging (V2G) ecosystem.

First of all, among Dutch stakeholders, in multiple cases, uncertainty seems to exist regarding the size of the benefits and costs. Especially, the size of benefits in terms of revenue generation were often subject of discussion. Although this research already gave some examples of previous research quantifying these benefits or costs, further quantification is considered highly important. Secondly, unclarity was observed among interviewees with regards to the distribution of benefits and costs over the involved ecosystem stakeholders. Being more elaboratively discussed in Chapter 6, two main topics of discussion among interviewees were the distribution of V2G revenues and the distribution of the inverter costs based on AC or DC charging. Based on the results, several management implications/recommendations are further discussed in Section 8.1.

8.1 Management implications/recommendations

To answer the research question, in this section, several recommendations are provided for a potential ecosystem orchestrator, stakeholders and future research based on previously discussed results.

Promote adoption by businesses with large EV fleets. During the research, it was found that the value distribution will most likely differ depending on whether the V2G connection is made via V2H, V2B, or V2P, the services that are offered and the amount of stakeholders are involved. Based on the expectations from literature and interviewees, the main commercialization of V2G is expected through V2H and V2B. In both cases, bidirectional charging could be implemented behind the meter at first, and start offering V2G services in a later stage. Since businesses are not placed within security of power supply, these could feel more costs and motivation to ecosystem development is expected to increase. Besides, businesses could perform some low-level aggregation when operating EV fleets and charging poles, making it easier to use for V2G services.

Create collaborative offering of interoperatible V2H/V2B solutions. To stimulate adoption of bidirectional charging in V2H and V2B context, behind-the-meter revenue models such as increased self-consumption and peak shaving can already introduced to home or building owners and facilitated by energy suppliers, the OEM and DSO. To diminish interoperability issues, energy suppliers and OEMs and could (collaboratively) offer a complete bidirectional charging package to the home or building owner, for example including interoperatable bidirectional EVs, bidirectional chargers and solar PV system.

Quantify (combined) revenue generation. As explained in Section 7.1, uncertainty with regards to the revenue size and distribution needs to be resolved. This requires the creation of complex simulation models which could estimate the potential future value and test for dependency on the identified sensitivities. Rather than most of the previous quantitative models, it is suggested that new models combine the various revenue streams. Also, country and regional specific factors should be accounted for and future values need to be predicted, as revenues highly depend on the adoption of EVs, electricity prices, feed-in tariffs and regional differences with regards to local grid congestion. However, in such simulations, it should be considered that judging value becomes more difficult with offerings that are so novel that a market for trading similar offerings does not yet exist (Autio, 2021; Autio and Thomas, 2018).

Examine the impact of bidirectional charging on the local distribution grid. Since the exact value for the distribution grid still has to be examined by the DSOs, the revenues in this market remain unclear. Potential locations could be identified where EVs offers grid capacity, and seeks for upgrading and replacement costs that could be avoided through V2G for each of these test locations. This will not only provide clearer insights into DSO services revenues, but also in the avoided costs of transformer upgrades and replacements. In collaboration with businesses, fleet managers, energy suppliers and OEMs, the DSO could first increase testing of the impact of behind-the-meter services such as peak shaving and self-consumption on the local grid, and later with optimization algorithms in front of the meter.

Create European standards and AC/DC decision by OEM branche organization. As explained, the interoperability of bidirectional charging technologies is considered a major challenge at this moment. According to the interviewees, this problem could be partly resolved through the development of more clear and interpretable standards for V2G on a European level. To resolve the alignment challenge described in Section 7.2, a decision regarding AC or DC bidirectional charging should be made by the branche organisation of OEMs. Based upon the results of this research, is expected that several OEMs will provide an on-board inverter in the EV in the future. This namely allows OEMs to provide an extra service of V2L and V2V to the EV owner and for them to take part of revenue generated through the introduced models. Furthermore, it keeps them in control with regards to potential battery degradation.

Create open data platform. It is recommended to a potential ecosystem orchestrator to prevent from overlap of V2G services and provide transparency throughout the different markets for wholesale energy, TSO services and DSO services. In collaboration with the TSO, DSO, energy suppliers and/or aggregators, a platform could be created which optimizes allocation of the available EV battery capacity to the grid.

9. Discussion

In this chapter, a discussion is provided on the applicability of the theoretical framework, limitations to the research and suggestions for future research.

