Unraveling the "X" in V2X

A comparative analysis of
Vehicle-to-Everything system designs
in five key dimensions

Thesis report

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Colophon

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Preface

Each individual strives for the ability to shape their own future. As well-educated individuals, we possess the special power to actively and deliberately shape the course of our shared future. I genuinely believe that, because of this, we bear the responsibility to utilize our knowledge and skills to actively and consciously shape a brighter future. A responsibility to make a significant impact in the field that resonates most with your interests and abilities. Throughout my time at TU Delft, I have come to realize that addressing the pressing climate challenges is the field that deeply resonates with me. We stand at a crucial point in human history, confronted with unparalleled challenges that require our attention and decisive action. The world today stands at a crossroad, where the consequences of our past actions have become painfully evident. But within the shadow of these sometimes seemingly unmanageable challenges lies an opportunity. A chance for us, as individuals, to become *game changers*.

While it may be true that one individual alone cannot single-handedly change the game of climate change, it is crucial not to underestimate the significance of a single action in the larger chain of transformative change. This makes it graspable for all of us to become a *game changer* in our own way. In this I have found energy and enthusiasm to contribute, specifically in the transition towards renewable energy infrastructure, which facilitates the transition to a more sustainable world while maintaining its harmony and avoiding disruption. As a true engineer, I am (overly) optimistic about the potential of existing and emerging technological advancements to drive this transition. However, I recognize that these innovations necessitate a collective societal shift from one status quo to another. I firmly believe in the significance of students who possess a combined education in engineering as well as management precisely because of this understanding. We are the link that connect two crucial worlds for effective change.

As I near the end of my journey at TU Delft, I hold a strong belief in the transformative power of change and our capacity to transition towards a new status quo, provided we wholeheartedly dedicate our energy and capabilities to it. I am enthusiastic and grateful to have discovered this purpose during such crucial years of my life.

Let us be inspired by those who have dared to challenge the status quo, and let us be the catalysts for change that reshape the world we live in.

Let us become *game changers*.

J.J.C. (Jolijn) van Dijk
Delft, July 2023

Acknowledgements

As I conclude the last six months, I find myself writing these acknowledgments. Despite the inherent challenges of avoiding cringe-worthy language in this section, I do recognize the significance of realizing that writing a thesis is not an individual effort. Many people have supported me throughout this process, and writing this section allows me to gratefully remember all the wonderful individuals who have been by my side.

I would like to express my sincere gratitude to my supervisors for their guidance and support throughout this research. I genuinely believe their support has unlocked my full potential and provided the motivation to make the most out of these past six months. Their expertise and encouragement have been incredibly helpful in shaping this research and discussing its outcomes. I would also like to express gratitude towards all the interviewees who shared their time and insights. Your contributions have been crucial in gathering essential data and enriching the findings.

I would like to specifically thank my graduation company, EVConsult, for the opportunity to use their expertise and network to the benefit of this research, and the insightful conversations with many colleagues while enjoying some drinks at Friday afternoons. During the whole period, I have been very aware of the freedom you have given me to shape my research as I wished. Maybe even more importantly, I have always felt very welcome and was always looking forward to my weekly day at the office. I would like to specifically thank Ruud for our many discussions and for always being on standby for help when needed. Without your help, I would have probably still been busy contacting potential interviewees.

Next, I want to express my appreciation to my friends and family, who have played a significant role in this process. I am incredibly grateful for the help I received with the one aspect I have experienced as most challenging during my thesis: designing a cover page. Niek, Bram, and Daniël, you are heroes. The many conversations with Kirsten, Marijn, Fenne, Ewout, Daan, Daniël, and my parents during our many coffee-breaks or end-of-the-day drinks were incredibly helpful, more than you probably realize. Lastly, I must acknowledge my dear roommates Jolan, Niek, Lot, and Bram for their unconditional support and their unfailing ability to pretend to be interested in the world of bidirectional charging.

Thank you all for being a part of this journey. Now, the time has come for me to start a new chapter.

J.J.C. (Jolijn) van Dijk
Delft, July 2023

Executive summary

Challenge and purpose

With the increasing transition to battery electric vehicles (EVs) and concerns about the capacity of the existing electrical infrastructure, the need for effective grid capacity management has become apparent. The V2X innovation, also known as bidirectional charging, has potential to enable EVs to interact with the electricity grid for various purposes, contributing to a sustainable and reliable transport and energy system. There are a variety of drivers and barriers to this innovation. The conducted literature review has highlighted a significant issue regarding the drivers and barriers of Vehicle-to-Everything (V2X) technology. While various drivers and barriers have been identified, there is inconsistency in their level of aggregation, even within the same articles.

Furthermore, most of the literature takes a generic view of the V2X system, with only a few articles focusing on specific national contexts. In particular, there is a complete lack of scientific literature that specifically investigates the performance of V2X in the Dutch context. Also, very few studies consider the impact of configuration decisions on the drivers and barriers of the system. This research gap is critical to address and fill, as it provides essential insights into the effects of configuration decisions on the performance and innovation potential of a bidirectional charging system. Understanding these effects will enable a more targeted use of resources and facilitate the practical implementation of V2X systems. This thesis aims to explore different V2X system designs in a socio-technical context, analyse their socio-economic performance and innovation potential, and provide valuable insights for the successful implementation and adoption of V2X technologies in the Netherlands.

Methodology

The research question is formulated as: ***How do different V2X system designs compare in terms of their socio-economic performance and innovation potential in the Netherlands?*** where performance refers to the current state of a system or technology, measured by its drivers and barriers, and innovation potential assesses a systems capacity to overcome barriers, create and strengthen drivers, and introduce new solutions for further development of the V2X system design. The Technological Innovation System (TIS) framework is implemented with inspiration from Multi-Level Perspective (MLP) concepts to capture the dynamics and interactions within the V2X system. Three V2X system designs are analyzed, labeled the *public V2G system design*, the *commercial V2B system design*, and the *islanded V2H system design*, all three carrying varying design-choices for five defined system design dimensions. Data is collected through desk research, event visits and interviews with experts and stakeholders. Nine semi-structured expert and stakeholder interviews were conducted, which unraveled the most important themes for comparison of the various V2X system designs. The research methodology aims to identify key dimensions, configuration choices and factors relevant for comparing V2X system designs in terms of socio-economic performance and innovation potential.

Results

The comparative analysis of the V2X system designs revealed important results regarding the performance and innovation potential. The research results highlight several key findings. First, the *public V2G system design* consistently performs the worst compared to the other designs across most of the topics evaluated, such as system interoperability, product availability and complexity of the stakeholder field. The system design faces numerous challenges and barriers that hinder its implementation and innovation potential in the Netherlands. It currently struggles with the dynamics between entrepreneurial activities that lead to the formation of a market, which are mostly due to the chosen charge topology (AC), and the charge location (public), which lead to considerable technical and interoperability issues. However, the lobbying and network forming efforts are effective for this design, leading to an increasing amount of attention despite its complexity.

In contrast, the *commercial V2B system design* has the lowest number of topics where it performs poorly and generally achieves average scores over all analyzed topics. This design shows better feasibility and potential for implementation in the Netherlands, as it tackles the most urgent issue in the Netherlands currently, being congestion management struggles. It performs relatively well with regard to entrepreneurial activities and the formation of a market, but has more issues with the formation of strong networks, which leads to a limited level of lobbying activity for this system design.

Finally, the *islanded V2H system design* has the highest number of issues where it performs very well as this is shown to be the simplest system design. However, it also has some areas where it performs poorly, especially with regard to economic potential. This system design is essentially ready for practical implementation, as there are no significant practical barriers in place. However, considering the Dutch context, the islanded V2H system design may not be the most viable option due to the current absence of reliability issues that would necessitate an energy independence solution, even though these issues may intensify in the future. Moreover, this system design does not directly address the pressing concern of congestion management. Hence, its suitability is diminished in light of the urgency associated with tackling congestion challenges in the Netherlands.

Conclusions

This research highlights the islanded V2H system design's relative superior *performance*, attributed to its simplicity, while it has relative low innovation potential, due to its (current) lack of urgency in the Dutch context. The study underscores the commercial V2B system design's relative significant *innovation potential*, derived from its capacity to address urgent issues alongside its straightforward design. Furthermore, the research reveals the complexities that impede the performance and innovation potential of the public V2G system design due to its many complex characteristics. Overall, these conclusions underscore the significance of strategic configurational choices in unleashing the full potential of different V2X system designs.

Implications

The research findings provide preliminary insights that can guide future policy making, particularly in the context of V2X system designs. Three key dynamics, namely the formation of collaborative networks, the creation of incentives for market formation, and market formation through pilot projects, serve as essential motors for innovation development. Conducting more pilots and experiments to address barriers and fill knowledge gaps will benefit all V2X system designs. Specific recommendations include focusing on technical pilots and ancillary service development for the public V2G system design, lobbying efforts for the commercial V2B system design, and creating economic incentives and exploring solar PV combinations for the islanded V2H system design.

List of Abbreviations

AC	Alternating Current
aFRR	Automatic Frequency Restoration Reserve
CCS	Combined Charging System, standard for EV charger
CHAdeMO	"Charge for Moving", standard of EV charger
CPO	Charge Point Operator
DC	Direct Current
DSO	Distribution Services Operator
EMSP	E-Mobility Service Provider
EV	Electric Vehicle
FCR	Frequency Containment Reserve
kW	KiloWatts
MLP	Multi-Level Perspective
MW	Megawatts
NAL	Nationale Agenda Laadinfrastructuur
OEM	Original Equipment Manufacturer
OCPP	Open Charge Point Protocol
TIS	Technological Innovation System
TSO	Transmission Services Operator
V1G	"Vehicle-one-grid", unidirectional (Smart) Charging
V2B	"Vehicle-to-Building", bidirectional charging directly connected to a building
V2B-g	"Vehicle-to-Building", connected to the grid
V2B-i	"islanded Vehicle-to-Building", not connected to the grid
V2C	"Vehicle-to-Customer", umbrella term for V2H and V2B
V2G	"Vehicle-to-grid", bidirectional charging directly into the grid
V2H	"Vehicle-to-Home", bidirectional charging directly connected to a home
V2H-g	"Vehicle-to-Home", connected to the grid
V2H-i	"islanded Vehicle-to-Home", not connected to the grid
V2X	"Vehicle-to-Everything", umbrella term for different types of bidirectional charging
W	Watt

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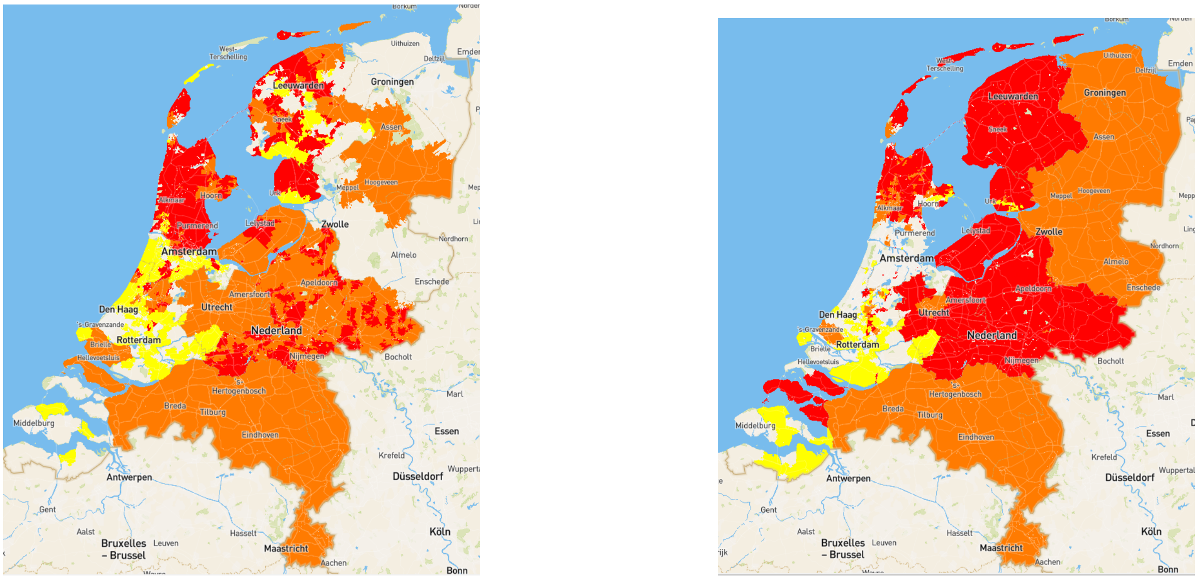
1 Introduction

1.1. Introduction of the topic

Countries around the world, including the Netherlands, are actively embracing the transition to battery electric vehicles as part of their commitment to achieving the goals set out in the Paris Agreement [19, 85]. However, this transition raises concerns within the energy industry about the capacity of the existing electrical infrastructure to handle the increased demand from charging these vehicles. The urgency for resolving grid-related issues becomes evident when looking at the current grid capacity. The need for effective grid capacity management in the Netherlands is illustrated by the capacity map produced by Netbeheer Nederland, which shows the currently available transport capacity for both electricity demand and supply [66]. In most areas of the Netherlands, the capacity has reached it limits. In addition, Alliander has given out a warning that decreasing grid quality is resulting in increasing power failures [8].

In response to this challenge, there is a growing momentum towards implementing the Vehicle-to-Everything (V2X) innovation, recognizing it as a vital step towards achieving a sustainable and dependable transportation and energy system. The V2X innovation, also known as *bidirectional charging*, empowers electric vehicles (EVs) to engage with the electricity grid, allowing for diverse interactions and functionalities. It allows EVs to utilize power from the grid during opportune moments and also contribute surplus power to the grid when necessary, functioning as a decentralized energy resource. The 'X' in V2X stands for *'everything'*, indicating the broad range of connections and interactions enabled by the V2X technology. It encompasses various communication and interaction capabilities between vehicles and other entities such as grids, homes, buildings, other vehicles or external devices. Thus, V2X is an umbrella term for multiple concepts. Vehicle-to-grid (V2G) was first introduced as technology that enables a flow of electricity from an electric vehicle battery directly towards an electricity grid [17]. Later, other types of bidirectional flows were examined, the most relevant being Vehicle-to-Building (V2B), Vehicle-to-Home (V2H). These two concepts combined are occasionally referred to as Vehicle-to-Customer (V2C) [37]. Since its introduction, a variety of use cases for V2X implementation have been introduced and investigated.

Often mentioned benefits of V2X are the enhanced grid stability and reliability, integration of renewable energy sources, peak shaving and load balancing, and emergency backup power capabilities [37]. With these benefits, V2X has the potential to alleviate multiple emerging challenges including grid capacity [66] and grid quality issues [8], and the recent energy dependence concerns caused by the war in Ukraine [20]. Given the urgency of these grid-related challenges and the potential benefits of V2X technology, it is crucial to investigate the feasibility and possibilities of implementing this innovation in the Netherlands. By exploring the potential of V2X technology, an assessment can be made of its ability to address grid capacity and quality issues, increase energy independence and contribute to the country's overall sustainability goals.
The V2X innovation has attracted significant interest and investment from the industry and research communities. Major car manufacturers (OEMs), energy companies and charging infrastructure providers have been actively involved in its development. Companies such as Renault, Nissan and BMW have initiated pilot projects and research collaborations to explore practical implementation [94]. A total of seventeen pilot projects have been conducted in the Netherlands thus far [94], with the aim of gaining experience and under-



(a) Power demand **(b)** Power supply

Figure 1.1: Capacity maps of the Dutch electricity system (status by 26th of April 2023), source: [66]

standing the potential of V2X technology in real-world scenarios. However, it is important to acknowledge that the V2X innovation is still in its early development stages, and very limited real-world application has yet demonstrated reliable and successful functionality, even on small scale. The We Drive Solar pilot project [82] stands as the closest example, but further development and testing are required to validate its effectiveness. Supportive policies and regulations have been developed by regulatory bodies, such as the European Union, to foster the widespread adoption of V2X technologies. Organisations such as CharIN are developing industry standards and protocols for seamless integration between charging networks [46]. Although there is significant activity surrounding this technology, challenges in the technical, economic, social, and regulatory domains still hinder its large-scale implementation despite industry enthusiasm. These can be partly solved by conducting targeted academic research.

1.2. Knowledge gaps and research objectives

Much research has been conducted on finding drivers and barriers for the large-scale implementation of the innovation (see findings in Chapter 2. Such researches result in both social, and technical drivers and barriers. The existing academic literature has predominantly focused on *general* drivers and barriers of the technology, leaving a notable gap in the understanding of specific use cases and effects of configurational decisions during implementation. Recognising this research gap, this Master's thesis aims to address this limitation by conducting an in-depth analysis of different and realistic V2X system designs in a socio-technical context in the Netherlands. The socio-technical perspective plays a crucial role in this research as it acknowledges that the implementation and adoption of V2X system designs rely not only on technical aspects but also on social, regulatory, economic, and organizational factors. By considering the interplay between technology, stakeholders and the wider socio-economic context, a comprehensive understanding of the complexities and dynamics associated with the adoption and diffusion of V2X technologies is provided.

The analysis of different V2X system designs allows a comprehensive exploration of the potential applications of the innovation. By comparing these system designs, this study aims to provide valuable insights into the key differences between V2X system designs and their implications. Analyzing the Dutch context is crucial due to the Netherlands' prominent position in the transition of electricity infrastructure. The country has taken significant strides by installing a substantial number of charging stations, making it a leader in this field. Additionally, the Netherlands' renowned "living lab" approach, demonstrated by seventeen V2X pilot projects already conducted, offers ample data for a comprehensive analysis. This rich data set allows for a thorough examination of the various aspects related to V2X systems, ensuring reliable findings and valuable insights for the research. This purpose has led to the formulation of the following research questions:

How do different V2X system designs compare in terms of their socio-economic performance and innovation potential in the Netherlands?

To answer this main research question, the following sub questions are formulated:

1. *Which key dimensions can be identified to determine a V2X system design?*
2. *Which configurational decisions for each key dimension form relevant V2X system designs for the context of the Netherlands?*
3. *What are the key factors relevant for comparing the socio-economic performance and innovation potential of different V2X system designs in the Netherlands?*
4. *How do these key factors score across different V2X system designs?*

Throughout the report, there are three recurring key terms that require clear definitions to effectively convey the intended message of the research. These key terms are a 'system design', a 'dimension', and a 'configuration'. Figure 1.2 visualizes the meaning of these key terms and their interrelations.

- A **dimension** refers to a specific aspect or characteristic that must be considered and decided upon in order to create a system design. In Figure 1.2, three dimensions are visualized within the system;
- A **configuration** refers to a specific alternative within a dimension. In Figure 1.2, four configuration-alternatives for each dimension are visualized. Within each dimension, one configuration-alternative is chosen;
- A **system design** refers to a set of configuration-decisions within each dimension in a system. In Figure 1.2 the chosen configurations within each dimension are marked by filling in the box.

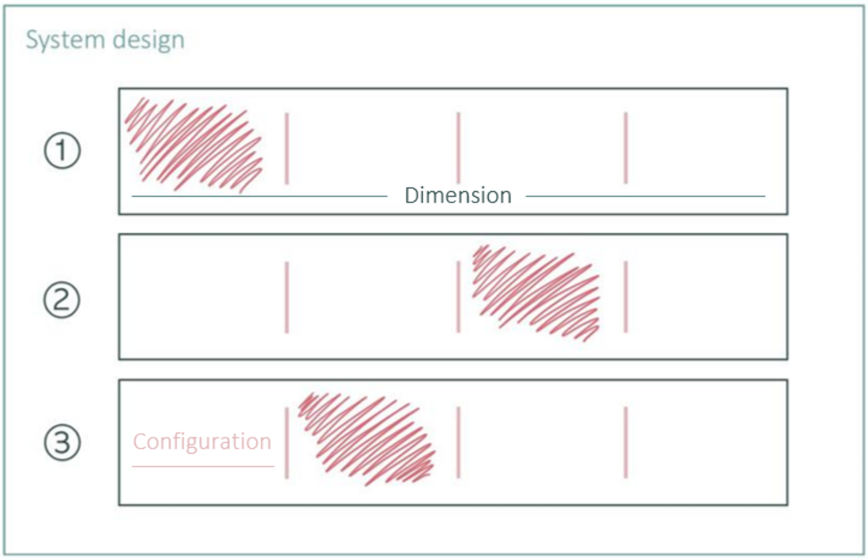


Figure 1.2: Visualization of the key terms 'system design', 'dimension', and 'configuration'

1.3. Research approach

A comprehensive research approach, including a well-defined methodology and data collection strategy, was developed to address the research objectives and bridge the identified knowledge gaps. The Technological Innovation Systems (TIS) framework by Hekkert et al. [40] was adopted for this research, in combination with the MLP framework by Geels [30].

The use of the Technological Innovation Systems (TIS) framework in this research is valuable as it provides a systematic and comprehensive approach to understanding and analysing the dynamics and interactions within innovation systems. By applying the TIS framework, this research can provide insights into the different dimensions of the V2X innovation systems, such as innovation development, knowledge flows, market formation and stakeholder support. This framework allows for a holistic examination of the socio-technical factors that influence the adoption and diffusion of V2X technologies in the Netherlands. The inclusion of the MLP framework adds value to the TIS analysis by providing a deeper understanding of the broader societal and socio-economic changes required for the successful adoption and diffusion of V2X technologies. In addition, the Motors of Innovation theory was used for the analysis of the key driving forces behind the development and diffusion of the V2X system designs in the Netherlands. This theory provides a framework to understand how different 'motors' or factors interact and influence the innovation process.

The data for this research is collected through several paths: by doing desk research, visiting events, and conducting semi-structured expert and stakeholder interviews. All data sources are used to discover the narrative on the development of the different V2X system designs, through the analysis of the seven defined system functions of the TIS framework. In total nine interviews were conducted to find information on the TIS dynamics, potentially (in)validating the information found throughout the desk research and event visitation. The data was coded using a modified version of the grounded theory. All this with the aim of comparing different V2X system designs and their key differences.

1.4. Theoretical and practical relevance

The theoretical relevance of this research lies in the exploration of the effects of configuration decisions and designs on the drivers and barriers of V2X technologies, addressing a current gap in the literature. Additionally, this study aims to provide theoretical insights specific to the context of the Netherlands. This research utilizes the Technological Innovation Systems Framework (which is further explained in the Methodology section), which is a novel approach in the context of V2X innovations, offering valuable insights into the usability and applicability of this framework for future research. On a practical level, this research contributes by empirically investigating the diffusion of multiple V2X configurations in the Netherlands, providing valuable data and insights into the performance and innovation potential of various V2X technologies in real-world contexts.

This research is specifically relevant to the learning goals of the MSc Complex Systems Engineering as it concerns a complex socio-technical issue. Implementing an innovative technology on a large scale is a complex and uncertain process due to numerous influencing factors. Such a problem should be approached with a helicopter-view, where not only the technical characteristics are regarded, but also economic, social, or regulatory components are brought to the attention. In addition, this research comprises both an engineering and design component, and shows the importance of a broad, conceptual view on the topic to understand the relevant dynamics for defining policy implications.

1.5. Outline of the report

This section provides an overview of the structure and organisation of this Master's thesis, outlining the key sections and their respective contents to guide the reader through the report. Chapter 2 consists of a literature review of the current academic research available. In this Chapter, an overview is given of the general drivers and barriers of V2X system designs. Chapter 3 discusses the methodology, consisting of the system delineation, the theoretical approach chosen, and the data collection and data analysis strategy for all research questions. In Chapter 4, the results of the research are summarized. First, the formation of three V2X system designs is discussed, followed by a comparative analysis of the three system designs. The chapter is closed by an analysis of the relevant motors of innovation. In Chapter 5, the conclusions are given for each research question. Chapter 6 is followed by a discussion of the research limitations, added value of the research, and recommendations for future research. An extensive analysis on which the results are based can be found in Appendix A.

2
Literature Review

Since the concept of a bidirectional flow between vehicle and grid was introduced in 1997 by scientists Kempton and Letendre [48], much research has been executed on the implications of its large-scale implementation [97].The concept of bidirectional charging was introduced to decrease the impact of battery-electric charging on the electricity grid [44]. As time progressed, the technology was expanded to encompass a wider scope, revealing additional possibilities for implementation.

2.1. Literature research process

The objective of the literature search is to acquire a comprehensive understanding of the existing literature concerning the implications of V2X system implementation. A study was undertaken to explore the drivers and barriers of V2X, as well as their application in specific use cases. Both Google Scholar and Scopus were employed in the search for relevant material. A publication range of 2020 until 2023 was used as a restriction to filter out outdated publications and to make the number of papers manageable. With the initial batch, multiple filtering moments have been conducted in order to reach to a final list of relevant literature. This filtering was based on removing duplicates, removing papers written in a language other than English or Dutch, removing non-accessible articles due to a paywall, and screening for relevance by reading the abstract.

A research term aimed at finding literature on drivers and barriers of various V2X use cases was employed. A combination of Google Scholar and Scopus was used. This combination is helpful as Scopus's database focuses on peer-reviewed literature, and Google Scholar could supplement this with technical reports or other relevant content. For the search in Scopus, an additional filtering was used by excluding the subject areas Computer Science, Mathematics and Chemistry. This way, articles solely focused on the technical understanding of V2X were excluded and the article number was more manageable. A visualization of the search process is given in Figure 2.1

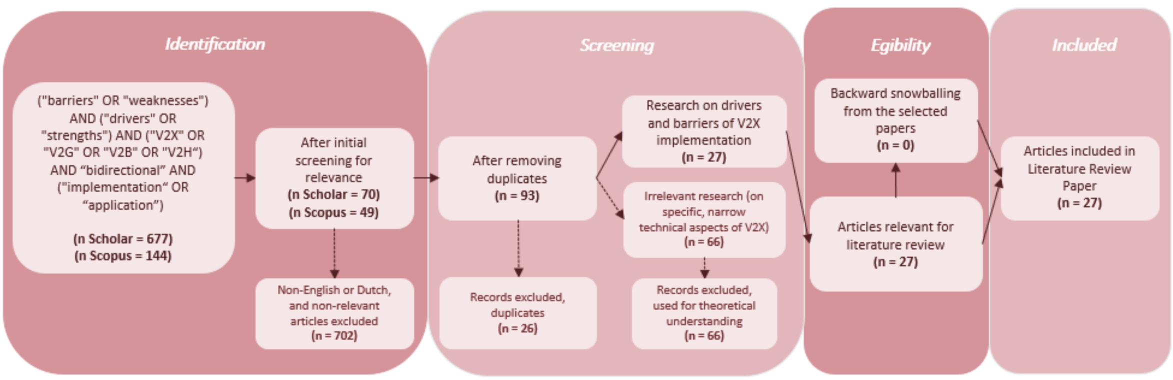


Figure 2.1: Literature research selection string

2.2. Drivers and barriers of V2X implementation

Studies on V2X implementation distinguish between technical-, social-, regulatory- and economic drivers and barriers (e.g. [77]). Studies that are concentrated on the technical aspects of V2X implementation make up most of the academic literature [37]. Some studies aim to define the main drivers and barriers of V2X. Khezri, Steen, et al. [51] conclude in their review on available literature that main benefits include social acceptance (increasing the general acceptance of EVs), market benefits (i.e. increasing the general acceptance of EVs) and economic benefits (i.e. decreasing the operation cost of EVs), and the main barriers include technical- (i.e. degradation of EVs battery), economic- (i.e. charging infrastructure costs), regulatory- (i.e. lack of standards and grid codes), and social barriers (i.e. range anxiety of EV owners).

On the other hand, Sturmberg et al. [86] define the main barriers to be uncertainty in financial returns and vehicle availability, and Sree Lakshmi et al. [84] argue that the main benefit of V2X is the ability to participate in the power market in providing services to the grid. It can be concluded that academic literature provides multiple main drivers and barriers of the V2X innovation. This difference can be attributed to the diverse interpretations of system levels, resulting in the identification of multiple levels of drivers and barriers. One author may define drivers and barriers at a specific level, while another author may define them at a more or less aggregated level. Moreover, the involvement of various stakeholders with distinct interests further contributes to the nuanced understanding of these drivers and barriers. This literature review aims to identify the specific stakeholders for whom a driver or barrier is most pertinent. In cases where the driver or barrier applies universally, the term 'system' will be used to represent the broader context.

The following paragraphs discuss the general drivers and barriers that could be derived from academic literature. Table 2.2 aims to summarize the found drivers and barriers. Each driver and barrier can be designated to a specific (group of) stakeholder(s). The guiding text lists the relevant stakeholders.

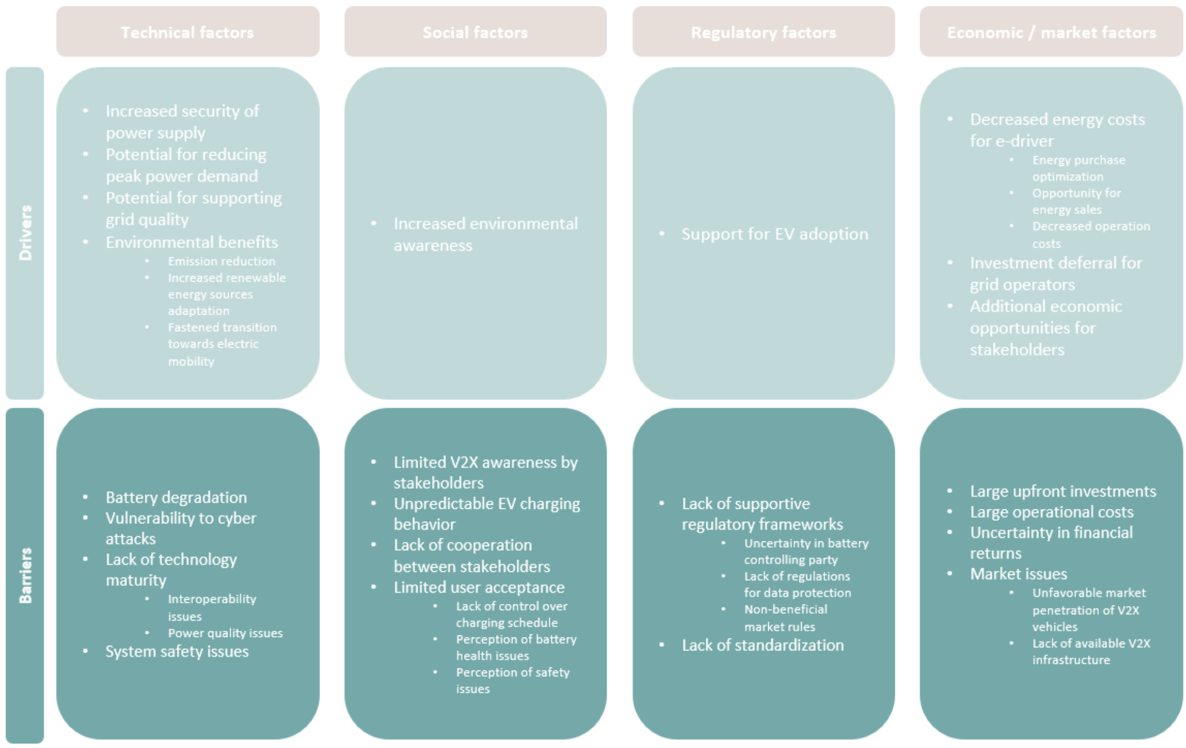


Figure 2.2: Overview of drivers and barriers of V2X implementation according to academic literature

2.2.1. Technical drivers and barriers

With regard to technical drivers, the *increased security of power supply* is often mentioned [69] as a driver for Transmission System Operators (TSOs) and Distribution System Operators (DSOs). With the current transition to intermittent energy sources, TSOs and DSO find guaranteeing power supply increasingly difficult. Bidirectional charging could provide increased flexibility to the electricity system in times where intermittent sources are not able to supply [86, 84]. Authors often discuss the ability of V2X to help *reduce peak demand*

[22, 75, 27, 23]. This is a specific driver for DSOs, as they manage congestion on the grid. Supporting grid quality is also mentioned in different forms, like by providing frequency balance services [22, 84], give standby power [83], and increase the grid's service reliability by providing ancillary services [83]. This is a specific driver for TSOs. Lastly, *environmental benefits* are a significant driver. Authors argue that a V2X system is compatible with a decarbonized electricity system [86] and could achieve emission reduction [51, 7, 41, 69], strengthen the transition towards electric mobility [69], and strengthen the renewable energy sources adaptation [75, 5]. The classification of 'environmental benefits' as a technical driver is chosen here because of its direct link to the technical performance and characteristics of the innovation. However, it is important to recognise that in different contexts or frameworks, 'environmental benefits' could also be considered as a social driver, given its alignment with societal goals and values related to environmental sustainability. Environmental benefits are drivers for the system as a whole.

One of the most often mentioned technical barriers in literature is *battery degradation* [51, 37, 22, 65]. This is a specific barrier for OEMs and owners of EVs, as this shortens battery life. However, not all studies agree on the negative influence of V2X on vehicle batteries. Some studies conclude battery degradation to be negligible in V2X contexts [73] or to even improve battery lifespan [72]. Due to this, many studies conclude that more research on this is necessary. This barrier, however, receives much academic attention. A barrier that seems to receive less attention is the vulnerability to cyber attacks[5, 75]. A bidirectional charging system involves a complex network of communication and data exchange between electric vehicles, the power grid and various IT systems, increasing cyber security concerns. These concerns directly affect the party to whom the data belongs, which is the EV owner, but also the parties that use this data for their activities. Eventually, issues with cyber security could negatively affect society as a whole. Other barriers that are mentioned are the lack of technology maturity [51], which results into interoperability issues [74, 22], and power quality issues [75]. This is a barrier for all parties involved in a future V2X system. Safety issues are also mentioned in combination with V2X [39]. This concerns the EV user and all that is located in the charging surroundings. A development of technical standards like communication or interconnection standards are necessary to overcome such barriers [37].

2.2.2. Social drivers and barriers

With regard to social drivers, Raouf, Mousavian, and Ghazinour [75] argues that society increasingly feels the urgency for climate mitigation. Thus, *increased environmental awareness* is argued to be a driver for e-drivers to become involved in a V2X system due to its environmental benefits, which were discussed in Paragraph 2.2.1.

The social barriers mentioned in academic literature are much more extensive than the drivers. Firstly, the *limited V2X awareness by stakeholders* forms an important barrier. Even though increased environmental awareness was just mentioned as social driver, the awareness of EV owners about the capabilities of V2X must be increased [51, 22]. Also, Emodi et al. [24] concluded that greater understanding by e-drivers about potential cost savings is needed, as well as greater understanding by policy makers on the attitudes of consumers to different V2X business models. The *badly predictable EV charging behavior* is another important social barrier [57] for commercial parties in the system, like CPOs and EMSPs. In order for them to develop a favorable charging scheme, the charging behavior must be as predictable as possible. The success is largely dependent on factors like plug-in rate which are determined by users [37].

Additionally, the *lack of cooperation between stakeholders* is an important barrier. This specifically entails the collaboration between parties directly involved in the execution of a V2X system, like CPOs, EMSPs, e-drivers and grid operators. Mojumder et al. [62] conclude that as of now, there is a lack of stakeholder incentive to cooperate. However, they do not mention a reason for this occurrence. A possible reason is mentioned by Sturmberg et al. [86], who refer to the immature relationship between the transport- and energy sector. To fully utilize the potential of V2X, a controlled charging arrangement must be created through collaboration between the EV industry, EV users, and energy utilities [24]. These two sectors are not used to having to take joint actions, as their operations have never crossed so far. A successful V2X implementation requires user voluntarism [83]. *User acceptance* is still limited for V2X [97]. This is partly due to the lack of control over the charging schedule [75, 69], which results in range anxiety [36]. In addition, the perception of battery degradation could very much form a barrier for implementation [37]. Safety perception also influences user acceptance [36].

2.2.3. Regulatory barriers

With regard to regulatory factors, the emphasis in literature is clearly put on the challenges. One driver that is mentioned, is the support for EV uptake [4] which varies across countries. Multiple barriers are mentioned, however. A *lack of supportive regulatory frameworks* is one of these barriers, which forms a barrier for all stakeholders directly involved in V2X activities [51, 37, 52]. Regulatory frameworks are needed to solve uncertainty in who will control the usage of V2X batteries [51], which forms a barrier for the e-driver, OEM, CPO, EMSP, and energy supplier who are all chasing this control. The lack of a regulatory framework for data protection is also mentioned [24], which forms a barrier for the data owners, which are the e-drivers. This barrier refers to the cyber security issues that were mentioned in Paragraph 2.2.1. Also, no regulations are currently in place to boost *beneficial market rules*. Some market rules even discriminate against V2X resources through outright bans on aggregation of energy sources [90]. Standardization of the V2X system, however, is concluded by Barreto, Faria, and Vale [5] to be a difficult operation. This is understood in the broadest sense, as the author does not specify what kind of standardisation they are referring to. All stakeholders directly involved in V2X activities would benefit standardization.

2.2.4. Economic / market drivers and barriers

Economic incentives are universally accepted as important factor to consider in the context of V2X [23, 51]. Overall, there seems to be a consensus that V2X could lead to cost-savings for several stakeholders and market participants [75], including grid operators as they could experience an investment deferral of up to 12%, according to Putrus et al. [74]. Grid operators have the potential to postpone the reinforcement of the electricity grid due to V2X technologies [37]. Also, *e-drivers* could achieve *decreased energy costs* [101]. This could be achieved in different ways. V2X could help decrease the costs for energy use by (1) purchase optimization [24], (2) energy sales [83], and (3) decrease operation costs for EV owners [51]. Besides cost savings, another economic driver often mentioned is the rise of *new economic opportunities for stakeholders*. V2X economically utilizes currently unused assets [86]. Sree Lakshmi et al. [84] argue that there might be economic benefits for e-drivers, charging providers and power grid operators. As the role of e-driver changes from solely consuming electricity towards an active participant in the energy market, they are able to obtain revenue from their participation [5]. Also, added revenue for grid operators is mentioned by Khezri, Steen, et al. [51]. A combination of both decreased costs and new economic opportunities could lead to an enormous economic benefit.

However, V2X also has some economic / market barriers to overcome. Firstly, *large upfront investments* are needed by e-drivers, charge point manufacturers, CPOs, and OEMs, as the investment costs for V2X-enabled equipment are high [41, 75]. Large investments are needed in both charging infrastructure (charge point manufacturer, CPO/e-driver) [51] and EVs (OEM, e-driver) [41]. The cost of technology learning are also considered to be high [51], for example for the optimization of V2X algorithms. This is a barrier for all stakeholders involved. Besides, the *operation costs* are also large; consisting of control and measurement system costs and administrative/transaction costs [69]. This is a barrier for operating parties. *Uncertainty in financial returns* [86] and the possibility of uneconomical practices [62] hold back the technological innovation as well. This counts for all stakeholders that aim for having economic benefit from this system. Therefore, a deeper comprehension of cost savings is required [24]. The cost-effectiveness will depend on the specific application of V2X and the electricity tariff design structure Emodi et al. [24]. As value streams are not yet clear [22], economic uncertainty cannot yet be resolved. Some studies try to clear up this issue. Corchero and Sanmarti [17] have created a framework, called the Value Stream Framework, for categorizing and communicating the full economic potential of V2X. This is, however, a general framework that is not concretely applicable to the context of a specific country. Lastly, several *market issues* play a role as well, which consists of the current challenges of market penetration of compatible EVs, which is not yet at a favourable level [83], and a lack of V2X-compatible infrastructure.

2.2.5. Current state of academic literature on V2X systems

A variety of drivers and barrier of V2X were found in academic literature. The drivers and barriers identified in the literature review serve as a foundational starting point for the comparative analysis conducted in this study. What is striking is that the drivers and barriers found are inconsistent in aggregation level, even within the same article. Almost all literature that was reviewed takes a generic view on the V2X system. Only two articles focus on a specific National context, being Australia [24] and England [74]. The performance and innovation potential of V2X in the Dutch setting were not specifically covered in any academic literature. More importantly, very little literature acknowledges the fact that configuration-decisions in a V2X system affect the drivers and barriers for the system. A handful of authors attempt to describe the practical difference between different V2X designs [38, 29, 7], but do not elaborate on the configuration-specific drivers and barriers. This research gap is crucial to address and fill, as it aids the understanding of the effects of configuration-decisions on the success potential of a bidirectional charging system. As the actual practical implementation of a V2X system will necessitate making configuration decisions, insights on the effects of configuration decisions will allow for more targeted deployment of resources. As the drivers and barriers found in the literature review are broad and diverse, varying in aggregation levels, it will be interesting to explore their alignment with the specific findings of this study's comparative analysis.

3

Methodology

This chapter describes the methods and research strategy used to address the primary research question. This question is formulated as: *How do different V2X system designs compare in terms of their socio-economic performance and innovation potential in the Netherlands?* The objective of this section is to explain the methodology used for the research, how it has been specifically applied, and how each sub-question was approached.

3.1. System delineation

It is crucial yet challenging to distinguish between an innovation system and its surroundings [61], as delineation is likely to affect the research findings. There is no correct or incorrect method for defining system boundaries. For a specific research, however, it is important to define the assumed system boundaries. This research focuses on passenger road vehicle transport. Other applications such as marine applications fall outside the scope of this research. With regard to time scoping, 1997 is taken as starting point, as the concept of V2G was introduced in that year [48]. As the aim of this research is to look at V2X implementation in the Dutch context, the geographical delineation would be at the national borders of the Netherlands. This geographic segmentation is crucial because institutions and organizations are essentially defined by a certain territorial sphere of influence [63].

Hekkert et al. [40] argue that technological systems often cross both geographical and sectoral boundaries. Electric mobility is a clear example of how an innovation converges two otherwise independent sectors [3]. The integration of the energy- and transport sectoral boundaries is an essential characteristic of V2X. These two sectors could be seen as two different focal regimes. In between these focus regimes, the TIS moves. As an integrated MLP-TIS framework is used, landscape- and niche developments are relevant to consider as well. Complementarity and competition of adjacent innovations plays an increasingly important role in a TIS system, also from a multi-system perspective, as different technologies embedded in different systems (or sectors) can have mutual influences on each other [80, 59]. The adjacent technologies were, therefore, scoped based on their frequent association with bidirectional charging in pilot projects, academic literature, or grey literature. Figure 3.1 visualize sthe system delineation that is used for this research.

3.2. Theoretical approach

The concept of vehicle-to-everything consists of niche innovations. Improved knowledge on innovation processes, such as that of vehicle-to-everything, is crucial because of the effects they have on policymakers, stakeholders, and the society as a whole. However, these innovation processes are *complex* and frequently rely on the concurrent modification of other aspects of the existing regime, as well as the co-development of other innovations [60]. Bidirectional charging systems can cause disruptions to current energy infrastructures and require adjustments to user behavior, grid management, and legal and regulatory frameworks. The formulation of appropriate policies and strategies is facilitated by taking into account socio-technical factors, which aid in identifying possible challenges, and possibilities related to the integration of V2X. A *socio-technical view* on such processes is essential to capture all relevant components.

In transition studies, four theoretical frameworks have received most attention over the last decades, being: transition management [49], strategic niche management [47], multi-level perspective on socio-technical

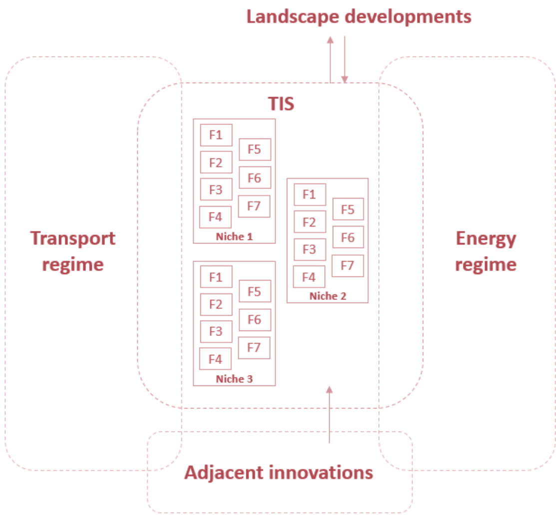


Figure 3.1: System delineation

transitions [30], and technological innovation systems [40]. Transition management puts emphasis on the governance aspects, whereas the other three frameworks focus on innovation management. SNM is relatively good at analyzing specific projects or events, while TIS is more focused on analyzing the system as a whole. As there are relatively little V2X projects conducted in the Netherlands so far, and information on these projects is scarce, the decision is made to analyze the system as a whole rather than focus on one or multiple of these specific projects. For this decision, TIS is a more suitable framework.

3.2.1. The Technological Innovation System framework

Within a Technological Innovation System, it is believed that the successful completion of seven functions leads to the development of new technologies. Finding 'system failures' is the key goal in order to offer a variety of (realistic) policy options [40]. The theory behind this framework is that the rate of technological advancement accelerates as the TIS expands, increasing the likelihood that the technology will succeed [40]. System functions do not, in the conventional sense, represent variables, but they might be thought of as categories of events [88]. Certain events could function as *motors of innovation*, others could form barriers for the same innovation.

The original TIS-framework consists of seven functions. However, as discussed in a paper that addresses six criticisms on the original framework, the particularities of each individual case must be taken into account to identify relevant context structures [58]. The authors acknowledge that the TIS framework pays little attention to the interaction of multiple technologies. In the context of V2X, complementary and competing technologies do play a large role in the system (this is also included within the system boundaries as explained in paragraph 3.1). Multiple authors have drawn attention to the importance of incorporating complementary and competing technologies within the analysis of energy transitions (e.g. [80, 59]. It is aimed to put more emphasis on these complementary and competing technologies in this research.