This research further contributed to the development of a bidirectional charging (V2G) ecosystem. With the help of the ecosystem view and several aspects of the value case methodology, it shed light on the value discovery and negotiation process around the topic of bidirectional charging (V2G) in the Netherlands. For international stakeholders, the insights from the literature review show the generally involved stakeholders and potential benefits and costs based on general V2G literature. Results from interviews with Dutch stakeholders and experts showed the current discussions and negotiations regarding the ecosystem structure and value distribution in practice.

The ecosystem theory contributed to this research by emphasizing the importance of finding an alignment structure consisting of actors, activities, positions and links. Besides, it made clear how the bidirectional charging ecosystem can further develop by overcoming certain alignment challenges. Based on Thomas et al. (2022), the importance of value discovery and negotiation among stakeholders for further ecosystem development was recognized.

However, where ecosystem literature described individual value offerings as essential motivators for stakeholders in ecosystem development, it did not offer a structured process of how these can be discovered, negotiated and aligned by the ecosystem stakeholders. Therefore, this research introduced a new approach that orchestrators could use, which guides the value discovery and negotiation process. The individual value offering was determined based on the outcome of the 'value case' introduced by Dittrich et al. (2015). This value case can be derived based on the monetary and non-monetary benefits and costs. Furthermore, it introduced value alignment as the desired outcome of the value negotiation process in early stage ecosystem development.

Furthermore, during the research process, it became clear how various configurations of the ecosystem exist, which partly integrate and overlap. It was found that three different use-cases of bidirectional charging for grid purposes exist: V2G through V2H, V2G through V2B, V2G through V2P. Each of these involve different stakeholders, activities, and result in a different configuration of benefits and costs, while all contributing to the same overall ecosystem value proposition. As explained in Chapter 4, within these ecosystem configurations, also a large variety of differences exists since the involved entities can take multiple stakeholder roles in the ecosystem. Because of this, it is expected that in each of these use-cases the entity taking the role of ecosystem orchestrator differs.

Limitations

From the research, it can be observed that qualitative research could already give an idea about the value offerings and motivations of stakeholders to contribute to ecosystem development. However, the qualitative nature of this research made it hard to identify the exact value alignment challenges. These were not necessarily derived from the value distribution itself, but rather based on the largest topics of discussion among interviewees. As recommended, extending this research with the insights from quantitative simulation models would offer deeper insights in the value alignment structure.

This research proposed to identify value cases with the help of the value case methodology (VCM). Yet, in the case of bidirectional charging mainly variable benefits and fixed costs were identified. This made it hard to create a clear value distribution which indicated the size of benefits and costs and the value offerings. Thus, when future research is performed, it is recommended to rather identify the net present value (NPV) of individual value offerings. Since this does not allow for environmental and social costs to be included, the use of monetization methods mentionded by Dittrich et al. (2015) should be considered.

Due to the limited research scope, only 10 stakeholders were interviewed, including the TSO, three DSOs and several market parties (one CPO, two energy suppliers, three potential aggregators, a fleet manager and two OEMs). Therefore, some stakeholder perspectives were well-covered, while other perspectives were might not have been covered enough during the research process. For example the EV owner/driver, businesses and the government or society. Other research (e.g. Van Heuveln et al., 2021) as well as several demonstration projects already investigated the role and perspective of the private EV driver/owner. However, it is still argued that future research could focus on enlightening these perspectives.

This research only explored the additional value of V2G compared to smart charging solutions to some extent. For smart charging, approximately the same types of benefits and costs were identified. However, smart charging does not allow for each type of revenue generation and does not require all of the costs, e.g. a DSO measurement and control system. Also, when quantifying the differences, the discussed benefits of lower value for smart charging. A bidirectional power flow namely creates more flexibility, which increases the revenue potential and each of the other (related) benefits.

Lastly, this research did not consider the additional value compared to other grid congestion solutions such as other types of storage solutions. Despite this, V2G was considered a preferable option, since it could reuse battery materials. It is suggested that future research could further quantify and make a more profound comparison of the costs and benefits of different grid solutions.

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Appendix

I. Demonstration projects in the Netherlands

Table 1. Specifications of demonstration projects in the Netherlands (V2G-hub, n.d.).