The definitions of the TIS functions, as used in this research, are:

1. *Entrepreneurial activities:* Refers to all activities done by entrepreneurs. Entrepreneurs can be established businesses that broaden their operations to take advantage of recent advancements or new businesses that recognize chances in emerging areas [67]. Function 2, 5 and 7 create the entrepreneurial climate in which entrepreneurial activities can blossom.
2. *Knowledge development:* Refers to learning mechanisms regarding the innovation. This includes both 'learning by searching' and 'learning by doing'. Function 6 influences the possible level and speed of knowledge development.
3. *Knowledge diffusion through networks:* Refers to the network of a system, which is essential for the exchange of information [67].
4. *Guidance of the search:* the actions taken inside the innovation system that have the potential to increase the visibility and understanding of certain desires among technology users. The areas that

will receive additional funding [67]. The outcomes of function 1 as well as function 8 influence the direction the search is guided to.

5. *Market formation:* Refers to the formation of the market in which the innovation exists. This includes the creation of temporary competitive (dis)advantages, or the creation of protected spaces for new technologies. Function 7 influences the way in which the market is formed.
6. *Resource mobilization:* Refers to financial, material and human capital available for the V2X innovation. This is necessary as a basic input to all the activities within the innovation system. Function 7 influences the amounts and types of resources that are mobilized.
7. *Creation of legitimacy:* Refers to the development of credibility for the innovation system within the existing regime. Stakeholder interests and power are included in this function. The outcomes of function 1 and function 2 influence the development of credibility.

Another criticism on the TIS framework, even though Markard, Hekkert, and Jacobsson [58] do not discuss this, is the little attention that is given to user behavior in the framework. This is, however, an important aspect in the context of V2X. Therefore, priority must be given to the incorporation of user behavior in the analysis. This is done by including an extensive analysis of stakeholders within the *creation of legitimacy* function.

A critique towards TIS that is mentioned by Markard and Truffer [61] is that it too puts little emphasis on niche dynamics. A conclusion that can be drawn by looking at the drivers and barriers found during the literature review (Table 2.2) is that almost all factors mentioned in academic literature are regime-based. This gives reason to explore more about potential drivers and barriers at other levels, such as the niche- and landscape-level like defined by Geels [30].

3.2.2. Multi-Level Perspective framework

The MLP framework views technological transitions as interdependent processes of change at the micro-level of niches and the meso-level of socio-technical regimes (defined in six key dimensions), both of which are immersed in a larger landscape of macro-level elements [30]. The *niche level* represents a protected space where new innovations emerge and develop. It is characterized by a small-scale and localized experimentation of novel technologies, practices, or business models that have the potential to bring about transformative change. The *regime level* refers to the dominant set of rules, structures, and practices that govern a particular sector or industry. Regime-level dynamics are characterized by stability, path-dependency, and resistance to change. The *landscape level* is a representation of the more general socio-technical, economic, and cultural setting in which the niche and regime levels function. It consists of externalǎvariables that might impact and shape the creation and spread of innovations.

The inclusion of regime-level variables in research is important because they influence the potential and dynamics of technological transitions. Each dimension of the regime exerts selection pressures on niche inventions, which has an impact on how they evolve and integrate into society [81]. As this does not happen often, radical innovations that are pioneered in niches could struggle to rise above the level of the niche towards the regime. By looking at niche-level variables, researchers can investigate how V2X systems might disrupt and transform the existing regime. It aids in identifying new trends, assessing the technical viability of V2X technologies, and comprehending the niche stakeholders involved. Landscape-level variables influence the overall context of socio-technical transformations. Landscape-level concerns for V2X systems might include analyzing public perceptions of electric cars, global energy patterns, and climate change imperatives.

3.2.3. Motors of innovation

Based on the theory of technological innovation systems, Suurs et al. [87] proposes hypotheses that explore the interplay and influence of various functions within different stages of innovation system development, known as *'motors of innovation'*. The author employs causal loop diagrams, drawing insights from extensive case studies to depict and analyze these relationships [98]. Four motors of innovation are identified by the author, being the 'science and technology push motor', the 'entrepreneurial motor', the 'system-building motor', and the 'market motor'. The author suggests that the analysis of a specific innovation within its context may reveal different and more intriguing motors that warrant further investigation. For example, the *market motor* is typically a motor that starts running when the *'death valley'* of an innovation is crossed, meaning that challenges in transitioning from the early development stage to successful commercialization are overcome. This motor is not interesting for innovations that have not overcome these challenges, yet.

3.2.4. Conclusions on theoretical approach

The MLP framework and TIS framework both put emphasis on system dynamics. Both frameworks have undergone extensive theoretical development over many years, as well as a substantial number of empirical case studies, in which they have been put to the test and improved. They share conceptual underpinnings and seek to explain similar empirical phenomena [3]. Markard and Truffer [61] argue that TIS has weaknesses to its approach that could be bettered with the integration of MLP. An example of this is the elaboration on the investigation of innovation dynamics at the niche level, something which is better handled with MLP.

The wish for more emphasis on the niche- and landscape-level calls for an integration of the TIS-framework by Hekkert et al. [40] with the MLP-framework by Geels [30], which has been repeatedly demonstrated in previous research, for example by Raven [76], Walz [99], and Langeland, George, and Figenbaum [54]. All three of these researches were focused on energy transition technologies, the latter focused on the uptake of electric vehicles in Norway. The value of this integrated framework is that it catches both the theoretical idea of motors of innovations, as well as the likely influence of external factors from the landscape- and niche-level. The *motors of innovation* theory is helpful in understanding the interplay of various TIS functions.

3.3. Data collection and analysis

The data for this research is collected through three paths: desk research, event visitation and semi-structured expert/stakeholders interviews. All three data sources are used to discover the narrative on the development of the V2X system, through the analysis of the seven defined TIS functions (see Paragraph 3.2.1. The literature review conducted in Chapter 2 served as a foundational and starting point for the subsequent desk research, providing a comprehensive understanding of the existing knowledge on the innovation. Both the empirical and conceptual data is concentrated on the context of the Netherlands. The data collection and analysis strategy for all four sub research questions will be discussed.

Q1: Which key dimensions can be identified to determine a V2X system design?

The data to answer this research question is collected through desk research. Relevant academic research as well as grey research is sought to discover the dimensions that are used to identify specific aspects or characteristics of V2X systems. The literature found is analyzed and categorizations are made based on own insights.

Q2: Which configurational decisions for each key dimension form relevant V2X system designs for the context of the Netherlands?

The data to answer this research question is collected through desk research and unstructured expert interviews. Relevant academic research as well as grey research is sought to discover the configuration-alternatives that are mentioned for V2X systems. A complete overview of all pilot projects that have been conducted in the Netherlands, is developed. For each of these pilots, data is sought on the configurational decisions made on each of the key dimensions identified under sub research question 1 (see 3.3).

For each defined key dimension, a list is made of the configurational alternatives used in Dutch pilot projects. This creates an extensive overview of the relevant configurational alternatives for each dimension in the context of the Netherlands. Next, relevant V2X system designs are developed with inspiration from the largest pilot project in the Netherlands, and the most popular configurational decisions in pilots in the Netherlands. Three experts are interviewed in an unstructured manner to validate the chosen system design. The unstructured interview type is chosen due to the exploratory aim of the interviews.

Q3: What are the key factors relevant for comparing the socio-economic performance and innovation potential of different V2X system designs in the Netherlands?

The data to answer this research question is collected through desk research, event visitation, and semi-structured interviews with experts and stakeholders. To find an answer to this research question, the MLP-TIS framework is used. The deliverable of this research question is an overview of key factors, or themes, that represent the underlying concepts that articulate the key differences between the different V2X system designs. Five experts and four stakeholders are interviewed with questions linked to the seven TIS functions (see 3.2.1).

The strength of interviews is that it is, more than quantitative research, open to new insights during the research process due to an open-ended inquiry [16]. As still much uncertainty exists in the V2X innovation system, and very little hard data is available yet, qualitative data collection through interviews is a suitable method. The interview protocol is created based on the seven TIS functions. There are prepared questions for each system function, formulated as open-ended as possible to avoid directing the response. The interview is semi-structured since further inquiries are made in response to the answers to these questions. The interviews were conducted until a theoretical saturation of insights was reached. More specific information on the interviewees and insight saturation is further explained in Appendix B.

Event visitation has facilitated data collection by providing an opportunity to observe and engage with relevant stakeholders, and experts. Through attending events, valuable insights are gathered, and a deeper understanding of the key factors that contribute to the socio-economic performance and innovation potential of different V2X system designs in the Netherlands is created. Desk research is conducted to strengthen and validate the findings derived from the interviews, enhancing the overall validity of the research. By corroborating the information gathered from primary sources with existing knowledge and literature, desk research contributes to a more robust and reliable narrative, ensuring that the research findings are well-supported and grounded in a broader context.

The semi-structured interviews are transcribed using the AI transcription tool *Whisper*, and thoroughly checked for possible mistakes. Although transcribing appears to be a straightforward technological procedure, choices must be taken, such as how much information is necessary. Audio recordings were created, which serve as the foundation for an in-depth transcription. The denaturalistic technique is used, which means the transcriptions do not incorporate the experts' nonverbal actions [100]. This strategy is adequate since the interviews' main goal is to gather content-related information; behavioral factors are irrelevant. For ethical considerations, all transcriptions were sent to the interviewees for approval. Their consent was asked for anonymous use of their quotes.

The transcriptions are coded with the use of *ATLAS.ti*. The transcriptions are coded with an adjusted version of the grounded theory [33]. To create the classifications into which categorization of the data is made, one goes through a cycle of data collection, analysis, and reflection until theoretical saturation is achieved. Instead of open coding, which is normally done by the application of the grounded theory, the interviews are coded by the seven functions defined by the TIS-framework. For each TIS function, a collection of quotes by interviewees arose. These quotes were then themed. The identified themes were subsequently integrated with the findings from desk research and attended events. An overview of the found themes is given in Appendix C. In cases where necessary, additional themes or sources found through desk research were included to enhance the comprehensiveness of the analysis.

As the TIS analysis is conducted for the three designs, the analysis is quite extensive. For readability purposes, the analysis of the TIS functions is described in Appendix A. Statements by interviewees are marked with their interviewee code, which starts for each interviewee with "INT" and ends with their respective interviewee number. The main takeaways from this analysis are discussed in the Results chapter. A detailed overview of the research process is shown in Figure 3.2.

Q4: How do these key factors score across different V2X system designs?

The data to answer this research question is collected through desk research, event visitation, and semi-structured interviews with experts and stakeholders. The event visits provided first-hand exposure to real-world implementations and insights into the practical aspects of V2X systems. It allowed direct observation of system functionalities, stakeholder interactions, and the contextual factors that influence system performance. Desk research complemented the findings from the event visits by reviewing existing literature, reports and studies on V2X system design performance.

In addition, semi-structured interviews with experts and stakeholders served as a valuable source of data. Five experts and four stakeholders are interviewed with questions linked to the seven TIS functions (see 3.2.1). Through these interviews, in-depth discussions were conducted to gain insights into the performance of the various V2X system designs with regard to the seven defined TIS functions (see Paragraph 3.2.1). By combining these data collection methods, the research obtained a rich and diverse data set that helped to analyze and compare the evaluation of key factors across different V2X system designs.

The deliverable of this sub research question is a scoring of each key factor on a scale of one through five, one being the worst score, and five being the best score. This scoring is relative compared to the other designs, and qualitative of nature. The analysis of the semi-structured interviews was done in the same manner as described under sub research question 3 (see Paragraph 3.3). The data collected through the desk research and event visitation empowered the narrative and validated the scoring of the performance of each key factor.

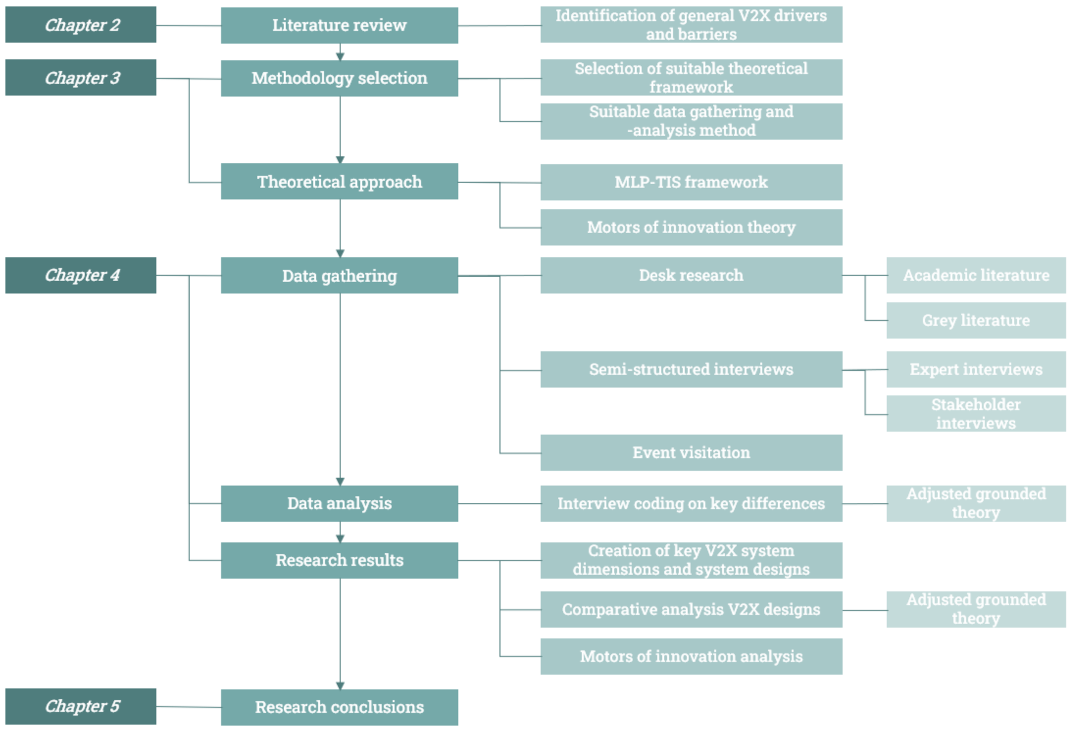


Figure 3.2: The Research Flow Diagram

3.4. Mitigation of research biases

As with all research, validity and reliability of data is crucial. Triangulation, or using data from many sources to address the research issues, ensures the validity of this study. The research results are anticipated to give an accurate image of the current V2X TIS by integrating numerous resources, including (grey) literature, data retrieved from event visitation, stakeholder interviews, and expert interviews. Even though the study's timeline was constrained by twenty-one weeks, which resulted in a relatively small sample size of interviewees, the findings can still be utilized to pinpoint essential elements of the innovation system and its dynamics. The transcriptions are checked and approved by the interviewee to assure all data is well interpreted. This is known as *respondent validation*. To ensure a more accurate interpretation of interviewees' statements, both audio recordings and transcripts were reviewed concurrently with the coding of the interview data. Other researchers might discover it challenging to reproduce interviews that were conducting in this study, due to its semi-structured approach. To guarantee reliability and verifiable, all interviews were transcribed. Every interviewee received the identical set of opening questions for each system function. Because of this, the responses are more easily compared.

The main challenge with regard to reliability for this research lies in the reliability of the interview coding. This research has not used coding by multiple coders, which is often referred to as *intercoding*. Intercoding is often discussed as a critical aspect of interview coding [13], as it requires that multiple independent coders of equal skill assign the same code to the same unit of text. This ensures consistency and accuracy in the coding process and contributes to the reliability of the study's findings. Although intercoding is desirable in qualitative research, it is not necessarily the case that research is negligible if it has not been intercoded. As long as the researcher provides clarity and transparency from start to finish (including coding processes) and explains high-quality research methods to readers, valuable information can be gained from single researcher studies. This research therefore aims to transparently discuss the coding process. In addition, by ensuring saturation or sufficiency of data, researchers can increase the prominence of themes. This means that collecting a sufficient amount of data allows for a comprehensive exploration of the research topic, leading to a more robust identification and development of themes. Thus, the saturation of insights is monitored and documented in this research. More on this can be found in Appendix C.

4 Results

4.1. Identification of key dimensions and configurations

The dimensions that V2X combinations might be constructed across are numerous. Gschwendtner, Sinsel, and Stephan [37] studied predominate trial project configurations around the world and defined three dimensions: (1) provided services, (2) charging locations, and (3) vehicle use types. These dimensions are not clearly defined by the authors. When it comes to the 'provided services', the authors mention the possibilities of bidirectional flows towards the Transmission System Operator (TSO), Distribution System Operator (DSO), or Consumers (homes or buildings). This regards the *service destination*. Another service related dimension that could be defined is the *service type* that is provided. Several authors mention different types of services. Four main types of services are found: *ancillary services*, in which short-term markets such as the FCR, and aFFR are targeted, *congestion management services*, which is provided via the GOPACS platform, *energy arbitrage*, where the intraday and day-ahead market are targeted, and *back-up energy*. An overview of service types is given in Table 4.1.

Service type	*Relevant market*	*Connected platform*	*Description*
Ancillary services	Frequency containment Reserves (FCR)	Equigy	Activated automatically based on grid frequency
	Automatic Frequency Restoration Reserve (aFRR)	Equigy	Activated by TSO after FCR is activated, works with bid-obligations
Congestion management services	Intraday market	GOPACS	Energy trading within day, works with "pay-as-bid"
	Day-ahead market	GOPACS	Energy trading 24 hours ahead of time, works with market clearing price principles
Energy arbitrage	Intraday market		Energy trading within day, works with "pay-as-bid"
	Day-ahead market		Energy trading 24 hours ahead of time, works with market clearing price principles
Back-up energy			(Renewable) energy storage for (emergency) usage

Figure 4.1: Defined service types and their corresponding markets, platforms, and description

Gschwendtner, Sinsel, and Stephan [37] outline the alternatives for charging locations as being at home, at work, or in public. Domestic or commercial use are the two distinct vehicle use types. A last important dimension is charger topology [93]. As the interest in grid architecture and charger topology research has always been in the electrical and computer sciences research communities [71], this dimension is hardly discussed, if at all, in the socio-technical field of academic literature. Yet, as practice shows, it is indeed an important dimension [92]. Discussions around the choice for direct current (DC) or alternating current

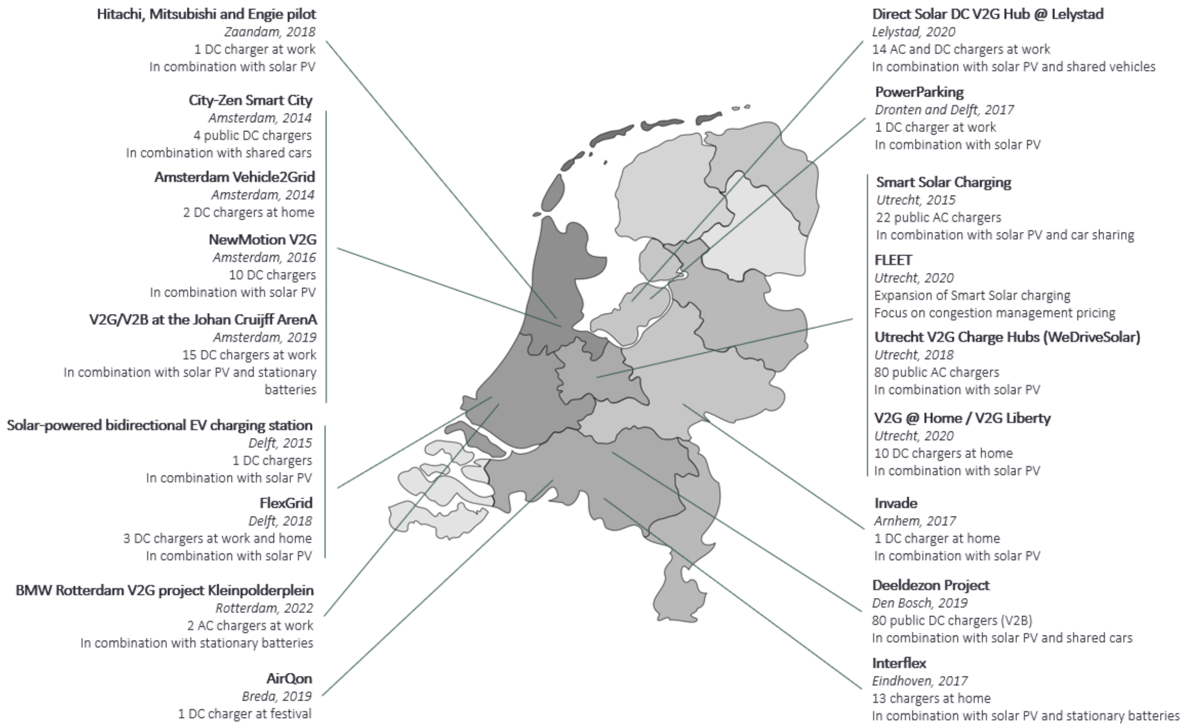


Figure 4.2: Pilot projects conducted in the Netherlands since the introduction of V2X

(AC) charging are widely reported [93]. The decision for AC- or DC-charging could, amongst others, imply differences in value streams, business models and incentives.

In conclusion, the following five dimensions are regarded as relevant: (1) service destination, (2) service type, (3) vehicle use type, (4) charge location, and (5) charger topology. These dimensions are considered to be the main decisions to be made when establishing a V2X system. The current inquiry revolves around identifying the most relevant configurations within these dimensions for further research. To address this, an analysis is conducted on all past pilot projects conducted in the Netherlands, totaling seventeen since the introduction of V2X. Figure 4.2 gives an overview of the pilot projects. Table 4.1 summarizes all conducted projects and their configuration decisions for the five dimensions. Table 4.2 is formed by collecting all configuration alternatives for each dimension. It is assumed that the configurations mentioned in Table 4.2 are the most relevant configurations in the Netherlands, as other configurations have not had any empirical underpinning in the Netherlands thus far.
By analyzing the configuration decisions documented in Dutch pilot projects (Table 4.1), an examination was conducted to identify the range of options available within each dimension. The resulting configuration options for each dimension are presented in Table 4.2 including a definition of each of the configuration options. Table 4.3 visualizes the research scope. The researcher acknowledges that there might be other relevant alternatives, but leaves this outside the scope of this particular research. It is assumed these alternatives are not relevant for the Dutch context, as they have not yet been experimented with in pilot projects.

4.1.1. Scoping of V2X designs

With five dimensions and multiple configuration alternatives within each dimension (including the option to choose multiple alternatives within some dimensions), hundreds of practically feasible combinations could be made to form a configurational design. As it is not feasible to analyze all configurational designs, a set of designs are chosen for an in-depth analysis with the use of the MLP-TIS framework. The designs are formed with two aims: (1) making the different designs as diverse as possible, given the configuration alternatives within scope, (2) developing logical designs given the context of the Netherlands. The We Drive Solar pilot design serves as the primary starting point for forming the designs, given its status as the largest bidirectional charging project in the Netherlands and Europe at presence [42]. The formation and validation

Table 4.1: Configuration decisions of Dutch pilot projects

Pilot project name	Service destination	Service type	Vehicle use type	Charge location	Charge topology
V2G @ home / V2G liberty	V2H-g	Congestion management Energy arbitrage	Domestic	Home	DC
Hitachi, Mitsubishi and Engie	V2B-g	Congestion management	Commercial	Work	DC
Smart Solar Charging	V2G	Congestion management	Domestic Commercial	Public	AC
FlexGrid	V2B-g, V2B-i, V2H-g, V2H-i	Ancillary services Congestion management Back-up energy	Domestic Commercial	Work Home	DC
Direct Solar DC V2G Hub @ Lelystad	V2B-g	Ancillary services Congestion management Back-up energy	Commercial	Work	DC, AC
Powerparking	V2G, V2B-g	Ancillary services Congestion management	Commercial	Public Work	DC
V2G / V2B at the Johan Cruijff Arena	V2G, V2B-g	Congestion management Back-up energy	Domestic	Work	DC
Share the Sun Project	V2G, V2B-g	Ancillary services Congestion management	Commercial	Home	DC
Utrecht V2G charge hubs (We Drive Solar)	V2G	Ancillary services Energy arbitrage	Domestic	Public	AC
City-Zen Smart City	V2G, V2B-g	Congestion management Energy arbitrage	Domestic Commercial	Public Work	DC
Solar-powered bidirectional EV charging stations	V2G, V2B-g	Congestion management	Domestic	-	DC
NewMotion V2G	V2G	Ancillary services	Domestic Commercial	Public Work Home	DC
Amsterdam Vehicle2Grid	V2H-g	Congestion management	Domestic	Home	DC
AirQon	V2B-i	Back-up energy	Commercial	Work	DC
Interflex	V2B-g, V2H-g, V2H-i	Ancillary services Congestion management Back-up energy	-	Home	DC
Invade	V2G	Ancillary services	Domestic Commercial	-	DC
BMW Rotterdam V2G project Kleinpolderplein	V2B-i	Congestion management Back-up energy	Commercial	Work	AC

Table 4.2: The set of alternatives for each defined dimension

Configuration dimension	Alternatives	Definition
Service destination	Vehicle-to-Grid Vehicle-to-Building (grid-connected) Vehicle-to-Building (islanded) Vehicle-to-Home (grid-connected) Vehicle-to-Home (islanded)	The power is supplied to the medium- or high-voltage grid The power is supplied to a building that is connected to the medium-voltage grid The power is supplied to a building that is not connected to the medium-voltage grid The power is supplied to a home that is connected to the low-voltage grid The power is supplied to a home that is not connected to the low-voltage grid
Service type	Ancillary services Congestion management services Energy arbitrage Back-up energy services	The power is used for the balancing markets (EQUIGY) The power is used for congestion management markets (GOPACS) The power is provided when market prices are high, and bought when low (SPOT) The power is used as a power reserve when grid prices are high or outages occur
Vehicle use type	Domestic Commercial	The vehicle is used for private, domestic purposes and owned by a private person The vehicle is used for commercial purposes and not owned by a private person
Charge location	Public Work Home	The bidirectional charging takes place at a public parking place The bidirectional charging takes place on private property of a company or organization The bidirectional charging takes place on private property close to a home
Charger topology	AC DC	The power between the charging station and EV is alternating current The power between the charging station and EV is direct current

of the other designs were carried out with the assistance of three experts, ensuring their feasibility and logicality in the Dutch context. This resulted in the creation of three designs. The configurational decisions for each dimension are stated in Table 4.3. The designs were labeled the *public V2G system design*, the *commercial V2B system design*, and the *islanded V2H system design* respectively.

Table 4.3: V2X system design scope and their corresponding configurational decisions

	Service destination	Service type	Vehicle use type	Charge location	Charger topology
1.	V2G	Ancillary services	Domestic	Public	AC
2.	V2B (grid-connected)	Congestion management services Back-up energy	Commercial	Work	DC
3.	V2H (islanded)	Back-up energy	Domestic	Home	DC

1. The Public V2G system design

The first V2X design is labeled the *public V2G system design*. A visual representation of the configurational decisions made for this design are shown in Figure 4.3. The 'public V2G' concept is a very open and public V2X design that makes use of AC charging because the Netherlands has a substantial public AC infrastructure. The medium voltage grid is directly linked to the charging station. This concept focuses mostly on domestically used vehicles, while it can also be paired with shared mobility, although that is not intended in this specific design.

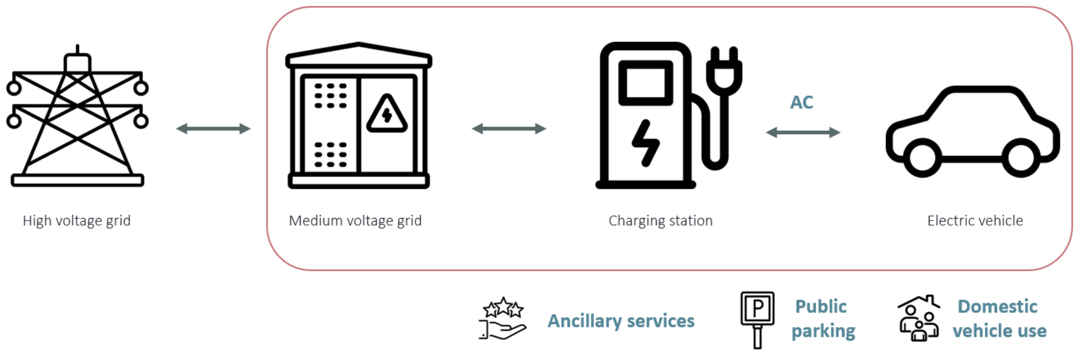


Figure 4.3: Visualization of the configurational desicions made in the public V2G system design

2. The Commercial V2B system design

The second V2X design is labeled the *commercial V2B system design*. A visual representation of the configurational decisions made for this design are shown in Figure 4.4. The 'commercial V2B' design involves connecting vehicles to an office building that is directly connected to the grid. The vehicles are owned by the company's EV fleet manager and used for commercial purposes. An example of this is a grocery delivery service that owns hundreds to thousands of EVs to carry out the delivery of groceries. The assumption is made that the EV fleet owners operates as its own CPO. Leasing options are not considered in this design, although this could be an interesting combination. DC charging is assumed in this design, as it complements local solar energy generation effectively, which is an often-used innovation in combination with a design similar to this one [94]. Due to a lack of incentive for fast charging, and additional financial barriers with high-power DC charging, the use of low-power DC charging stations are assumed.

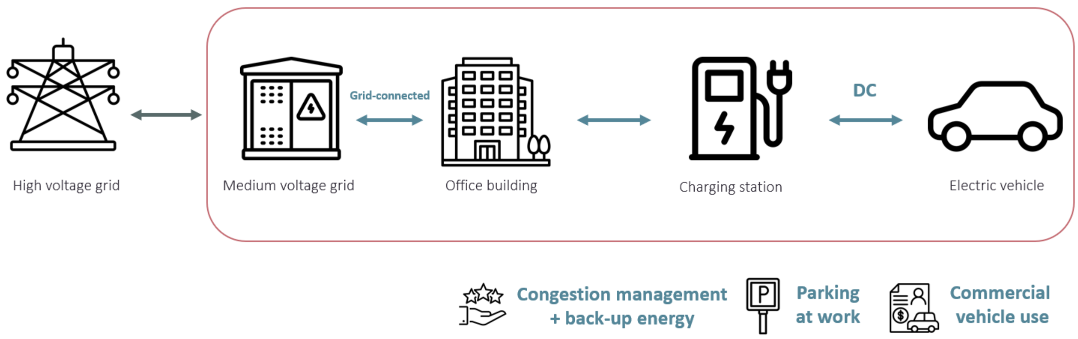


Figure 4.4: Visualization of the configurational desicions made in the commercial V2B system design

3. The Islanded V2H system design

The third V2X design is labeled the *islanded V2H system design*. A visual representation of the configurational decisions made for this design are shown in Figure 4.5. The "islanded V2H" concept calls for a home with the potential to be cut off from the main power grid. The possibility of the home receiving energy from the central electricity grid still exists, but it is not covered by this design. On the private property of the residence, vehicles are charged. In this design, DC charging is assumed in this design, as it complements local solar energy generation effectively, which is an often-used innovation in combination with a design similar to this one [94]. Due to a lack of incentive for fast charging, and additional financial barriers with high-power DC charging, the use of low-power DC charging stations are assumed.

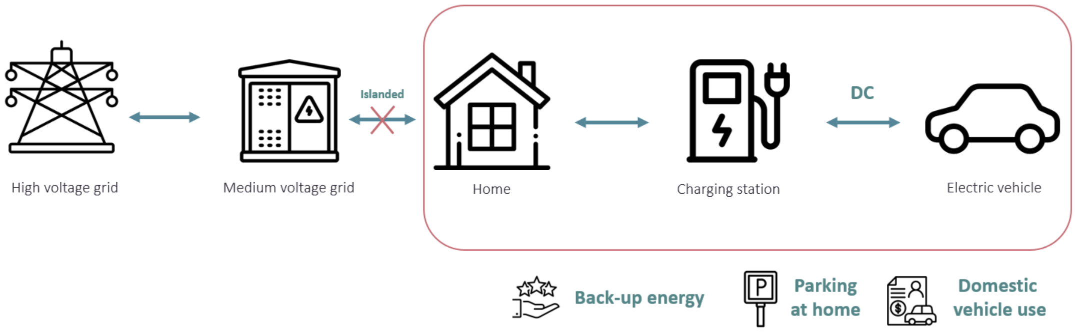


Figure 4.5: Visualization of the configurational desicions made in the islanded V2H system design

4.2. Comparative analysis of the V2X designs

In this section, a comprehensive comparative analysis is carried out to examine the three V2X designs: public V2G, commercial V2B, and islanded V2H designs (as defined in 4.1.1). To facilitate this analysis, themes are defined to highlight the fundamental differences between these V2X system designs. These thematic considerations provide a framework for assessing and understanding the key differences between the designs, allowing for a structured and comprehensive comparison. For each TIS function, multiple themes have been defined. These themes have been identified by the interviewees as important factors that highlight the differences between V2X system designs. In some cases, additional themes have been included based on desk research.

Each system function is discussed, initiated with a visual overview of the relevant themes for that function (Figures 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, and 4.12). The theme representing the highest level of aggregation is represented by the darkest colour, indicating the system function. Progressing toward the right, the themes become progressively more specific. The analysis focuses only on the themes at the most specific level, which may comprise a collection of themes from different levels of aggregation. Each system function is accompanied by a visual overview of the relevant themes, followed by an analysis of how the V2X system designs perform in relation to these themes. This performance is scored with a number ranging one through five. A score of one indicates that a system design performs *relatively* poorly in terms of that particular theme, while a score of five indicates the best performance of a system design. The comparative analysis concluded with a comparative Table that visualizes the performance of each V2X system design on all relevant themes.

These thematic considerations do not operate in a vacuum, but could be interdependent. The dynamics between these thematic considerations are discussed through the Motors of Innovations framework by Suurs et al. [87] in Paragraph 4.3. The comparative analysis conducted in this paragraph is based on the thorough analysis of the Technological Innovation System (TIS), described in Appendix A. For readability purposes, this information is not included in this section. For more information on statements made in this section, such as interviewee quotes, sources, or definitions of concepts and themes, the researcher directs the reader to Appendix A.

4.2.1. F1: Entrepreneurial activities

The function *entrepreneurial activities* refers to the set of activities undertaken by entrepreneurs, innovators, and organizations to develop and commercialize new V2X innovations. Three themes that articulate the key differences among the different V2X system designs for this system function are: the level of configurational focus of pilot projects for each system design, the level of EV fleet captivity for each system design, and the

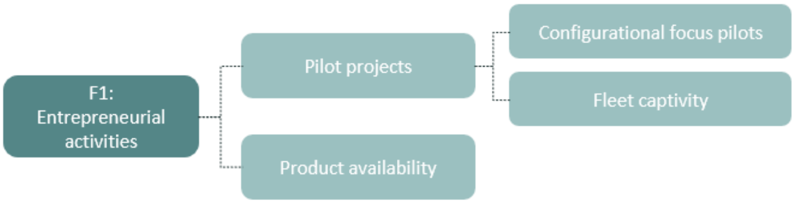


Figure 4.6: Themes Illustrating Key Differences in V2X Designs Linked to Entrepreneurial activities

Table 4.4: Relevant themes and performance scores for the function *Entrepreneurial activities*

Theme	System design	Description	Score
Configurational focus pilots	Public V2G	▪ Pilots worldwide are significantly less focused on AC charging ▪ Existing public AC infrastructure in the Netherlands has stimulated focus on this configuration	4
	Commercial V2B	▪ A preference for behind-the-meter configurations was found ▪ A preference for congestion management services was found ▪ A slight preference for work-located charging was found ▪ A significant preference for DC charging was found worldwide, including DC-DC charging with solar PV	5
	Islanded V2H	▪ A preference for behind-the-meter configurations was found ▪ A significant preference for DC charging was found, including DC-DC charging with solar PV ▪ Pilots are significantly less focused on islanded-modes in the Netherlands, due to the lack of issues with reliability thus far	2
Fleet captivity	Public V2G	▪ A wide range of potential parties that may be involved in the system, which leads to a low level of fleet captivity ▪ It was concluded that this becomes better for the public V2G system design when the system is combined with shared mobility	1
	Commercial V2B	▪ Non-public charging has a positive influence on the level of fleet captivity ▪ EV fleet manager has the ability to assemble an appropriate fleet ▪ When the EV fleet manager possesses a substantial number of EVs, the level of fleet captivity decreases	3
	Islanded V2H	▪ The islanded V2H system design exhibits the highest level of captivity, as it requires only one vehicle to operate with a privately owned charging station.	5
Product availability	Public V2G	▪ Only CHAdeMO AC bidirectional chargers on the market, while CCS is the standard in the Netherlands ▪ OEMs do not have many bidirectional-compatible EVs, especially not AC-compatible as it requires an onboard charger	1
	Commercial V2B	▪ A limited selection of CCS DC bidirectional chargers on the market. Because of the low demand, there are currently no economies of scale ▪ OEMs do not have many bidirectional-compatible EVs. However, the most popular models are DC	3
	Islanded V2H	▪ A limited selection of CCS DC bidirectional chargers on the market. Because of the low demand, there are currently no economies of scale ▪ OEMs do not have many bidirectional-compatible EVs. However, the most popular models are DC	3

Lowest performance 1 2 3 4 5 Highest performance

product availability of necessary products for the implementation of each system design (Figure 4.6). The public V2G system design performs worst on both fleet captivity and product availability, while the islanded V2H system design performs worst for the configurational focus of pilots. This is shortly explained. For a more extensive argumentation, see Appendix A.2. An overview of the themes, performance scores and descriptions is given in Table 4.4.

Regarding the *level of configurational focus of pilots* for each system design, the commercial V2B system design scores best, indicating a strong emphasis on exploring various configurations, especially worldwide. The public V2G system design scores slightly worse, as a strong preference for behind-the-meter (INT03) as well as DC pilots (INT04)[53] was shown. Contrary to other nations where V2X pilots are being conducted, the Netherlands has given the public V2G system design considerably more consideration (see Figure A.2. The islanded V2H pilot scores worst, as there are the littlest amount of pilots that have been conducted related to the design. This might be due to the relative reliability of the Dutch electricity grid thusfar (INT01, INT02). However, as there is still a broad focus on all configuration alternatives, the differences between the designs are limited.

In terms of *the level of fleet captivity* for each system design, the public V2G system design scores poorly as a wide range of potential parties may be involved in the system design (INT05). It is easier to conduct a pilot with a captive fleet that you are able to control (INT03). However, the combination of shared mobility could mitigate this barrier and increase fleet captivity, as was argued. The commercial V2B system design, on the other hand, scores better on this theme, due to the management of EVs and charger types by the EV fleet manager. On the contrary, a larger fleet size could potentially have a negative impact on fleet captivity, considering the potential variations in fleet sizes. The islanded V2H system design demonstrates the highest fleet captivity as the it involves only one privately owned vehicle and charging station.

Regarding the *product availability* of necessary products for the implementation of each system design, an important aspect is the availability of DC bidirectional chargers for the commercial V2B and islanded V2H system design, while AC chargers remain unavailable for the public V2G system design (INT01, INT03, INT04). While CHAdeMO AC bidirectional chargers are commercially available, their implementation is not feasible in the Netherlands due to the prevalence of the CCS charging standard. However, both charging infrastructure and EVs show limited availability in terms of bidirectional charging compatibility, even for DC. In light of this, they perform just marginally better than the public V2G system design. In addition, OEMs have not brought many bidirectional-compatible EV models on the market yet. As for DC charging, the EV does not require an onboard charger, the availability of compatible EVs is more feasible than for AC bidirectional EVs.

The identified themes can be correlated with the drivers and barriers discussed in Chapter 2. The level of configurational focus observed in pilots is associated with various barriers, including the *lack of technology maturity*, *limited V2X awareness*, and *lack of supportive regulatory frameworks*. This concerns technical, social, and regulatory factors. Specifically, product availability is linked to the *lack of technology maturity* barrier, as certain V2X products are currently unavailable due to technological immaturity. The level of fleet captivity does not exhibit a direct correlation with any variable defined in Chapter 2. This observation could be attributed to the limited focus on system designs with public charge locations, as indicated in Figure A.2.

4.2.2. F2: Knowledge development

Figure 4.7: Themes Illustrating Key Differences in V2X Designs Linked to Knowledge development

The function *knowledge development* refers to the process of generating, accumulating, and disseminating knowledge within the bidirectional charging innovation system. Two themes that articulate the key differences among the different V2X system designs for this system function are the level of user behavior predictability for each system design, and the amount of use case specific knowledge for each system design (Figure 4.7). For a more extensive argumentation, see Appendix A.3. An overview of the themes, performance scores and descriptions is given in Table 4.5.

The level of *user behavior predictability* for each system examines the extent to which each V2X design can foresee and predict user behaviors and charging patterns. The public V2G system design scores low for this theme, which is explained by the fact that it is difficult to predict user behavior because of the numerous complicated variables and other elements, such as EV and charging station differentiation, relevant in the public V2G system design (INT03) [15]. The commercial V2B system design makes use of a single user's or business's EV fleet, enabling more regular and controlled charging schedules. Due to the usage of just one sole vehicle and the lack of various users and their varied demands, the islanded V2H system design receives the best score on this theme.

Use case specific knowledge examines the availability and breadth of research and information particular to each V2X system design. Generally, there is a clear lack of use case specific knowledge for all V2X use cases (INT04). More specifically, little academic research has focused on consumer related variables impacting V2X designs. Understanding about revenue models is lacking in all three V2X designs, as well as

Table 4.5: Relevant themes and performance scores for the function *Knowledge development*

Theme	System design	Description	Score
User behavior predictability	Public V2G	▪ There are many variables to consider when predicting charging behavior	2
	Commercial V2B	▪ There are relatively fewer variables to consider when predicting charging behaviour ▪ The system design involves multiple users with diverse demands and usage patterns	4
	Islanded V2H	▪ There are relatively significantly fewer variables to consider when predicting charging behaviour ▪ The system design involves only one user with one use pattern	5
Availability of use case specific knowledge	Public V2G	▪ Too little knowledge on optimization algorithms, and economic benefit ▪ The large amount of involved stakeholders exacerbates the issue of knowledge gaps	3
	Commercial V2B	▪ Too little knowledge on congestion management services implementation ▪ Too little knowledge on optimization algorithms, and economic benefit ▪ The considerable amount of involved stakeholders exacerbates the issue of knowledge gaps	3
	Islanded V2H	▪ Too little knowledge on economic benefit ▪ The little amount of involved stakeholders mitigates the issue of knowledge gaps	4

Lowest performance 1 2 3 4 5 Highest performance

clarity on the distribution of the economic benefit received from participation in a design (INT05, INT07, INT09). This barrier, however, becomes smaller with little stakeholders involved, as there are simply less stakeholders to figure out the distribution with. Therefore, the islanded V2H system design scores slightly better in this regard. A relatively low score for both the public V2G and the commercial V2B system design compared to the islanded V2H system design indicates a larger barrier in this regard for the first two designs.

The identified themes can be correlated with the drivers and barriers discussed in Chapter 2. The user behavior predictability aligns with the social barrier identified as *unpredictable EV charging behavior*. Conversely, use case-specific knowledge does not demonstrate a direct correlation with any driver or barrier identified in Chapter 2. As concluded, the drivers and barriers in Chapter 2 pertain to the general V2X concept and do not concern use case-specific variables.

4.2.3. F3: Knowledge diffusion through networks

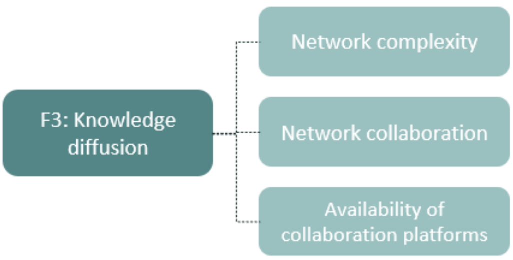


Figure 4.8: Themes Illustrating Key Differences in V2X Designs Linked to Knowledge diffusion through networks

The function *knowledge diffusion through networks* refers to the process of spreading and disseminating knowledge and information within networks of actors involved in the bidirectional charging system. Two themes that articulate the key differences among the different V2X system designs for this system function are: the complexity of the networks involved in each system design, and the availability of necessary collaboration platforms for each system design (Figure 4.8). For a more extensive argumentation, see Appendix A.4. An overview of the themes, performance scores and descriptions is given in Table 4.6.