Project	**Main partners**	**Timeline**	**Chargers**	**Services**
SCALE V2G/V2X	Elaad; Equigy Hyundai; Renault; ABB	2022-now	-	Arbitrage, Distribution services, Frequency response
Direct Solar DC V2G Hub Lelystad	Mijndomein; Energie; Venema; Emobility; i.LECO	2020-2023	14	Frequency response Distribution services Time shifting Emergency backup
V2G @ Home	Seita; Wallbox	2021-2022	1	Time shifting, Emergency backup
V2G/V2B at Johan Cruijff ArenA in Amsterdam	Royal BAM; The Mobility House; Johan Cruijf ArenA; SEEV4City	2019-now	1	Distribution services Emergency backup
AirQon	SBPF; iHomer Faraday Keys; Kairos Events	2019-now	-	
Share the sun / Deel de zon project	Zonnova, Mijndomein i.Leco Buurauto Zuidtrant Overmorgen Venema Emobility	2019-2021	80	Frequency Response Distribution Services Time shifting
We Drive Solar Utrecht V2G charge hubs	WeDriveSolar Renault	2018-now	80	Arbitrage

Hitachi, Mitsubishi and Engie	Hitachi Mitsubishi Engie	2018-now	1	Time shifting
FlexGrid	Delft University of Technology Stedin Alfin	2018-2022	1	Frequency response Time shifting Emergency backup
Powerparking	Province of Flevoland; Municipality of Dronten; Eneco Alfen; Schiphol Nederland; Lelystad Airport; Pontis Engineering	2017-2022	1	Time shifting
NewMotion V2G	Mitsubishi; Nuvve; TenneT	2016-2018	10	Frequency response
Smart Solar Charging	WeDriveSolar; Utrecht Science park; Utrecht Central Stadion area; Driebergen zeist; Renault, Hyundai	2015-now	22	Distribution Services Time shifting
Solar-powered bidirectional EV charging station	Delft University of Technology Breda; Last Mile Solutions; Nissan; ABB; UT Austin	2015-2017	1	Time shifting
City-Zen Smart City	Alliander; Enervalis; Magnum cap	2014-2019	4	Arbitrage Distribution services
Amsterdam Vehicle2Grid	Engie; Mitsubishi	2014-2017	2	Time shifting

II. Literature research

Table 2 Scientific articles, reports and findings.

Reference	SQ1: Ecosystem stakeholders	SQ2: Ecosystem benefits	SQ2: Ecosystem costs
Gough et al. (2017)	-	Revenue models: (Self-consumption, Traid and peak demand; Short term operating reserve (STOR); Wholesale market; Capacity market)	Infrastructure cost; Installation costs; Costs of battery degradation (future falling costs)
Kaufmann (2017)	Individual EV owner; EV fleet owner; home PV owner; EV manufacturer; utilities (TSO, DSO); charging station manufacturers (EVSE); (aggregator) service providers (e.g. car sharing)	Revenue models (ancillary service market; DSO congestion market; energy trading) Efficient integration of intermittent RES; flexibility and mobility; reducing costs of ownership; less energy loss; avoiding grid expansion.	AC-DC conversion costs; aggregatio costs; EV driver behavioural change: mobility & flexibility; EVSE hardware costs (on-board charger); regulatory costs (standards)
Geske & Schumann (2018)	EV users	-	Range anxiety/immobility
Quirós-Tortós et al. (2018)	-	Provision of grid services; reduction of peak demand; lowering need for transformer upgrades	-
Reynolds et al. (2018)	TSO; DSO; Third party intermediary (e.g. energy market party); Consumer	Revenue models: (Frequency response; Reserve; Arbitrage; Distribution services; Time shifting)	-

Arias et al. (2019)	TSO; DSO; RES power producers	TSO services (frequency regulation; spinning reserves; congestion management; black start provision)); DSO services (congestion management; load shifting; peak shaving; valley filling; voltage drop); Smooth RES grid integration; RES intermittance reduction; RES energy curtailment reduction.	-
Borne (2019)	TSO; DSO; aggregator; BSP; car manufacturer; users	FCR services, FRR services; RR services; self-consumption; Capacity services; Distribution grid services	Aggregation algorithm; investment costs
Cenex (2019)	TSO; DSO; EV customers (council fleet; EV car pool clubs; retired professionals; eco-professionals; run-around)	Revenue models (Behind-the-meter services; Transmission system services; Distribution system services; Wholesale energy markets services; Battery management services)	-
IREC (2019)	TSO; DSO; BRP; OEM / EV manufacturer; Aggregator; EVSE	Revenue models (Frequency response; Behind-the-meter optimization; V2H back-up power; Battery degradation)	-
Noel et al. (2019)	TSO; DSO; aggregator; EV owner; EV driver; EV manufacturer; fleet manager;	High power capacity; quick response; improved power quality; voltage	Predictive/control algorithms; Advanced metering infrastructure (AMI); Battery