The *network complexity* of each system design is assessed based on the movement of goods, information, and services within each design. The islanded V2H system design is the least complex, while the public V2G system design suffers the most system complexity. Between these two extremes is where the commercial V2B

Table 4.6: Relevant themes and performance scores for the function *Knowledge diffusion*

Theme	System design	Description	Score
Network complexity	Public V2G	▪ Complex flow of goods and services ▪ A relatively high level of interoperability issues with large-scale implementation. The system design requires the assurance of interoperability of a large number of potentially involved parties within one stakeholder due to its public characteristic ▪ Simplicity of the network increases when multiple roles within the stakeholder network are fulfilled by the same party. This is not typically the case for this system design, but could in some cases be for the roles of EMSP and energy supplier	1
	Commercial V2B	▪ Complex flow of goods and services, but slightly less complex compared to the public V2G system design ▪ An average level of interoperability issues with large-scale implementation. The system design requires the assurance of interoperability of a delimited number of potentially involved parties within one stakeholder due to its private characteristic ▪ Simplicity of the network increases when multiple roles within the stakeholder network are fulfilled by the same party. The roles of aggregator, CPO and EV fleet manager could potentially merge.	3
	Islanded V2H	▪ Simplest and clearest flow of goods and services ▪ A low level of interoperability issues with large-scale implementation. The system design requires minimal interoperability due to the limited number of involved stakeholders, and since only one vehicle needs to be compatible with a single charging station. ▪ Simplicity of the network increases when multiple roles within the stakeholder network are fulfilled by the same party. This is not the case for the involved stakeholders, as the number is already limited.	5
Network collaboration	Public V2G	▪ Strong collaboration networks, mostly due to the pilot project sequence by We Drive Solar	5
	Commercial V2B	▪ Weak collaboration networks even though a considerable number of pilot projects is conducted	2
	Islanded V2H	▪ Weak collaboration networks. However, this is less problematic for this system design as the design is relatively simple and necessitates less complex collaborations	3
Availability of collaboration platforms	Public V2G	▪ The relevant available collaboration platform is Equigy, which aims at lowering the threshold for offering small-scale balancing flexibility. The platform is still in early development, and is not yet available for the general public. ▪ Considering TSOs are unlikely to reduce their existing threshold of 1 MW for trading on the balancing markets, the system design needs to be implemented on a significant scale to enable the provision of ancillary services.	3
	Commercial V2B	▪ The relevant available collaboration platform is *GOPACS*, which aims to mitigate congestion on the grid. Such platform is necessary to prevent one grid operator from aggravating another grid operator's congestion issues. ▪ The platform has been launched less than a year ago, and is not yet available in every area of the Netherlands	3
	Islanded V2H	▪ As only small-scale energy optimization is the aim, no centrally organized platforms are needed for this system design. A platform that is necessary is an energy management platform. Multiple types of such platforms exist.	5

Lowest performance 1 2 3 4 5 Highest performance

system design lies. When a single party performs numerous responsibilities within the stakeholder network, which is more common in the islanded V2H system design and to a lesser extent in the commercial V2B system design, the complexity of the network is said to be simplified (INT03) [50]. This is less often the case for the public V2G system design. In addition, because the public V2G system design involves a wide range of possible partners for each stakeholder, moving from pilot projects with a small number of stakeholders to a large-scale deployment presents difficulties. For the commercial V2B and even more so for the islanded V2H system design, the variety of parties within each stakeholder that is involved, is lower (see Figures A.6, A.7, and A.8).

The *network collaboration* of each system design is assessed based on the level and density of formed collaboration networks. For the public V2G system design, this collaboration network is well-formed. Collaborations have been formed through the pilot sequence of We Drive Solar (INT05). The commercial V2B and islanded V2H system design profit less network collaboration. However, for the islanded V2H system design, as it is relatively simple, the necessity of strong network collaborations is lower compared to the more complex commercial V2B system design. However, for both system designs it forms a significant barrier.

Regarding the *availability of collaboration platforms*, specific platforms have been created for each service provided within each design and are (to some extent) available. Equigy is a collaboration platform designed to facilitate the provision of small-scale balancing flexibility, although it is currently in early development and not accessible to the general public (INT09) [32]. To enable the provision of ancillary services, the system design must be implemented on a substantial scale, considering that transmission system operators (TSOs) are unlikely to lower their current 1 MW threshold for trading on balancing markets [32] (INT04). GOPACS is a collaboration platform designed to address grid congestion issues by facilitating coordination among grid operators [35]. This platform is crucial in preventing one grid operator from exacerbating congestion problems faced by another operator (INT03). The GOPACS was launched less than a year ago and is not yet accessible in all areas of the Netherlands (INT02).

For the islanded V2H system design, since the focus of this system design is on small-scale energy optimization, there is no requirement for centrally organized platforms. However, an energy management platform is necessary to facilitate the coordination and control of energy flows. Various types of energy management platforms are available to fulfill this role.

The identified themes can be correlated with the drivers and barriers discussed in Chapter 2. Network complexity is not directly translatable to a driver or barrier mentioned in literature. Network collaboration is directly correlated with the *lack of cooperation between stakeholders* barrier, as well is the availability of collaboration platforms theme. the barrier could be seen as an umbrella term for both themes.

4.2.4. F4: Guidance of the search

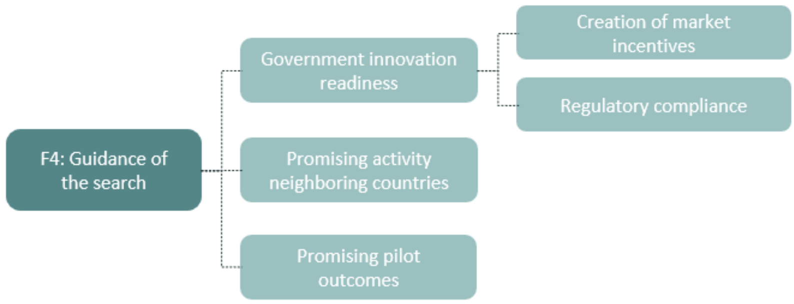


Figure 4.9: Themes Illustrating Key Differences in V2X Designs Linked to Guidance of the search

The function *guidance of the search* refers to providing direction and support in the search for V2X innovations and solutions. Four themes that articulate the key differences among the different V2X system designs for this system function are: the creation of market incentives for each system design, the level of regulatory compliance of current laws and regulators for each system design, the level and nature of promising activity of neighboring countries for each system design, and the level and nature of promising Dutch pilot outcomes for each system design (Figure 4.9). For a more extensive argumentation, see Appendix A.5. An overview of the themes, performance scores and descriptions is given in Table 4.7.

The *creation of market incentives* for each system design includes initiatives aimed at stimulating the uptake and use of V2X technologies. For the public V2G system design, market incentives are partly created by the "V2G-ready" requirement in public tenders for charging infrastructure, although the focus is primarily on hardware rather than software (INT03, INT07, INT09) [93]. Similarly, for the commercial V2B system design, the introduction of the "energy saving obligation" for companies in 2023 serves as a market incentive [79]. However, there is currently no monitoring or enforcement of this obligation, which could, if done properly, further increase the incentive (INT04). While some steps have been taken for both the public V2G and commercial V2B system design, the extent of market incentives remains limited. With regard to the islanded V2H system design, households benefit from the legal security of energy supply, which guarantees an electricity supply [91]. In contrast, businesses in the commercial V2B system design do not enjoy this guarantee. This creates an incentive for business to become more self-sufficient by implementing a commercial V2B system design (INT05). This incentive is, thus, not created for the islanded V2H system design. For the islanded V2H system design, active creation of market incentives is not evident, possibly due to its limited impact on the overall system.

Table 4.7: Relevant themes and performance scores for the function *Guidance of the search*

Theme	System design	Description	Score
Creation of market incentives	Public V2G	▪ Market incentive is created through the addition of the "V2G-ready" requirement to public charging infrastructure tenders. As these requirements are only focused on hardware, much uncertainty remains on software implementation.	3
	Commercial V2B	▪ A relevant market incentive has been created with the introduction of the 'energy savings obligation' in 2023. However, this obligation is not yet actively enforced by the government ▪ Commercial buildings lack electricity supply security through regulations, which incentivizes the design	4
	Islanded V2H	▪ No active creation of market incentives	1
Regulatory compliance	Public V2G	▪ The Dutch government does not require grid operators to offer small-scale flexibility providers to provide services for them ▪ The Requirements for Generators (RFG) need to be made more stringent ▪ The Smart Charging Requirements that serve as guideline for public charging tenders are not legislated ▪ Since the success of this concept depends on the interoperability of a wide range of EV models, the fact that certain OEMs don't share this data poses a particular issue for this design ▪ The current need for a traffic decision ('verkeersbesluit') for the placement of each public charging station presents a regulatory barrier ▪ Double energy taxation is a considerable issue as it occurs fully in front of the meter	1
	Commercial V2B	▪ The Dutch government does not require grid operators to offer small-scale flexibility providers to provide services for them ▪ The Requirements for Generators (RFG) need to be made more stringent ▪ The laws and regulations surrounding the use of the GOPACS platform for congestion management services are not fully implemented ▪ Double energy taxation is a relevant issue as energy is also (at least partially) injected into the grid for congestion management purposes.	1
	Islanded V2H	▪ The net metering policy ('salderingregeling') presents the main regulatory barrier for this system design	1
Promising activity neighboring countries	Public V2G	▪ The promising activity mostly occurs with regard to enshrining bidirectional charging in laws and regulations, as the charging takes place on public grounds. ▪ In California, all vehicles are obliged to be V2X-compatible by 2027	4
	Commercial V2B	▪ France has implemented a requirement for solar carports over car parks. Taking inspiration from France in this regard means an additional market incentive for the commercial V2B system design ▪ In Belgium they decided to focus on energy peak enforcement. This way, more money has to be paid by users of larger grid connections, which stimulates the minimization of the grid connection	4
	Islanded V2H	▪ A significant business case was confirmed in the UK with the Octopus project ▪ The Belgian method of putting monetary value on energy peak usage could stimulate the implementation of the islanded V2H system design	4
Promising pilot outcomes	Public V2G	▪ The PowerParking project concluded it to be economically beneficial within 4 to 5 years ▪ TSOs have decided to not reduce the minimum bid size to ease the market entrance. It was concluded that the prequalification process for new FCR providers is rather time consuming, and energy losses were a concern during pilot projects	3
	Commercial V2B	▪ Multiple pilots highlight the significance of connecting the V2X concept to buildings for optimizing behind-the-meter sustainable energy usage. This builds self-sufficiency, sustainability, and reduces grid dependency, fostering a balanced and efficient energy ecosystem ▪ The absence of a current trading market for congestion management services and the fact that DC charging is currently compatible with the CHAdeMO standards, while CCS is more popular in the Netherlands are mentioned as barriers ▪ It was found that, as the demand from DSOs is still sporadic and difficult to predict, the business model is still rather fragile with a small market share. ▪ The combination of V2B and stationary batteries is concluded to be a worthwhile combination with regard to energy reliability	5
	Islanded V2H	▪ The PV-EV combination is also area of interest for this design, and has been concluded to be more energy efficient than a comparable AC system. The design in general was also concluded to be cost efficient, with participants paying less than one cent per driven kilometer ▪ The Interflex project concludes that the design still struggles with economic challenges. However, these might be diminished in the future with more price volatility as a result of a higher percentage of intermittent energy sources	5

Lowest performance 1 2 3 4 5 Highest performance

The theme *regulatory compliance* highlights the challenges posed by existing regulations for the implementation of V2X concepts. Current regulations tend to be focused on centralized energy systems (INT02), while the landscape is shifting toward more localized and intermittent energy sources (See Paragraph A.1). In the case of the public V2G system design, a significant regulatory barrier is the legislation surrounding the quality of the power fed back into the grid (INT02). Existing permissible deviation percentages are based on the assumption of only one unit feeding back into the grid, which accumulates deviations when multiple units contribute simultaneously in V2G scenarios. Other barriers include the need for a traffic decision (in Dutch: Verkeersbesluit) for the placement of each charging station in V2G (INT09), and double taxation concerns due to its full in-front-of-the-meter concept (INT05, INT06, INT09). Regulatory compliance is, thus, still a long way off for the public V2G system design. An incomplete implementation of laws and regulations for the GOPACS platform forms a barrier for the commercial V2B system design. In the islanded V2H system design, the 'salderingsregeling' (roughly translated to 'net metering policy') represents the most significant regulatory barrier that prevents the economic benefits of self-sufficiency (INT02, INT03, INT04, INT07). The salderingsregeling is a policy in the Netherlands that allows owners of solar panels to deduct the electricity they produce from their total electricity consumption [91]. Essentially, it allows individuals to offset the energy they produce with their solar panels against the energy they consume from the grid, resulting in potential savings on their electricity bills. Furthermore, the security of energy supply for households in the public V2H system design discourages the development of back-up energy supply plans. In conclusion, this theme, however for different reasons, poses a significant barrier for all three V2X designs.

The level and nature of *promising activities in neighboring countries* show significant developments to the advancement of V2X concepts. In the case of public V2G system design, notable activity is taking place to embed bidirectional charging in laws and regulations, with California mandating V2X compatibility for all vehicles by 2027 (INT09) [6]. Similarly, in the commercial V2B system design, France has introduced requirements for solar carports in car parks, creating a market incentive for solar panel providers to expand their business to include charging stations (INT04). For the islanded V2H system design, Belgium has imposed fines on heavy grid connections for residential customers, providing an incentive to reduce electricity consumption (INT09). These activities show promising developments in neighboring countries, but are still at an early stage of development and are not yet able to fully address the existing barriers to large-scale deployment of all three system designs.

The *level and nature of promising pilot outcomes* in the Netherlands sheds light on the results and findings of the pilots conducted for the three V2X concepts. In the case of the public V2G system design, the lack of ability to physically implement bidirectional AC charging, and energy losses [28] are significant barriers for positive pilot outcomes. In addition, the Newmotion V2G pilot revealed challenges for aggregators in building a positive business case for volumes below 1 MW, while the prequalification process for new frequency control reserve (FCR) providers was found to be time consuming [25, 89]. These findings highlight the economic barriers associated with V2G deployment.

Conversely, commercial V2B pilots demonstrate the importance of integrating the bidirectional charging concept with buildings to optimize sustainable behind-the-meter energy use [11]. Challenges for V2B include the lack of a current trading market for congestion management services and the compatibility of DC charging with CHAdeMO standards, while CCS standards are more prevalent in the Netherlands [28]. V2B pilots also show that the business model is still fragile due to sporadic and unpredictable demand from distribution system operators (DSOs) [43]. In the case of V2H, only a limited number of pilots have been carried, which highlight the economic challenges. However, the potential for overcoming these challenges is recognized [95], particularly with increased price volatility resulting from a higher proportion of intermittent energy sources (See Paragraph A.1).

The identified themes can be correlated with the drivers and barriers discussed in Chapter 2. The creation of market incentives theme could be correlated to the *market issues* barrier, the regulatory compliance theme could be correlated to the *lack of supportive regulatory frameworks* and *lack of standardization* barriers. The promising activities in neighboring countries is not directly translatable. The level and nature of promising pilot outcomes cannot either. Both are a clear result of the incorporation of landscape developments and niche innovations in the analysis.

4.2.5. F5: Market formation

The function *market formation* refers to the process of creating and developing markets for the bidirectional charging technology and its three analyzed designs. Six themes that articulate the key differences among the different V2X system designs for this system function are: the level of compatibility of each system design with the current Dutch system, the interoperability level of each system design, the level of present market competition for each system design, the potential market size for each system design (both on the demand

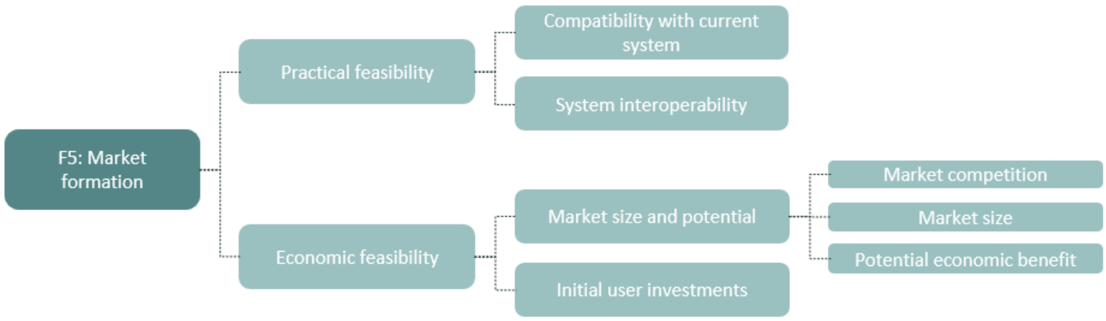


Figure 4.10: Themes Illustrating Key Differences in V2X Designs Linked to Market formation

and supply side), the potential economic benefit for each system design, and the need for and level of initial user investments for each system design (Figure 4.10). For a more extensive argumentation, see Appendix A.6. An overview of the themes, performance scores and descriptions is given in Table 4.8.

The level of *compatibility with the current system* for each system design generally faces challenges due to the current system not being designed for small-scale energy flexibility (INT02). However, given the landscape developments described in Paragraph A.1, adjustments to this current system are necessary. Although this might simplify future compatibility, this theme focuses on the current state of the Dutch electricity and transport system.

The public V2G system design aligns with the ongoing shift towards local energy generation in the landscape development. However, significant barriers exist, such as the inability to participate in the balancing market with less than 1 MW contribution and the challenge of ensuring available power from non-stationary EVs (INT01, INT04, INT06). Additionally, dynamic pricing is not widely implemented (INT03, INT04), and AC onboard chargers create grid noise (INT01, INT04), posing a barrier. Another notable challenge for the public V2G system design is the chicken-and-egg problem, where the introduction of EVs capable of bidirectional charging depends on the availability of supporting infrastructure and vice versa, which is particularly problematic for the public V2G system design, as the success of public charging infrastructure depends heavily on user demand (INT01).

The commercial V2B system design faces barriers due to the nationally organized energy market and the need for local-level energy market organization (INT02), and the limited availability of dynamic pricing for commercial buildings (INT03, INT04). The system design, however, aligns with the landscape development of the transition toward local energy generation and the increased use of solar PV panels on building rooftops (see A.1).

The islanded V2H system design demonstrates higher compatibility with the existing system, leveraging existing — although limited [9] — contracts with hourly dynamic energy prices and integrating seamlessly into household energy systems. In addition, the system design aligns with the landscape development of the transition toward local energy generation and the increased use of solar PV panels on homes (see A.1).

The level of *system interoperability* for the system designs poses challenges across all three designs, albeit to varying degrees. The public V2G system design experiences the most significant issues due to the multitude of potential combinations of customers and suppliers (INT02, INT04), exacerbated by vague protocols and standards with ISO 15118-20 being the most important one (INT05, INT06, INT07). The commercial V2B and islanded V2H system designs also face interoperability challenges due to limited aligned ISO 15118-20 implementation. However, as the network is less complex for these two system design, an integrated system is easier to reach. Among the designs, the islanded V2H system design offers the most favorable conditions for achieving an integrated and interoperable system.

The *market competition* for the system designs also plays an important role in the ranking of the three concepts studied. The public V2G system design scores low on this theme. In particular, large-scale stationary batteries emerge as strong competitors, especially for ancillary services [14]. The current energy management system leans toward centralised organisation, which gives an advantage to existing parties with market access, which parties with large-scale stationary batteries usually are. The commercial V2B system design scores

Table 4.8: Relevant themes and performance scores for the function *Market formation*

Theme	System design	Description	Score
Compatibility with the current system	Public V2G	▪ System design is compatible with the landscape development of the transition toward local energy generation ▪ Large barrier is the inability to enter the balancing market with a smaller contribution than 1 MW, and the inability of EVs to give the desired guarantee of available power due to their non-stationary nature ▪ Dynamic pricing is no common practice ▪ A barrier is the noise caused on the grid by AC onboard chargers ▪ Chicken-and-egg problem	1
	Commercial V2B	▪ System design is compatible with the landscape development of the transition toward local energy generation, the increased use of solar PV panels on building rooftops ▪ Dynamic and local pricing is no common practice	1
	Islanded V2H	▪ System design is compatible with the landscape development of the transition toward local energy generation, and the increased use of solar PV panels on homes ▪ Dynamic pricing contracts are currently offered by multiple energy suppliers	5
System interoperability	Public V2G	▪ Large number of potential combinations of customers and suppliers, which leads to interoperability issues ▪ No consistent ISO 15118-20 implementation by all parties	1
	Commercial V2B	▪ Ability to make arrangements to diminish interoperability issues ▪ No consistent ISO 15118-20 implementation by all parties, but integrated system is easier to reach	4
	Islanded V2H	▪ Ability to make arrangements to diminish interoperability issues ▪ No consistent ISO 15118-20 implementation by all parties, but integrated system is easier to reach	5
Market competition	Public V2G	▪ The current system leans toward a more centrally organized energy management with better market-entering conditions, which makes large-scale stationary batteries a considerable competitor	1
	Commercial V2B	▪ No competition from large-scale stationary batteries due to centrality ▪ Small-scale stationary batteries are most relevant competitive innovation due to its ability to guarantee access to electricity ▪ Small-scale stationary batteries serve as complementary innovation as well, specifically for this design due to large electricity demand	3
	Islanded V2H	▪ Small-scale stationary batteries are most relevant competitive innovation due to its ability to guarantee access to electricity ▪ Small-scale stationary batteries could serve as complementary innovation	4
Market size	Public V2G	▪ FCR market has volume of only 130 MW, quick saturation will occur ▪ Demand market is largest of all three designs due to public charging	3
	Commercial V2B	▪ Day-ahead market has volume of 4000 - 5000 MW, saturation is less problematic ▪ Demand market is limited as not all buildings own private property for charging	4
	Islanded V2H	▪ By 2030, only 25% of homes in the Netherlands will be able to charge on private property	3
Potential economic benefit	Public V2G	▪ The potential economic benefit must be distributed over a large number of involved parties ▪ The potential revenue for this market is argued to be the highest	4
	Commercial V2B	▪ Congestion management services ensure less potential revenue compared to ancillary services ▪ This system design will potentially become more economically beneficial in the future due to grid operators stopping to give out larger grid connections ▪ More economic potential due to its ability to scale to dozens of vehicles	4
	Islanded V2H	▪ The reduction of the grid connection is currently the most proven business model. However, this is fully hampered by the net metering policy ('salderingsregeling') ▪ The inability to scale to multiple vehicles make the economic potential lower	1
Initial user investments	Public V2G	▪ Charging infrastructure investments are relatively low, due to AC charge topology ▪ Investment is made by a party with investment capacity (CPO and/or government)	4
	Commercial V2B	▪ Charging infrastructure investments are relatively extremely high due to DC charge topology, could be improved with economies of scale ▪ Investment is made by a party with investment capacity (EV fleet manager)	2
	Islanded V2H	▪ Charging infrastructure investments are relatively extremely high due to DC charge topology, could be improved with economies of scale ▪ Investment is made by a private individual with little investment capacity (e-driver)	1

Lowest performance 1 2 3 4 5 Highest performance

slightly better on this theme. It benefits from the absence of competition from large stationary batteries for congestion management services, as its centralised and stationary position is disadvantageous for congestion management services [14].

The commercial V2B and islanded V2H system design face competition from small-scale stationary batteries that are always connected to the grid. Despite being competitors, small-scale batteries can also act as complementary innovations and offer behind-the-meter energy optimization (INT07). In addition, solar charging, facilitated by PV panels on building rooftops, serves as a complementary innovation for both the commercial V2B and islanded V2H system design, reducing barriers such as lacking economic benefits (INT04, INT07). This is specifically relevant for the commercial V2B system design, as the demand for electricity is higher [96]. Overall, the islanded V2H system design receives the highest score concerning market competition, benefiting from its compatibility with small batteries and the potential benefits of solar charging. However, for all designs, serious competitors are present.

The *market size* for the system designs is evaluated in terms of supply and demand. The public V2G system design faces potential saturation with a small FCR market volume of 130 MW and a limited number of bidirectional charging vehicles (INT01, INT05) [34]. In contrast, the commercial V2B system design taps into a larger day-ahead market volume of 4000 to 5000 MW (INT01), showing more promising potential. The islanded V2H system design, relying on private charging facilities, is expected to reach only 25% of households by 2030 [18], limiting its supply market size. Limited data is available for the supply market size of the commercial V2B system design, but its market size is also considered limited due to the small percentage of office buildings with their own parking facilities.

The *potential economic benefit* for the system designs is influenced by two opposing dynamics. Firstly, the transition to intermittent energy sources leads to fluctuating energy prices, which increases the potential economic benefit (INT01, INT03). However, as more vehicles contribute energy from their batteries, the economic offset becomes smaller. In the public V2G system design, the potential economic benefit needs to be shared among many parties. Although the market for ancillary services is limited, it is argued that the potential revenue in this market is the highest (INT01, INT08).

In the commercial V2B system design, congestion management services are more predictable, but offer less potential revenue. However, as grid operators will probably limit new or larger network connections due to capacity issues, the commercial V2B system design is expected to become more economically advantageous in the future (INT04). The scalability of the commercial V2B system design to multiple vehicles to from a fleet offers greater economic potential. Conversely, the islanded V2H system design must rely on a single vehicle, which limits its economic benefit. Moreover, with regard to the islanded V2H system design, it is currently more financially advantageous to feed excess energy from solar PV panels back into the grid and purchase energy when needed, due to the net metering policy ('salderingsregeling') (INT01, INT04, INT09). However, once this barrier is overcome, the potential of the islanded V2H system design is considerable as only a limited number of stakeholders are eligible for a piece of the economic profit.

For the *initial user investment* essential for the implementation of the system designs, the cost of DC bidirectional chargers is significantly higher than the AC chargers used in the public V2G system design. This translates into significantly higher initial investments for the commercial V2B and islanded V2H system design (INT03), particularly for the latter due to its limited scale of deployment. On the other hand, companies implementing the commercial V2B system design can spread the cost over multiple chargers and vehicles, potentially benefiting from economies of scale and making the investment more cost-effective. In addition, the time frame for recouping these initial investments is critical. Another important factor is the identification of the party responsible for making these investments (see Figures A.6, A.7, and A.8). In the case of the public V2G and commercial V2B system design, this is a party with access to significant capital. For the islanded V2H system design, however, this a private individual. Also, in the public V2G system design, the investments on the vehicles and infrastructure are made by a separat party. The charging infrastructure investment is made by the charging point operator (CPO), while the vehicle investment is made by the electric vehicle (EV) driver. In the commercial V2B and islanded V2H system design, both investments are made by the same party: the EV fleet manager, and the e-driver respectively.

The identified themes can be correlated with the drivers and barriers discussed in Chapter 2. Most of those are economic or market factors. The compatibility with the current system could partly be correlated to the *market issues* barrier, where the lack of available EVs and infrastructure is specified. Market competition and market size could also fall under the umbrella of market issues. The system interoperability is mentioned under the barrier *lack of technology maturity*. The theme potential economic benefit could be correlated with the economic driver *additional economic opportunities for stakeholders*. The initial user investment theme could be correlated with the *large upfront investments* barrier.

4.2.6. F6: Resource mobilization

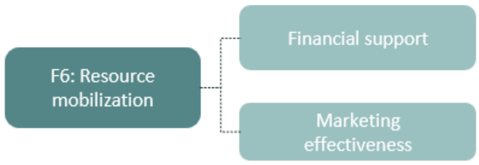


Figure 4.11: Themes Illustrating Key Differences in V2X Designs Linked to Resource mobilization

Table 4.9: Relevant themes and performance scores for the function *Resource mobilization*

Theme	System design	Description	Score
Financial support	Public V2G	▪ Multiple pilot projects related to this system design have received governmental subsidy or funding, however most subsidy is still going toward the development of unidirectional smart charging	3
	Commercial V2B	▪ Multiple pilot projects related to this system design have received governmental subsidy or funding, however most subsidy is still going toward the development of unidirectional smart charging ▪ The government has contributed on a significant level to the development of DC charging	3
	Islanded V2H	▪ Multiple pilot projects related to this system design have received governmental subsidy or funding, however most subsidy is still going toward the development of unidirectional smart charging ▪ The government has contributed on a significant level to the development of DC charging	3
Marketing effectiveness	Public V2G	▪ Significant amount of marketing with the main example named being the visitation of the King to the We Drive Solar project	5
	Commercial V2B	▪ Very little marketing and public attention for this system design	2
	Islanded V2H	▪ Very little marketing and public attention for this system design, likely due to the irrelevance of the design for the system as a whole	2

Lowest performance 1 2 3 4 5 Highest performance

The function *resource mobilization* refers to the process of acquiring and deploying the necessary resources to support the development and diffusion of the bidirectional charging innovation. This includes securing the financial, human, technological and organizational resources that are critical to the successful implementation and advancement of V2X. Two themes that articulate the key differences among the different V2X system designs for this system function are: the level of financial support available for each system design, and the presence and effectiveness of marketing efforts for each system design (Figure 4.11). For a more extensive argumentation, see Appendix A.7. An overview of the themes, performance scores and descriptions is given in Table 4.9.

The level of *financial support* available for the system designs shows that nine out of seventeen pilot projects in the Netherlands received subsidies (see Table A.2 for an overview). No clear preference for financial support was found for these subsidies. However, in the area of DC charging, the government contributed to development subsidies, which benefited the commercial V2B and islanded V2H concepts (INT04). Even though the financial support for the different use cases might come from different corners, there is no substantial difference between the three system designs.

The *presence and effectiveness of marketing efforts* highlights the disparity in marketing efforts between the three system designs. The public V2G system design received significant attention, including high profile visits such as the King's visit to the We Drive Solar project (INT03, INT05), indicating a strong marketing presence. However, for the commercial V2B and islanded V2H system designs, marketing effectiveness is minimal. There is limited discussion and partnership around these designs, with the islanded V2H system design considered less relevant to the Dutch context due to grid reliability (INT01). Considering the landscape developments in Paragraph A.1, it is important to note that it is an evident scenario that the reliability will drop in the near future, leading to more relevance for the islanded V2H system design. For now, however, this is not the case. Therefore, marketing effectiveness scores high for the public V2G system design, but low for the commercial V2B and islanded V2H system design.

The identified themes can be correlated with the drivers and barriers discussed in Chapter 2. The theme financial support could be translated to the *lack of supportive regulatory frameworks* barrier, as the financial support concerns a regulatory variable. The theme presence and effectiveness of marketing efforts cannot be correlated with any drivers or barriers mentioned in Chapter 2.

4.2.7. F7: Creation of legitimacy

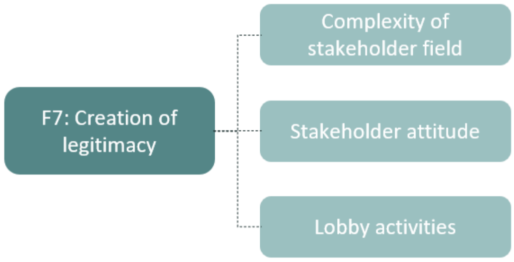


Figure 4.12: Themes Illustrating Key Differences in V2X Designs Linked to Creation of legitimacy

Table 4.10: Relevant themes and performance scores for the function *Creation of legitimacy*

Theme	System design	Description	Score
Lobby activities	Public V2G	▪ Lobby activities play a prominent role in this system design, primarily due to the well-established networks within this context, an important one being We Drive Solar. This collaboration has facilitated the formation of strong lobbying efforts	5
	Commercial V2B	▪ There is currently limited active lobbying. This can be attributed to the relatively early stages of development and fewer established networks within these specific contexts	1
	Islanded V2H	▪ There is currently limited active lobbying. This can be attributed to the relatively early stages of development and fewer established networks within these specific contexts	1
Complexity of stakeholder field	Public V2G	▪ Most extensive list of involved stakeholder. Six of those stakeholders have large influence on the system: the e-driver, the charge point operator, the local and regional authorities, the aggregator, and the TSO ▪	1
	Commercial V2B	▪ Slightly less extensive list of involved stakeholders compared to the public V2G system design. However, more of those have large influence on the system, seven in total. These are the e-driver, the energy supplier, the OEM, the EU and national regulators, the EV fleet manager, the DSO, and the aggregator ▪	2
	Islanded V2H	▪ Least extensive list of involved stakeholders. Four of those stakeholders have large influence on the system: the e-driver, the energy supplier, the OEM and the national government ▪ Achieving alignment and removing legitimacy barriers for highly influential stakeholders may prove less challenging compared to other system designs	5

Lowest performance 1 2 3 4 5 Highest performance

The function *creation of legitimacy* refers to the process of establishing and maintaining credibility, acceptance, and support for the V2X innovation. Two themes that articulate the key differences among the different V2X system designs for this system function are: the level of complexity of the stakeholder field for each system design, and the level of lobby activities occurring for each system design (Figure 4.12). For a more extensive argumentation, see Appendix A.8. An overview of the themes, performance scores and descriptions is given in Table 4.10.

The *lobby activities* have proven to be specifically strong for the public V2G system design, with strong collaborations between stakeholders being formed, specifically due to the We Drive Solar concept. For the commercial V2B and islanded V2H system design, the lobby activities are limited to non-existent. The level of *complexity of the stakeholder field* is visualized through the creation of a power-interest grid for each design. A power-interest grid is a visual tool used to assess the level of influence and interest of stakeholders in a particular issue or project [56]. The scoring on this theme is based on the complexity of the stakeholder field revealed by the power-interest grid. The stakeholder field of each system design is discussed below.

Complexity of the stakeholder field of the Public V2G system design

Figure 4.13 visualizes the involved stakeholders in the public V2G system design. The stakeholders are clustered by their role in the system. The total of twelve stakeholders are also placed in the Power-Interest grid, which is depicted in Figure 4.14.

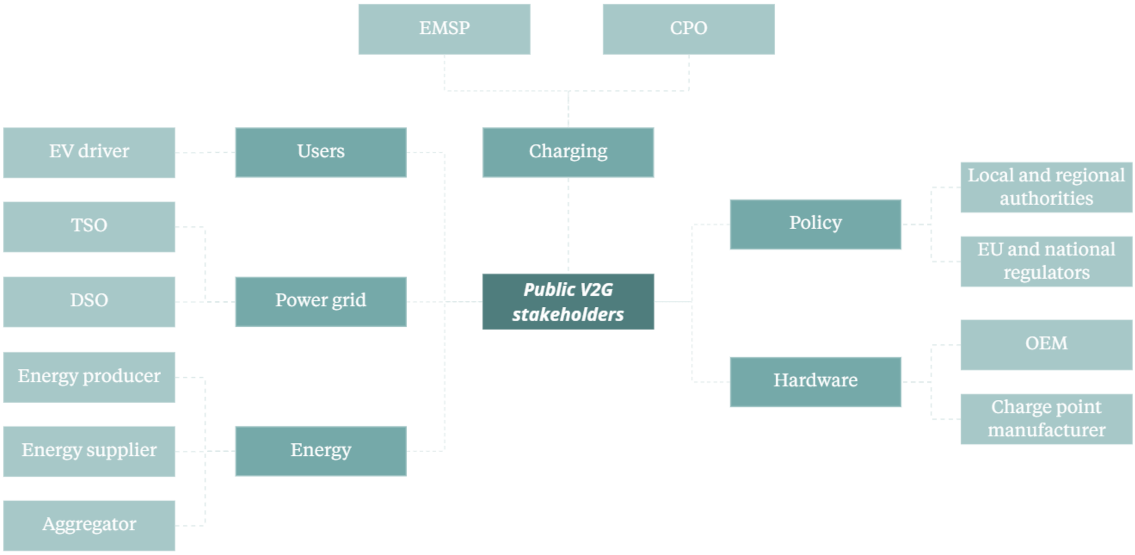


Figure 4.13: Overview of the involved stakeholder in the public V2G system design

The power-interest grid in Figure 4.14 provides insight in the relative power and level of interest held by different stakeholders involved in the public V2G system design. The argumentation behind this Figure can be read in Appendix A.8. By analyzing the position of stakeholders in the system, it becomes possible to understand their influence and importance, which helps defining current drivers and barriers. In the public V2G system design, there are five stakeholders in the quadrant with both high power and interest. These are the e-driver, the TSO, the OEM, the aggregator, and the local and regional authorities. Stakeholders with high power, but limited interest are the charge point manufacturer, and the EU and national regulators. These seven stakeholders are capable of highly influencing the implementation of a public V2G system design.

Complexity of the stakeholder field of the Commercial V2B system design

Figure 4.15 visualizes the involved stakeholders in the commercial V2B system design. The stakeholders are clustered by their role in the system. The total of ten stakeholders are also placed in the Power-Interest grid, which is depicted in Figure 4.16.

The power-interest grid in Figure 4.16 provides insight in the relative power and level of interest held by different stakeholders involved in the commercial V2B system design. In the commercial V2B system design, there are five stakeholders in the quadrant with both high power and interest. These are the Energy supplier, the DSO, the OEM, the aggregator, and the EV fleet manager. Stakeholders with high power, but limited interest are the e-driver and EU and national regulators. These seven stakeholders are capable of highly influencing the implementation of a commercial V2B system design.
The commercial V2B system design demonstrates the presence of seven key stakeholders who wield significant influence over its development and implementation. Among these stakeholders, five exhibit a high level of interest in the design.

Complexity of the stakeholder field of the Islanded V2H system design

Figure 4.17 visualizes the involved stakeholders in the islanded V2H system design. The stakeholders are clustered by their role in the system. The total of seven stakeholders are also placed in the Power-Interest grid, which is depicted in Figure 4.18.

The power-interest grid in Figure 4.18 provides insight in the relative power and level of interest held by different stakeholders involved in the islanded V2H system design. In the islanded V2H system design, there are three stakeholders in the quadrant with both high power and interest. These are the e-driver, energy supplier, and OEM. A stakeholder with high power, but limited interest are the EU and national authorities.

Figure 4.14: A Power-Interest Grid of the public V2G system design

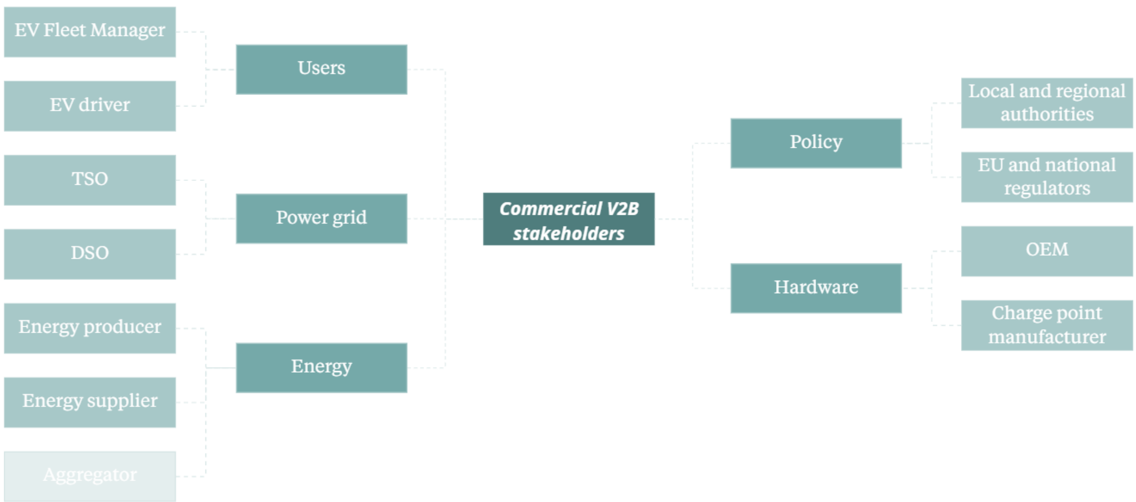


Figure 4.15: Overview of the involved stakeholder in the commercial V2B system design

These four stakeholders are capable of highly influencing the implementation of the islanded V2H system design.

Comparison of stakeholders' power and interest in the system designs

The e-driver has both high power and interest in the public V2G and islanded V2H system design, but has limited interest in the commercial V2B system design, as the opportunity for revenue generation lies with the EV fleet manager in the latter design. Similarly, the energy supplier, a significant stakeholder in the islanded V2H system design, encounters a decrease in both influence and interest regarding the commercial V2B system design, and this decline is further amplified in the public V2G system design. This can be attributed to the reduced revenue generation opportunities arising from an increased energy independence, which diminishes for the commercial V2B system design and even more so for the public V2G system design.

Figure 4.16: A Power-Interest Grid of the commercial V2B system design

Figure 4.17: Overview of the involved stakeholder in the islanded V2H system design

The DSO plays a significant role in the commercial V2B system design, but their involvement is relatively limited in the public V2G system design. This is due to the diminishing ability to provide a solution for grid congestion issues. Conversely, the TSO's level of involvement is higher in the public V2G system design compared to the commercial V2B system design, which is connected to the grid stability service provided. Neither the DSO nor the TSO are involved in the islanded V2H system design. The charge point manufacturer has high power only in the public V2G system design as the design is dependent on the manufacturer's development of a bidirectional AC charger, which is not yet on the market. The local and regional authorities are highly involved in the public V2G system design, as this design is implemented on public property. Therefore, infrastructure challenges are their responsibility. However, this involvement decreases in the commercial V2B system design, and even more so in the islanded V2H system design, due to relevance.

The identified themes can be correlated with the drivers and barriers discussed in Chapter 2. The level of complexity of the stakeholder field could be partly correlated with the *lack of cooperation between stakeholders*, but does not fully grasp the concept. The level of lobby activities occurring for each system design cannot be correlated with any drivers or barriers mentioned in Chapter 2.

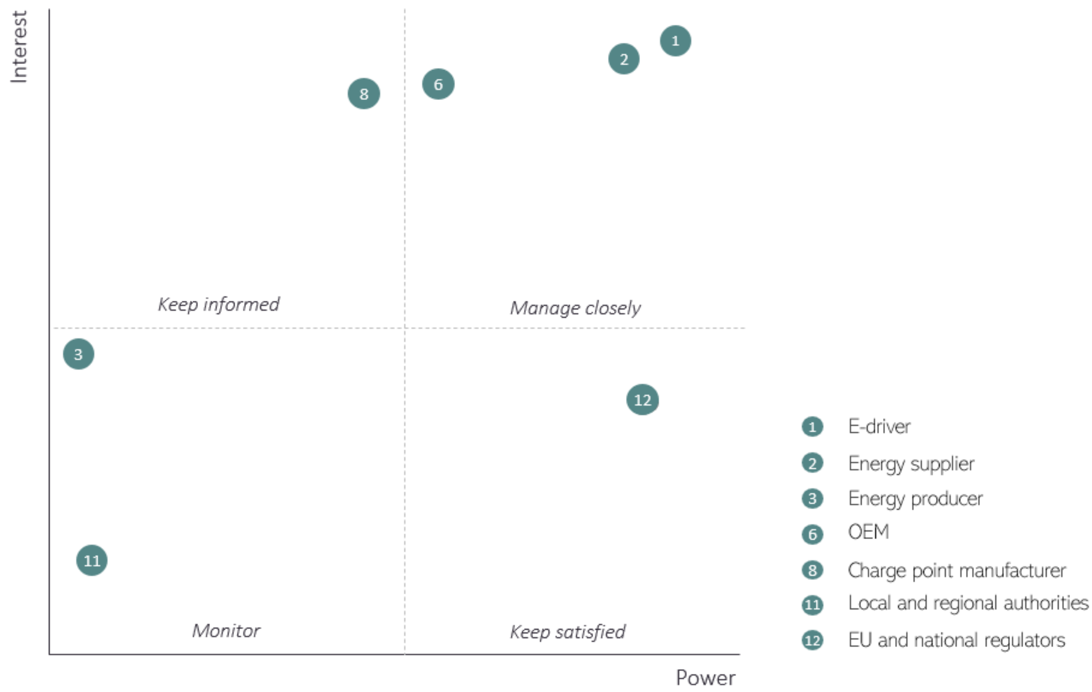


Figure 4.18: A Power-Interest Grid of the islanded V2H system design

4.2.8. Performance of the V2X system designs

Table 4.11 illustrates the performance scores of the analyzed V2X system designs for each technological innovation system function. Darker colours indicate a lower performance for a specific system design compared to the others, and lighter colours indicate a higher performance for a specific system design.

Table 4.11: Scoring of V2X system design performance on TIS function themes

		Public V2G	Commercial V2B	Islanded V2H
F1	Configurational focus pilots			
	Fleet captivity			
	Product availability			
F2	User behavior predictability			
	Availability of use-case specific research			
F3	Network complexity			
	Network collaboration			
	Availability of collaboration platforms			
F4	Creation of market incentives			
	Regulatory compliance			
	Promising activity neighboring countries			
	Promising pilot outcomes			
F5	Compatibility with the current system			
	System interoperability			
	Market competition			
	Market size			
	Potential economic benefit			
	Initial user investments			
F6	Financial support			
	Marketing effectiveness			
F7	Lobby activities			
	Complexity of stakeholder field			

Lowest performance → Highest performance

The public V2G system design demonstrates the lowest performance across most identified themes, while the islanded V2H system design excels in most areas. The commercial V2B system design, on the other hand, has the lowest number of low-performing themes compared to the other system designs. The public V2G system design faces challenges related to entrepreneurial activities (F1), knowledge development (F2), and market formation (F5), while the islanded V2H system design struggles with guidance of the search (F4) and resource mobilization (F6). The commercial V2B system design faces difficulties with resource mobilization (F6) and creation of legitimacy (F7).

Comparison with literature review findings

Not all themes that were found by interviewing experts and stakeholders were translatable to drivers and barriers that were found in the literature review conducted in Chapter 2. Themes that found no correlation with the findings in the literature review are: fleet captivity, use case specific knowledge, network complexity, availability of collaboration platforms, promising activity of neighboring countries, promising pilot outcomes, marketing effectiveness, and lobby activities. The other sixteen themes did have a correlation with a driver or barrier found in the academic literature. As for the eight themes that did not correlate, this could have several reasons.

Firstly, contextual differences may explain the variations between the findings in the literature review and the results of this study. While the literature review adopts a more generalized view of V2X, this study focuses specifically on the Dutch context, leading to more context-specific outcomes relevant to the Netherlands. Factors such as socio-economic conditions, regulatory frameworks, infrastructure, and cultural influences can contribute to diverse drivers and barriers in different regions. Secondly, discrepancies might arise from variations in the level of aggregation when presenting drivers and barriers. The literature review may present these factors at a broader level, while this study delves into more specific and detailed aspects of V2X system designs. For instance, the theme 'availability of collaboration platforms' is a distinct example of this difference. Lastly, the differences could be attributed to variations in research methodologies and data collection techniques employed in this study compared to existing academic literature. Each approach may highlight different aspects of V2X system designs. As this is the first study to utilize the TIS framework in the context of V2X, it places more emphasis on socio-economic and regulatory aspects, contrasting the existing literature's primary focus on technical aspects.

In conclusion, the variations between the literature review and this study's results can be attributed to contextual differences, differences in aggregation levels, and variations in research methodologies. By focusing on the Dutch context and utilizing the TIS framework, this study sheds light on more context-specific and detailed aspects of V2X system designs, emphasizing socio-economic and regulatory factors alongside technical aspects.