	government; electricity producer	support; transmission congestion relief; increased electricity reliability; wind and solar integration; store excess wind and solar energy generation; V2G revenues (frequency regulation); reduce electricity grid costs, especially frequency market costs to TSO; DSO services; environmental/health benefits;	degradation; Energy losses (charger efficiency); EVSE equipment; Regulatory costs
Pearre & Ribberink (2019)	ISO (TSO); RTO (DSO); load-serving entities, capacity planners, distribution utilities and other grid managers	Frequency regulation; spinning reserves; Transmission & distribution upgrade deferral; Voltage support and power factor correction; Energy arbitrage and similar services; Renewable energy integration; Backup power in case of power outages;	AC/DC power transfer standard; Battery degradation; algorithm optimization
SCIS (2019)	National/European regulatory body; TSO; DSO; energy suppliers; EV customers.	DSO services; TSO services (energy reserve); Revenue generation; environmental benefits.	Hardware and software costs; Social costs (Range anxiety); Controling algorithm; Supporting infrastructure; Battery degradation (insurance and guarantee); Tariffs and taxation costs; Utility-grade settlement meters; Conversion energy loss;

Cenex (2020)	Drivers; Vehicle owners; Energy & facilities manager; DSO; TSO; Energy system regulator; Energy supplier; Aggregator; Vehicle manufacturer; Chargepoint manufacturer; eMSP; CPO; Government; General public	Revenue-generating energy trading (arbitrage); Resilience; Personal net zero/self sufficiency; Benefit to society (environmental); Enhanced battery management	-
Sovacool et al. (2020)	Automotive manufacturers; battery manufacturers; vehicle owners; energy suppliers; TSO; DSO; fleet; aggregators; mobility-as-a-service providers; renewable electricity independent power providers; public transit operators; secondhand markets and secondary markets.	Revenues through equipment; Grid services; Aggregation; bundling; Secondary markets; Transaction costs.	-
Aasbøe (2021)	Aggregator; EV owner; large consumers; grid operators;	Ancillary services / frequency regulation; peak shifting; peak shaving; revenue generation	AC/DC charger; Battery degradation; charging infrastructure costs; Range anxiety
ENTSO-E (2021)	EV users/owners; Manufacturers Charging operators; Aggregators / energy market operators; Grid / system	Peak shaving; Generation cost reduction; CO^2 emissions Grid balancing; Grid congestion (for re-dispatching and	-

	operators; Decision makers; Research and associations	distribution grid); Voltage control / reactive power; RES over-generation reduction; Behind-the-meter services; Hyper chargers	
Englberger et al. (2021)	-	Revenue models: Self-consumption; Peak shaving;	-
Jones et al. (2021)	Vehicle dealers; Manufacturers; Fleet managers; Charging providers; Charge platform providers; Fuel companies Generators; Aggregators Networks; Market operators Energy retailers; Government and regulators; Users	Affordability; Resilience; Status and sustainability; Differentiation; Balancing intra-day supply/demand; Energy market participation; Frequency control services; Congestion management; Power quality; Network security; Data/demand forecasting; System resilience; Equity; Health and climate; Trust	-
PWC (2021)	EV OEM; EV driver; e-MSP; Aggregator; CPO; Energy supplier (BRP); Regional grid operator; National grid operator; Energy producer	Lower investments in the electricity grid; Lower costs of energy; Lower CO^2 emissions; Costs for infrastructure; Battery degradation	-
Energinet (2022)	EV user; Society; Car manufacturer	Maximizing self-consumption; Optimisation through	-

	Charging operator; Commercial energy markets; Energy datahubs EU decision-makers; National government; Regional government TSO; DSO; Tax authority; Knowledge institutions	time-of-use tariffs; Offering flexibility services	

III. Interviews and additional sources

Table 3. Reference list of interviewees

Ref.	Type	Interviewee	Stakeholder	Stakeholder type
I1-TSO	Interview	Len Wismeyer (NL); Fabian Zimmermann (DE)	TenneT	TSO
I2-DSO	Interview	Baerte de Brey	Stedin/Elaad	DSO / knowledge institute
I3-MP	Interview	Robin Berg	WeDriveSolar	Car sharing company / EV owner / CPO
I4-DSO	Interview	Arjan Wargers	Enexis/Elaad	DSO/ knowledge institute
I5-DSO	Interview	Marisca Zweistra	Alliander/Elaad	DSO / knowledge institute
I6-OEM	Interview	Mayk Thewessen	Lightyear / TU/e	OEM / knowledge institute
I7-MP	Interview	Sam Warmerdam	Vandebron	Energy supplier / BRP / BSP / CPO / aggregator
I8-MP	Interview	Lucien Joppe	PowerD	Energy supplier / CPO / / aggregator
19-OEM	Interview	Roberto	Equans	CPO / BSP
I10-OEM	Interview	Jens Kronen (DE)	Hyundai	OEM