4.3. Motors of innovation

As explained in Paragraph 3.2.3, the motors of innovation theory by Suurs et al. [87] defines distinctive motors that help gain understanding in the interplay between the different TIS functions. The authors leave room for the design of other types of motors if the context of a specific system requires this. The researcher acknowledges three key dynamics in the interplay between system functions, based on the data gathered through interviews, desk research and event visitation. These dynamics play a significant role in shaping the innovation potential of the various V2X system designs:

- First, there is the dynamic of **building collaborative networks and gathering relevant resources**. This dynamic emphasises the importance of building strong and interconnected networks between stakeholders within the TIS. Collaborative efforts, such as partnerships, knowledge sharing and joint initiatives, facilitate the exchange of ideas and resources, thereby fostering innovation and progress;
- Second, the dynamics of **creating incentives to form a market** emerge as a crucial factor. Incentives play a key role in encouraging stakeholders to participate actively in the transition process. By providing economic, regulatory or political incentives, a favourable environment is created to stimulate market development and attract investment in sustainable technologies and practices;
- Finally, **the formation of markets through pilot projects** is identified as an important dynamic in the V2X context. Pilot projects serve as experimental platforms where new technologies, business models and practices are tested and refined. Successful pilots not only demonstrate the feasibility and effectiveness of sustainable solutions, but also attract attention and create momentum for wider adoption and market expansion.

The subsequent paragraphs will examine each innovation motor individually. Arrows connecting system functions are color-coded, with the darkness of the color indicating the extent to which the respective dynamic acts as a barrier to the formation of a positive feedback loop. Lighter arrows indicate more favorable dynamics.

4.3.1. The Collaborative Network Motor

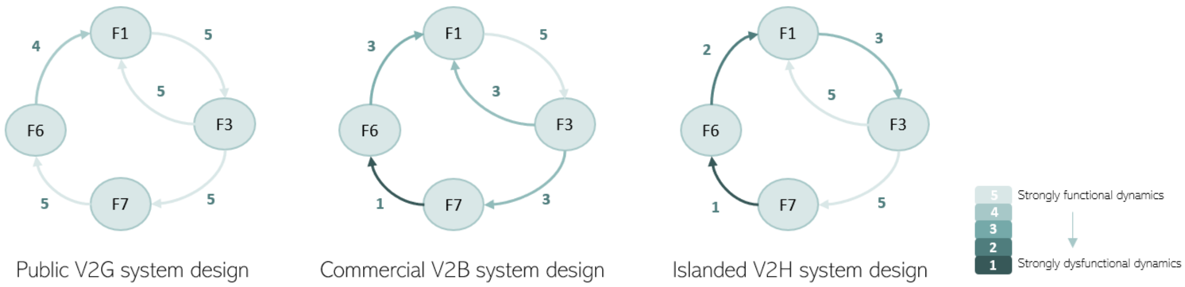


Figure 4.19: The dynamics of the Collaborative Network Motor for the three V2X system designs

The *collaborative network motor* (Figure 4.19) highlights the significance of fostering networks and collaborations among relevant stakeholders on the functioning of the entire system design. This motor, which is visualized in Figure 4.19, operates through a feedback loop, commencing with entrepreneurial activities focused on a specific system design (F1). These activities interact with the development of collaboration and information sharing networks (F3), as stakeholders collaborate to shape pilot projects, and the networks, in turn, influence the nature of entrepreneurial activities. The growth of collaboration and information sharing networks (F3) impacts the establishment of legitimacy and engagement among stakeholders, as well as the implementation of lobby activities (F7). These lobby activities and stakeholder engagement affect the mobilization of resources, including financial, material, and human resources (F6). The availability of such resources, in turn, influences the entrepreneurial activities associated with the system design.

The key finding is that the market formation motor plays a crucial role in driving innovation within the public V2G system design, while its impact is considerably weaker in the other two system designs. The main dynamics hampering a strongly running motor for the commercial V2B and islanded V2H system design are the dynamics between the creation of legitimacy and the mobilization of resources.

For the public V2G system design, this collaborative network motor is effectively driving the innovation system. None of the dynamics between the relevant system functions form a barrier for a positive feedback loop. With We Drive Solar being the largest bidirectional charging project in Europe, and the project connecting numerous parties with different stakeholder roles, the interplay between entrepreneurial activities (F1) and the creation of collaboration and information sharing networks (F3) is going well. Because of this extensive list of parties involved in the system design, lobby activities (F7) are triggered from different angles. As a result, the mobilization of resources for this design scores by far the best. Municipalities like Utrecht, are largely involved in the implementation of bidirectional charging infrastructure and the development of pilot projects (F1). For the public V2G system design, thus, there are no significant barriers for a well-running collaborative network motor.

For the commercial V2B system design, the dynamics between lobby activities (F7) and resource mobilization (F6) is the only interplay that present a significant barrier for the formation of a positive feedback loop. The other dynamics in this motor are presenting no significant barrier, but scoring less well compared to the public V2G system design. As the largest number of pilot projects in the Netherlands is conducted for this system design, the dynamics from entrepreneurial activities (F1) toward knowledge diffusion (F3) is going well.

Different parties are involved in the pilot projects, which increases knowledge on the system design. However, none of the pilot projects conducted reach the scale of the We Drive Solar concept, resulting in a less pronounced formation of network collaborations compared to the public V2G system design. This results in less stimulation of entrepreneurial activities (F1), and less stakeholder engagement (F7). As the stakeholder engagement is limited, there is little to no lobby activity (F7) found for this particular system design with the aim of mobilizing resources (F6). Although there is no lobbying for this design, the mobilization of financial resources (F6) is considerable, thanks to the mostly European funding projects funding a wide range of system designs. Due to this, there is still room for much entrepreneurial activities (F1) for this system design. For the commercial V2B system design, thus, the main barriers for a well-running collaborative network motor are the limited mobilization of resources due to the limited lobby activity.

For the islanded V2H system design, the interplay between lobby activities (F7), resource mobilization (F6), and the formation of entrepreneurial activities (F1) presents a notable challenge in establishing a positive feedback loop. Due to a limited number of stakeholders involved in the system design, the dynamics between the collaboration networks (F3) and the creation of stakeholder engagement (F7) do not present a significant barrier to overcome for this design. However, the relatively simple design also presents a negative influence to the motor of innovation.

As there is a limited number of stakeholders involved in the system, and their interests in the system design are currently held back by variables such as the net metering policy ('salderingsregeling') that hamper the creation of a market incentive for e-drivers, there is no legitimate reason for any stakeholders involved to perform lobby activities. As a result, the islanded V2H system design receives limited attention from policy makers and other parties able to provide resources for its development. Consequently, there are few pilot projects focusing on this design, leading to limited formation of collaborative networks. This, however, is not necessarily a barrier as the islanded V2H system design was shown to be rather simple. With only a limited number of stakeholders necessary for a successful implementation of the design, the dynamics between entrepreneurial activities (F1) and the development of collaboration networks (F3) are not an obstacle. For the islanded V2H system design, thus, the main barriers for a well-running collaborative network motor are the limited mobilization of resources due to no lobby activity, resulting in limited configurational focus of pilots for this system design.

4.3.2. The Market Formation Incentive Motor

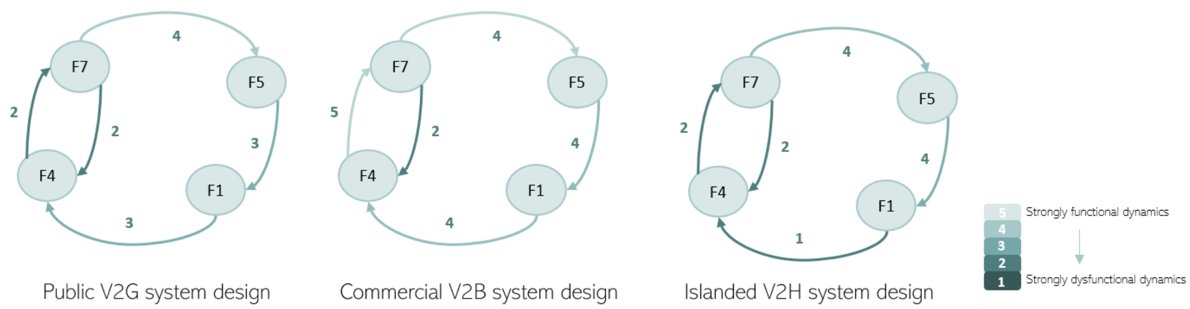


Figure 4.20: The dynamics of the Market Formation Incentive Motor for the three V2X system designs

The *market formation incentive motor* (Figure 4.20) highlights the importance of the creation of an incentive for participation in a market, and the formation of the market. This dynamic shows that pilot projects (F1) could stimulate the active creation of incentives for stakeholders to participate in an innovation system (F4), which on its turn could stimulate the involved stakeholders to actually participate with a positive attitude towards the innovation (F7). An active participation could lead to a faster and more successful formation of the market (F5), which on its turn could stimulate more pilot projects that investigate the innovation further (F1). The key finding is that the public V2G system design faces challenges in creating market incentives due to its complexity and diverse stakeholder landscape, while the islanded V2H system design struggles to gain legitimacy and overcome political barriers. In contrast, the commercial V2B system design has the most functional motor, but faces obstacles in stakeholder dynamics. Nevertheless, it benefits from stronger market incentives than the other designs.

For the public V2G system design, the several pilot projects conducted (F1) create governmental attention (F4) for the creation of market incentives. An example of this is the large-scale placement of V2G-compatible charging stations in the municipality of Utrecht. However, due to both significant regulatory compliance issues such as the minimum bid size for provision of ancillary services (F4), and the complexity of the stakeholder field for this system design (F7), the dynamics between these two functions are strongly dysfunctional.

However, due to strong lobby activities (F7) caused by a strong collaboration network created for this system design (see the Collaborative Network Motor), the dynamics towards a formation of the market (F5) are considerably favorable, mostly because of the potential economic benefit for this system design.

For the commercial V2B system design, the creation of market incentives (F4) is strongest due to the extensive pilot experience (F1) for this system design. The incentive is for example created through a lack of regulated energy supply guarantee for business, and through the inability of grid operators to offer larger grid connections. Due to the creation of incentives, stakeholders are more likely to participate in the innovation system (F7), even though the stakeholder field is rather complex and the lobby activities are limited, which results in a negative feedback to the guidance of the search (F4). As stakeholders for this system design are relatively incentivized to participate, the market for this system design is formed relatively well. This is also due to a relatively simple system interoperability, and significant potential economic benefit.

For the islanded V2H system design, the limited pilot project experience (F1) leads to a limited governmental attention for the system design (F4). Even though the stakeholder field is simplest, the lack of attention and lack of incentives created for stakeholders to participate (F7) leads to weak dynamics between guidance of the search and creation of legitimacy. As the stakeholder field is simplest, however, the market is most easily formed, which is why these dynamics are relatively functional.

In conclusion, the public V2G system design faces challenges in creating market incentives due to the complexity of its design and the diversity of stakeholders involved. In addition, the lack of regulatory compliance hinders the ability to incentivise stakeholders and facilitate the formation of markets for this system design. On the other hand, the islanded V2H system design faces difficulties in gaining legitimacy among stakeholders. The lack of market incentives and, in some cases, existing policies that discourage innovation hinder its progress. Overcoming these challenges and establishing the necessary legitimacy will be crucial for the successful implementation of the islanded V2H system design. In contrast, the commercial V2B system design has the most functional engine of the three designs. However, it encounters an obstacle between Function 7 and Function 4, mainly due to the complex stakeholder landscape and the lack of lobbying activities supporting this particular system design. Nevertheless, the commercial V2B system design benefits from comparatively stronger market incentives than the other two designs.

4.3.3. The Entrepreneurial Market Formation Motor

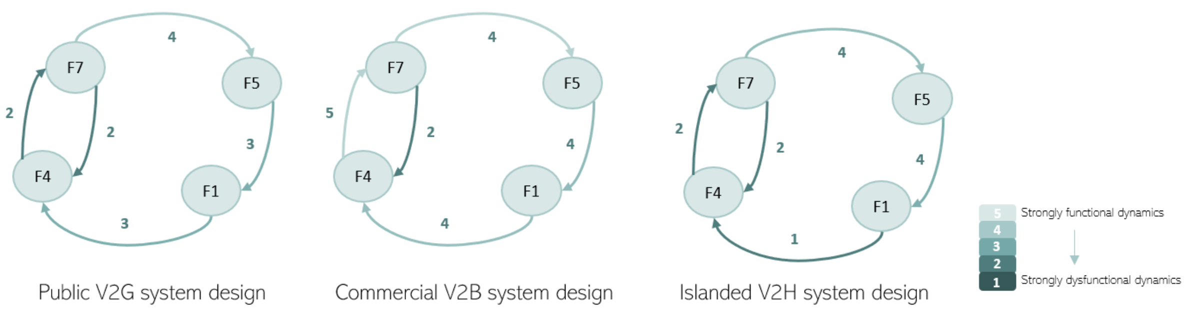


Figure 4.21: The dynamics of the Entrepreneurial Market Formation Motor for the three V2X system designs

The *entrepreneurial market formation motor* (Figure 4.21) highlights the importance of market formation by entrepreneurial activity in the comparison between different V2X system designs. As the market formation function was concluded to be one of the most important functions for the success of a V2X system design, the dynamics are interesting to analyze. This motor starts with initiating pilot projects (F1), that result in positive or negative outcomes (F4). The general idea is that positive research or pilot outcomes lead to diminishing uncertainty about the innovation (F2), which leads to an incentive to form collaboration networks and spread the information that has led to a diminishing uncertainty (F3). These networks are then able to participate in entrepreneurial activities (F1), which again lead to a guidance of the search (F4). This feedback loop then influences the formation of markets either positively or negatively. The key finding is that the public V2G system design shows dysfunctional dynamics, while the dynamics of the commercial V2B and islanded V2H designs are relatively better. Among them, the commercial V2B system design shows the most functional dynamics, with ongoing entrepreneurial activities stimulating the formation of its market. On the other hand, the islanded V2H design faces challenges due to limited entrepreneurial activities and insufficient efforts to address uncertainty issues.

For the public V2G system design, the market formation motor is currently not functioning well. This explains why the public V2G system design currently struggles with relatively the most market formation barriers. As discussed, the entrepreneurial activities (F1) for this design are going well, but the outcomes of the pilots are not always too successful. This leads to a difficult interplay between entrepreneurial activities (F1) and guidance of the search (F4). As the outcomes are not too positive, a limited level of uncertainty has been taken away (F2). User behavior predictability, therefore, currently still presents a significant barrier for a well-functioning dynamic between guidance of the search (F4) and knowledge development (F2).

Because of the uncertainty on user behavior, as well as the unavailability of use-case specific research, networks have difficulty with forming. This is also negatively influenced by the network complexity. Nevertheless, as explained earlier, the We Drive Solar concept has established a well-functioning network that leads to a well-functioning dynamic between knowledge diffusion (F3) and entrepreneurial activities (F1). This system design, thus, has somehow managed to form strong networks regardless of the high level of uncertainty. This has led to more entrepreneurial activities, which guides the search for the formation of the market. However, as the market formation still knows relatively many barriers compared to other system designs, this is labeled a negative feedback loop. For the public V2G system design, thus, the main barriers for a well-running market formation motor are the lack of use-case specific research, the user behavior unpredictability, and the issues with pilot outcomes.

For the commercial V2B system design, the entrepreneurial market formation motor is currently running relatively well. The commercial V2B system design struggles with less market formation barriers, compared to the public V2G system design. The entrepreneurial activities (F1) for this system design are going well, and the outcomes of the pilots have a more positive trend. This leads to a more successful interplay between entrepreneurial activities (F1) and guidance of the search (F4). Because of this, uncertainty is less of a barrier for this system design, even though not too much use-case specific research (F2) is available, yet. The user behavior predictability (F2) is less of an issue for this system design due to its characteristics. As the network complexity is also lower, the link with knowledge diffusion (F3) is also less hampering. Therefore, this system design receives much configurational focus for pilots, which then again leads to a guidance of the search in this direction. This positively influences the market formation. For the commercial V2B system design, thus, there are no main barriers for a well-running entrepreneurial market formation motor.

For the islanded V2H system design, there are also less significant barriers compared to the public V2G system design. As there are limited entrepreneurial activities (F1) on this system design, however, this hampers the motor significantly. With limited entrepreneurial activities, there is also only limited guidance toward this particular system design (F4), which leads to a limited solve of uncertainty issues. However, uncertainty issues play a significantly smaller role in this design, as user behavior predictability is no issue. The same goes for the formation of collaboration networks (F3), which is easily established for this simple system design. For the islanded V2H system design, thus, the only main barrier for a well-running entrepreneurial market formation motor is the execution of entrepreneurial activities, which is currently taking place on a limited level.

Comparison of motors of innovation

In conclusion, while the public V2G system design has strongly dysfunctional dynamics for this motor of innovation, the dynamics are better for the commercial V2B and islanded V2H system design. The commercial V2B system design has the most functional dynamics within this motor. The market formation through entrepreneurial activities is running for the commercial V2B system design. This does not necessarily mean that the market is fully forming for this system design, but that the entrepreneurial activities and their promising pilot outcomes stimulate the formation of this system's market the most. For the islanded V2H system design, the lack of entrepreneurial activities hampers a fully functioning motor, as well as limited activity in solving uncertainty issues for the system design.

5
Discussion

Contributions of the research

While prior studies have identified various drivers and barriers of the large-scale implementation of the V2X concept, they often lack clear associations with specific configurational decisions and designs, hindering a precise understanding of their effects on particular V2X systems. Additionally, academic literature commonly portrays V2X as a singular system, overlooking the profound influence of design choices on the system's dynamics and relevant factors and themes. This research aimed to enhance the understanding of the bidirectional charging system's performance and innovation potential by analyzing various V2X system designs in the Dutch context. The study emphasized the importance of viewing V2X as a collection of interconnected systems, each influenced uniquely by configurational decisions. It highlighted the significance of viewing the V2X innovation not as a single system, but as a diverse range of potential systems shaped by configurational choices. This understanding is crucial for comprehending the technology's socio-economic implications. This study contributes to the academic understanding of different V2X system designs rather than V2X as one concept, opening up possibilities for further research and development in this domain.

The practical relevance of this research lies in the valuable insights it offers into the performance and potential of different V2X system designs. These findings can guide policy makers, industry professionals, and stakeholders in making informed decisions about implementing and developing V2X technologies. However, it's essential to clarify that this research does not determine whether this innovation should be adopted or invested in. Instead, its conclusions provide valuable direction for the design and implementation of V2X systems when the decision to do so is made.

Methodological reflection

In terms of methodological reflection, the use of the Technological Innovation System (TIS) framework in this study proved to be highly advantageous for several reasons. Firstly, one of the major strengths of the TIS framework lies in its ability to analyze the system as a whole. This holistic approach allowed the research to consider the intricate interplay of various components, stakeholders, and contextual factors within the V2X innovation system. As a result, the study was able to capture a more nuanced and comprehensive picture of the performance and potential of different V2X system designs in the Dutch context. Secondly, the TIS framework is interconnected with the motors of innovation framework, which significantly aided the analysis of critical dynamics within the V2X technological innovation system. By conducting an analysis with these two frameworks, the study gained a comprehensive understanding of the drivers and barriers influencing the system's performance and innovation potential.

One notable point of consideration is that the Technological Innovation Systems (TIS) framework used in this study may have placed insufficient emphasis on adjacent innovations, which potentially play a significant role in shaping the context of V2X system designs. To address this limitation, an option for expanding the TIS framework by incorporating an additional function to capture adjacent innovations could be explored in future research. On the other hand, exploring alternative frameworks that place greater emphasis on the niche aspect, such as the Strategic Niche Management (SNM) framework, may provide a more comprehensive understanding of this context's dynamics and potential. Another concern of the TIS framework is its limited focus on the consumer side, a recognized issue in innovation studies using the TIS framework. In the context of V2X system designs, understanding consumer behavior and preferences becomes even more critical, given their pivotal role in the adoption and success of such innovations. This makes it essential to consider innovative ways to integrate the consumer perspective more comprehensively into future research.

Notably, the Multi-Level Perspective (MLP) has proved valuable in capturing essential context factors, such as the dynamic landscape, and identifying important adjacent innovations in the niche-level. These adjacent innovations were recognized due to the MLP framework, but lacked recognition in the further TIS analysis. However, the recognition of these adjacent innovations have enriched the analysis and have uncovered the importance of including adjacent innovations in further research. Furthermore, the Motors of Innovation theory has been instrumental in concretizing the relevant dynamics within the V2X context and facilitating the translation of research findings into actionable policy implications. By identifying and categorizing the various motors driving innovation in the V2X domain, the theory has provided a clear framework to assess the strengths and weaknesses of different system designs and their potential impact on sustainable mobility and energy infrastructure.

Reflection on the use of ChatGPT

Throughout the research process, ChatGPT was utilized solely for rewriting purposes. Its strengths and advantages lie in its efficiency and speed, enabling quick generation of coherent and easily understandable text. However, some limitations and challenges were observed, including its limited ability to grasp contextual nuances and the potential for biased content based on its training data. To ensure the accuracy and reliability of the information presented in the report, every output from ChatGPT underwent human review and editing. Ethical considerations were also taken into account, emphasizing the importance of avoiding plagiarism by properly citing sources, refraining from using confidential data, and being transparent about the use of ChatGPT in the research process by reflecting on its use.

Research limitations

This research, while providing valuable insights into the socio-economic performance and potential of different V2X system designs, does carry some limitations that warrant consideration. Firstly, a larger sample size, encompassing a wider range of stakeholders or a higher interviewer-to-stakeholder ratio, could have enriched the study's depth. Moreover, data collection presented challenges, particularly in acquiring information on pilot outcomes, leading to limited access to relevant data and hindering a comprehensive understanding of specific aspects of V2X configurations. Additionally, this research focused specifically on selected dimensions and aspects of V2X designs, which may not fully encompass the entire spectrum of potential factors affecting V2X implementation. Finally, the intercoding reliability could have been improved by employing a secondary coder, a step that was not taken in this study. Despite these limitations, the findings remain valuable due to their systematic analysis of key dimensions and relevant themes influencing the performance and innovation potential of system designs. These insights offer a solid foundation for decision-makers to understand the critical factors influencing the successful large-scale implementation of V2X system designs, facilitating strategic planning and targeted interventions.

Recommendations for future research

As this research is not able to fill all the current existing knowledge gaps, multiple recommendations for future research could be made. Three separate recommendations for future research are discussed.

1. *A comparative V2X study for other countries or regions*

Further research should include comparative studies conducted across different countries or regions to investigate how contextual factors impact the performance and adoption potential of various V2X system designs. By exploring the influence of factors such as policy frameworks, infrastructure availability, and market dynamics, a more comprehensive understanding of the contextual nuances can be obtained. According to V2G-hub.com, there are currently 27 countries where V2X pilots are executed. The two clear front runners are the US and the UK [94]. Studying these countries could be interesting and relevant, as they likely exhibit the most developed innovation dynamics.