Table 2. Other qualitative sources

Ref.	Type	Involved people	Involved stakeholder(s)
Battery on Wheels (2022)	Congres/ webinar	Mayk Thewessen (Lightyear); Masisca Zweistra (Elaad); Pieter van Kerkhof (RVO).	DeeldeZon & VER, Elaad, Lightyear; RVO (and more)
Ecomobiel (2022)	Webinar	Hugo Niesing	Gemeente Amsterdam / Resourcefully (and more)

Road to Decarbonisatio n (2022)	Congres	Matthijs Kok (UU); Juliette Thijs (SCALE); Marisca Zweistra (Elaad)	REMove, Gemeente Arnhem, UU, SCALE, Elaad (and more)

Figure 1. Interviewees in stakeholder network.

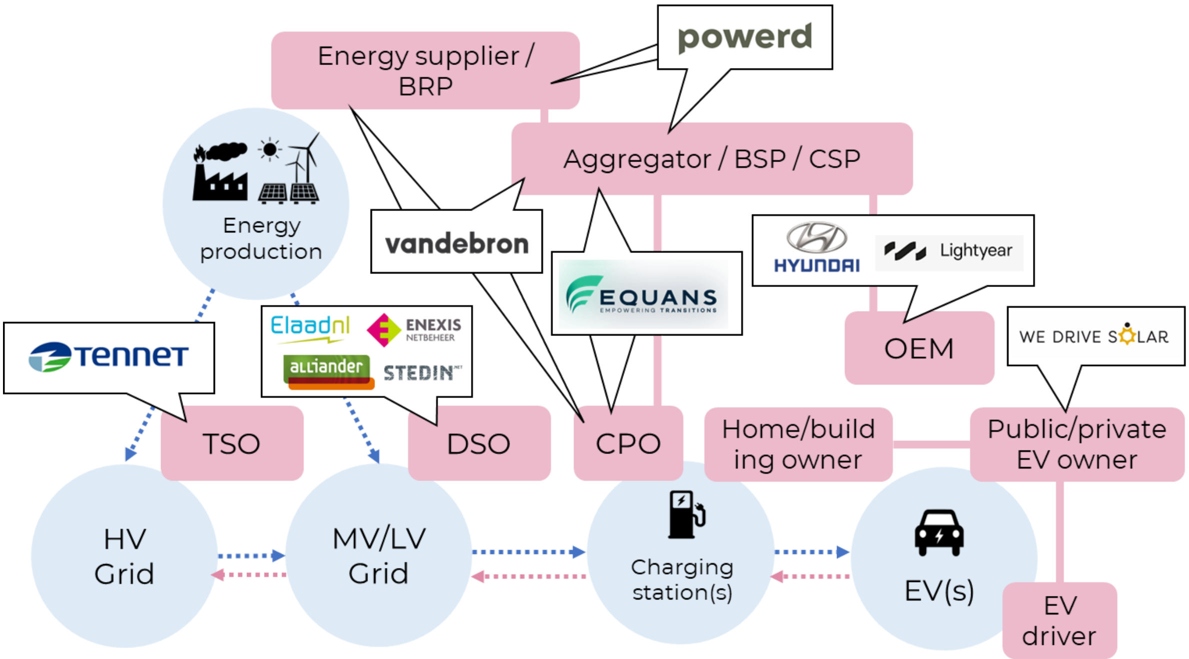

Table 3. Interview questions.

Research questions	*Interview questions*
SQ1: Ecosystem roles and responsibilities	• What role(s) is [stakeholder] expecting to take? • What responsibilities does [stakeholder] have? • What projects did [stakeholder] previously perform? • Which stakeholders should be involved?
SQ2: Ecosystem value distribution	• In what ways could [stakeholder] benefit? • How do other stakeholders benefit? • What costs do you see for implementation? • What challenges still exist for implementation? • Who reaps the benefits and who pays the costs?
SQ3: Value alignment challenges and opportunities	• What challenges still exist for implementation? • What discussions are currently taking place amongst stakeholders? • How is value negotiated among stakeholders?