2. *A comparative V2X study with a broadened system delineation to include adjacent innovations*

It is beneficial to extend the scope of future research to include adjacent innovations and their interactions with V2X system designs to provide a more comprehensive understanding of the overall ecosystem. As was concluded during this research, adjacent innovations play a considerable role in the ecosystem. Therefore, it is advisable to include these mentioned innovations (shared mobility, large-scale and small-scale stationary batteries, and solar PV) in the system delineation. This could involve incorporating an additional TIS function into the analysis, allowing a deeper exploration of the synergies and complexities that arise when different innovative elements are combined. On the other hand, exploring alternative frameworks that place greater emphasis on the niche aspect, such as the Strategic Niche Management (SNM) framework, may provide a more comprehensive understanding of this context's dynamics and potential. By examining the interactions between different innovations, researchers can gain insights into the broader implications and potential trade-offs involved in implementing V2X systems in real-world contexts. A notable example is the combination between the public V2G system design and the concept of shared mobility. This combination has been proven to increase performance and adoption potential for this specific V2X system design.

3. Investigate the opportunity to implement multiple V2X system designs combined

Future research should explore the feasibility and benefits of implementing multiple V2X system designs in a coordinated manner, and how they can complement and enhance each others performance. The various V2X system designs might not hinder each other's functioning, as they could offer distinct services, engage in various markets, and cater to different target groups in diverse locations or time frames. As an illustration, a commercial V2B system design could potentially harmoniously coexist with an islanded V2H system design, as they do not significantly hinder each other's market potential. Through coexistence, a greater proportion of EVs could partake in the bidirectional charging system, potentially yielding even more advantages. However, the combination of multiple V2X system designs could also lead to additional obstacles that must be overcome. By investigating the potential synergistic effects of integrating different V2X designs, researchers can uncover new opportunities to optimize energy management, grid stability and overall system efficiency. This allows for the uncovering of potentially new relevant performance-related themes and adoption potential of the innovation.

6 Conclusions

This researchs main question was: ***How do different V2X system designs compare in terms of their socio-economic performance and innovation potential in the Netherlands?*** where *performance* refers to the current state of a system or technology, measured by its drivers and barriers, and *innovation potential* assesses a system's capacity to overcome barriers, create and strengthen drivers, and introduce new solutions for further development of the V2X system design.

In this study, five critical dimensions were identified to determine a V2X system design:

- *Service destination*, which refers to the target recipient of the electricity flow, which could be the medium-voltage grid, a building or a home;
- *Service type*, indicating the specific functions provided by the V2X system, such as congestion management, ancillary services, or energy back-up services;
- *Vehicle use type*, considering the intended usage of the connected vehicles, whether they are commercial fleets, or private vehicles;
- *Charge location*, focusing on where the charging infrastructure is placed, including public charging stations, at-home premises, or at-work setups;
- *Charge topology*, which refers to the type of electric current used for charging electric vehicles (EVs) and the method of connection between the charging infrastructure and the vehicle, being either Alternating Current (AC), or Direct Current (DC).

Three diverse yet relevant system designs were defined for the context of the Netherlands:

1. The public vehicle-to-grid system design that is connected to a public AC charging station, which is connected to the medium-voltage grid and delivers ancillary services;
2. The commercial vehicle-to-building system design that is connected to a private low-power DC charging station, which is connected to a commercial building, and delivers congestion management and back-up energy services;
3. The islanded vehicle-to-home system design that is directly connected to a private low-power DC charging station, which is connected to a home, and delivers back-up energy services.

By assessing the strengths and weaknesses of each design, and considering the challenges and opportunities they present, meaningful comparisons could be made. Twenty-two key themes emerged through conducted interviews as being crucial. Exemplary themes are: product availability, fleet captivity, system interoperability, market size, network complexity, and potential economic benefit. The twenty-two themes combined collectively define the important variables for comparing different V2X system designs.

The analysis of the three V2X system designs reveals distinct *performance* patterns. The islanded V2H system design stands out with the strongest overall performance, due to its relative high number of themes for which the system design scores high. Themes like fleet captivity, user behavior predictability, network complexity, and compatibility with the current system form no barrier at all for large-scale implementation of the system design. In contrast, the public V2G system design exhibits relatively low performance scores across multiple themes, like fleet captivity, product availability, user behavior predictability, network complexity, and market competition, indicating a relatively large amount of barriers to successful implementation. Most barriers for the public V2G system design are technical in nature, but also regulatory and market barriers are found. The commercial V2B system design falls in between the previous two system designs, showcasing a mixed performance across the evaluated themes. However, the commercial V2B system design demonstrates the least number of low-performing themes, indicating fewer hard barriers for implementation in the Netherlands compared to the other designs. The only hard barriers lie in its regulatory compliance, its compatibility with the current system, and the current lack of lobby activities. Currently, the islanded V2H system design emerges as the most favorable option in terms of performance, while the public V2G system design lags behind with its less advantageous characteristics, making it currently the least suitable choice for the Dutch context.

The comparison of *innovation potential* among the V2X system designs depends on the time frame considered. In the short term, the potential for V2X in general is not very high as all designs face numerous barriers. However, in the longer term, some barriers might be overcome, with variations in difficulty resulting in variations of innovation potential of the system designs. The public V2G system design, although the most developed in the Netherlands, has limited innovation potential for large-scale implementation due to its complexity in multiple facets. The system not only faces the highest technical complexities but also encounters challenges in terms of stakeholder, market, and network complexities.. On the other hand, the islanded V2H system design is simpler to implement but lacks urgency and economic potential in the Dutch context which limits its potential greatly. The commercial V2B system design strikes a balance, making it highly suitable for implementation in the Netherlands. It effectively addresses the urgency for congestion management while presenting a relatively simple system design with minimal complexities.

An essential inquiry revolves around the generalizability of the findings to diverse contexts, such as other system designs or countries. The research's wide exploration of different system designs contributes to the potential for generalizability, yet it is essential to recognize that not all findings can be directly translated to every conceivable system design. While the study's results and conclusions offer valuable insights for informing the development of various system designs, they may require modification and contextualization when applied to specific cases or unique configurations. It becomes evident that changing one configurational choice within a system design can have profound implications for its overall performance and innovation potential. For instance, a simple alteration like transitioning the public V2G system design from AC to DC can result in significant ramifications for the system's functioning and its capacity to foster innovation. Factors like 'product availability' are largely influenced by the charge topology selected in the system design. In the case of the public V2G system design, switching from AC to DC would elevate the 'product availability' factor from performing extremely poorly to an average level. Hence, this research emphasizes the importance of considering the individual nuances and context-specific factors that may influence the applicability of its findings to different V2X system designs.

The generalizability of the research results to other countries beyond the Netherlands should be approached with caution. While the investigation of various V2X system designs in the Dutch context provides valuable insights and understanding, the applicability of these findings to different countries may vary due to varying socio-economic, regulatory, and infrastructural factors. Important differences between the Netherlands and other countries include its extensive availability of AC public infrastructure, and its relatively reliable electricity grid, which has largely influenced the outcomes of this study. Nevertheless, both the methodology and the identified themes can serve as a valid starting point for conducting research in other countries.

In terms of policy implications, the results offer preliminary insights that can guide future policymaking, while it does not provide definitive recommendations. Three dynamics are found that together form the key motors for innovation development: the formation of collaborative networks, the creation of incentives to form markets, and the formation of markets through pilot projects. These three identified dynamics, along with the relevant performance themes, form a basis for concrete policy implications. Conducting more pilots and experiments to fill knowledge gaps and solve technical, regulatory, social and market barriers will benefit all V2X system designs. For the public V2G system design, focusing on technical pilots to address technical barriers and investing in platform and knowledge development for ancillary services could be beneficial. Additionally, exploring combinations with shared mobility is worth investigating. The commercial V2B system design requires more attention and lobby efforts to secure resources for developing a congestion management platform and increasing its awareness in society. Investigating combinations with stationary batteries and solar PV can further enhance its potential. Lastly, to boost the urgency for the islanded V2H system design, creating economic incentives is vital, while also exploring its combination with solar PV as a promising avenue for advancement.

To conclude, this research highlights the significant differences in *performance* and *innovation potential* between the various V2X system designs. It shows the islanded V2H system design's relative superior *performance*, attributed to its simplicity, and underscores the commercial V2B system design's relative high *innovation potential*, derived from its capacity to address urgent issues alongside its relatively straightforward design. Furthermore, the research reveals the complexities that obstruct the performance and innovation potential of the public V2G system design due to its many complex characteristics. Overall, these conclusions underscore the significance of strategic configurational choices in unleashing the full potential of the V2X innovation.

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A
TIS analysis

A.1. Landscape developments

The technological innovation system of bidirectional charging in the Netherlands is significantly influenced by several landscape developments. First, there is a discernible shift toward energy sources that are more intermittent, such wind and solar energy. This change brings to greater energy supply volatility, which leads to more occurrences of negative energy prices. *Last month, we had five days with negative energy prices.* – INT08 [68]. These negative prices indicate times when there is an abundance of power produced but little demand, giving bidirectional charging systems the chance to absorb extra energy and store it in vehicle batteries. By utilizing bidirectional charging, fluctuating energy sources may be integrated more effectively, improving grid stability and maximizing the use of renewable energy.

Another landscape development shaping the technological innovation system is the growing emphasis on local energy generation, particularly through solar energy. In the Netherlands, solar power is becoming a more popular option for households and municipal communities. As stakeholders look to optimize their energy consumption patterns and lessen dependency on the grid, the shift toward decentralized energy generation has increased the demand for local demand flexibility. In this situation, bidirectional charging systems are essential because they enable electric vehicles to function as mobile energy storage systems. Users may increase their energy independence, maintain the stability of their local grid, and boost their overall resilience by combining local energy generation with bidirectional charging.

The ongoing conflict between Russia and Ukraine has brought forth a heightened sense of urgency for energy independence. The war raises questions about energy security and the vulnerability of relying on outside energy supplies. The circumstance has highlighted the need for nations to diversify their energy mix, invest in renewable energy sources, and increase domestic energy production capabilities in order to lessen reliance on imports. It is relevant to consider the above mentioned landscape developments throughout the analysis of the Technological innovation System of the three V2X designs. The environment in which bidirectional charging takes place is shaped by these landscape developments, which include the shift to intermittent energy sources, the growth of local energy production, and the increasing urgency for energy independence. The possible benefits and challenges involved with establishing bidirectional charging systems may be better graspable by appreciating these landscape factors.

A.2. F1: Entrepreneurial activities

The function *entrepreneurial activities* refers to the set of activities undertaken by entrepreneurs, innovators, and organizations to develop and commercialize new V2X technologies or innovations. The identified themes, as depicted in Figure A.1, highlight the key differences observed among V2X designs in relation to entrepreneurial activities. Three distinctive factors have been identified that embody the differences between the three use case designs within this function: configurational focus of pilots, fleet captivity, and product availability.

The factor *configurational focus of pilots* refers to the specific emphasis or orientation of pilot projects in terms of their configurations or design aspects. Figure 4.2 visualizes the pilot projects that have been

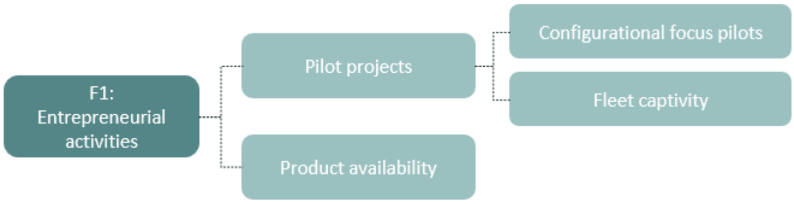


Figure A.1: Themes Illustrating Key Differences in V2X Designs Linked to Entrepreneurial Activities

conducted in the Netherlands. These pilot projects have varying configurational designs. Figure 4.3 visualizes the number of pilot projects with a specific configurational design choice. The findings indicate a diverse range of configurations being explored, with pilot projects demonstrating a relatively balanced distribution across V2G, V2B, and V2H service destinations. When comparing behind-the-meter charging (V2B + V2H) and in-front-of-the-meter charging (V2G), there seems to be a preference for behind-the-meter charging. This is also acknowledged by INT03: *Those both behind-the-meter do happen more than in front of the meter.* The distribution over domestic or commercial charging also seems quite even. There seems to be a slight preference for work-located charging.

The preference for congestion management and DC-charging seems very clear. The focus on DC-pilots is confirmed by INT04. Worldwide, 93% of pilot projects have been focused on DC [53]. One of the Dutch pilot projects, Flexgrid, aims at developing a Direct Solar Charger through a DC-DC converter (see Figure 4.2). This is particularly advantageous for V2C designs, as it enables direct charging of vehicles using solar PV panels. *Direct Solar Charging is a well-known phenomenon, where people want their solar power directly put into their vehicles. And they then want to get that power out of that vehicle at night, because the sun is not shining then. You see the logic toward DC emerging there.* – INT04. The Netherlands has seen a relatively high number of AC pilots, due to the extensive public AC charging infrastructure that currently exists (INT05). *Pilot configuration decisions are mainly determined by the availability of the technology.* — INT04. We Drive Solar is the best-known AC pilot project [82]. *They thought: all public charging stations in Utrecht so far are AC. That is convenient, then we'll just add more charging stations on AC — INT01. The thought was: the power grid is AC, so V2G must also be via AC* — INT03. When looking at the focus of configurational decisions in pilot projects, the commercial V2B system design seems to receive most entrepreneurial attention (see Figure A.2). Even though the public V2G system design executes an AC charging topology, which is not popular for entrepreneurial activities, it receives a considerable amount of attention in specifically the Netherlands. The islanded V2H system design receives relatively little attention, which is partly due to the relative reliability of the Dutch electricity grid (INT01, INT02). *That use case is less in the Netherlands because we just have a much more reliable network, especially if you compare that to the US* — INT02.

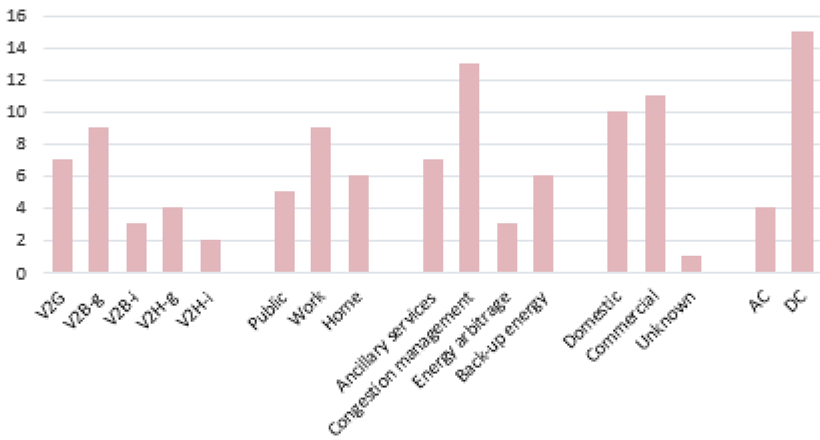


Figure A.2: Configuration choice distribution of Dutch pilot projects

Fleet captivity refers to the degree of control or influence that a specific entity or organization has over a fleet of vehicles within a given context. *It is easier to do a V2G pilot with a fleet, a group of users you* *know, that you have control over.* — INT03. *For public charging, it's just not really doable. To make it all interoperable. Unless you make sure you have availability of the charging stations, like they have the same energy supplier, and the same vehicles. Then it works as an integrated solution. But so then you have to manage all those vehicles, and so have a sharing system.* — INT05. Thus, a combination of public charging and shared mobility aims at bettering the fleet captivity. The captivity of the fleet is better for the commercial V2B system design, as the charging station is not publicly accessible and the EV fleet manager has the ability to assemble an appropriate fleet. The islanded V2H system design exhibits the highest level of captivity, as it requires only one vehicle to operate with a privately owned charging station.

Product availability refers to the readiness and accessibility of viable bidirectional charging products or solutions in the market. An important aspect here is the availability of DC bidirectional chargers, but unavailability of AC ones (INT01, INT03, INT04). *Go ahead and try to buy a vehicle-to-grid AC charging station. That is pretty complicated.* – INT04. However, as they have not yet benefited from economies of scale, DC bidirectional chargers are still somewhat costly. Bidirectionally compatible vehicles are not often offered by OEMs. The Mitsubishi Outlander PHEV and Nissan Leaf are the most well-known types, and both can be charged with DC. This creates an important barrier for the public V2G system design. With the exception of the constrained product selection possibilities, there are no substantial barriers to the availability of products for the commercial V2B and islanded V2H system designs.

A.3. F2: Knowledge development

Figure A.3: Themes Illustrating Key Differences in V2X Designs Linked to Knowledge development

The function *knowledge development* refers to the process of generating, accumulating, and disseminating knowledge within the bidirectional charging innovation system. The identified themes, as depicted in Figure A.3, highlight the key differences observed among V2X designs in relation to knowledge development. The most important differences in use cases for this function could be described in two themes: user behavior predictability and use case specific knowledge.

User behavior predictability refers to the degree to which the user patterns, like charging behavior and preferences of EV owners can be accurately anticipated or forecasted. *Especially in the field of social variables, much knowledge development is still needed.* – INT04. *How can you properly package this to make users happy? And should a user change their behaviour? And if so, how realistic is that? Or what kind of way then? How would that work? I imagine these kinds of issues are still under-researched.* – INT03. However, *a lot of data about charging behaviour is already available.* – INT05. Therefore, it is possible to predict charging behavior. However, there seems to be very little attention to social factors in academic literature. Less than 2.1% of V2G related academic studies between 2015 and 2017 mention consumer routines and norms [31]. *You want to be able to make a good prediction in advance about how long someone will spend at the charger and how much energy they need. But, being able to predict very well is still very difficult.* — INT03. This is particularly the case if the fleet has a low level of captivity. In the islanded V2H and commercial V2B system design, there are relatively fewer variables to consider when predicting charging behaviour. For example, as there is only one charging station in the islanded V2H system, decisions about its location do not play a role. Chakraborty et al. [15] concluded that multiple factors influence charge location decisions, like dwelling type, gender, electric range and influence on choice of the location. These factors need to be considered in the public V2G system design. The predictability of the commercial V2B system design is poorer than the islanded V2H system design because it involves multiple users with diverse demands and usage patterns.

Use case specific knowledge refers to the understanding, expertise, and insights that are specific to a particular use case within a given context or domain. *When you talk about what knowledge development is needed, a lot of knowledge development on use cases is still needed.* – INT04. Specifically the clarity of potential revenue with congestion management services is mentioned. *So you can see that there is not yet enough certainty about congestion management to develop a revenue model there.* – INT07. However, when asked about revenue models of other services, no interviewees could specifically state numbers other than single pilot projects conducted. This also relates to the specific optimization algorithm that is chosen. *You can choose cost optimisation, for example. But also for battery performance. You can also choose to minimise CO2 emissions. And you have to make some kind of optimal decision on that.* – INT05. In addition, the specific financial *distribution* of profits is unclear (INT09). This barrier becomes larger when more stakeholders are involved. In the public V2G and commercial V2B system design, significantly more stakeholders are involved compared to the islanded V2H system design.

A.4. F3: Knowledge diffusion through networks

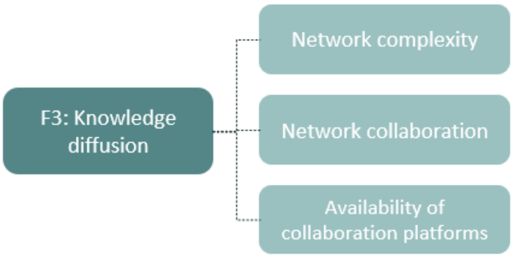


Figure A.4: Themes Illustrating Key Differences in V2X Designs Linked to Knowledge diffusion through networks

The function *knowledge diffusion through networks* refers to the process of spreading and disseminating knowledge and information within networks of actors involved in the bidirectional charging system. The identified themes, as depicted in Figure A.4, highlight the key differences observed among V2X designs in relation to knowledge diffusion through networks. The most important differences in use cases for this function could be described in three themes: network complexity, network collaboration, and availability of collaboration platforms.

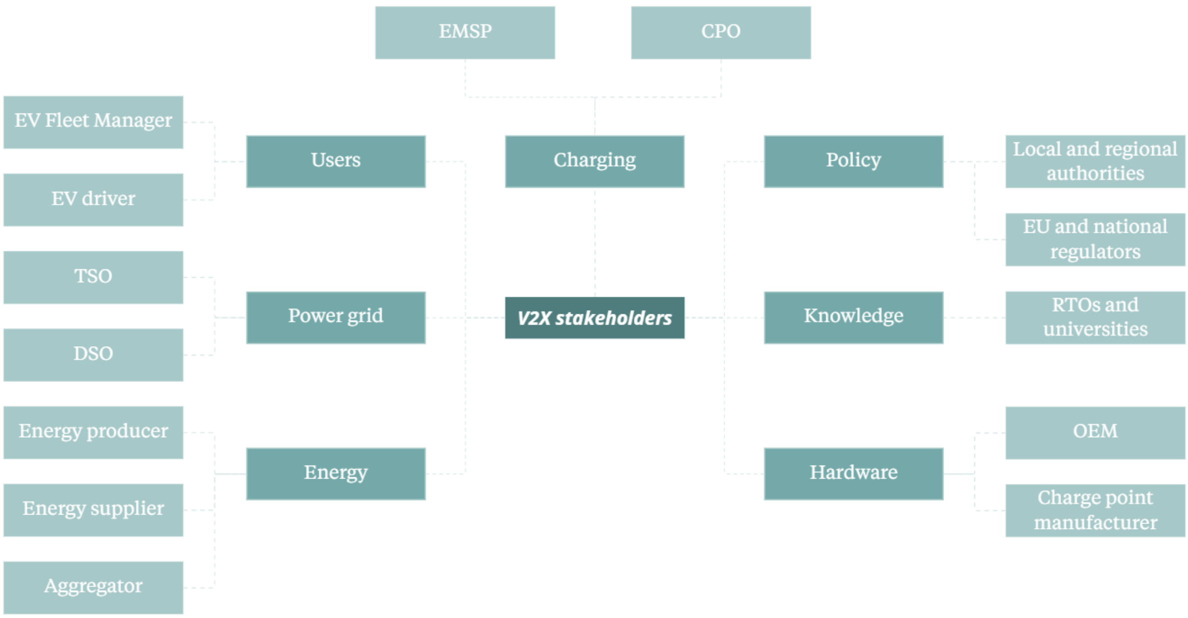


Figure A.5: Overview of involved stakeholders in a general V2X system

Network complexity refers to the number of actors involved, the diversity of their roles and relationships, and the intensity of interactions among them. Figures A.6, A.7, and A.8 visualize the flow of goods and services through the network of stakeholders for the three system designs. The arrows represent the flow of goods, information or services from one stakeholder to another. As can be seen at first instance, the flow of the public V2G system design is much more complex and extensive than that of the islanded V2H system design. The commercial V2B system design's level of network complexity falls in between the two system designs. Simplicity of the network increases when multiple roles within the stakeholder network are fulfilled by the same party. For example, the roles of the CPO, aggregator, and EV fleet manager could potentially be merged in the commercial V2B system design. Multiple stakeholders have expressed interest in the aggregator role, including the CPO and energy supplier (INT03, INT06). Also, currently, the role of EMSP and energy supplier is often fulfilled by the same party [50].

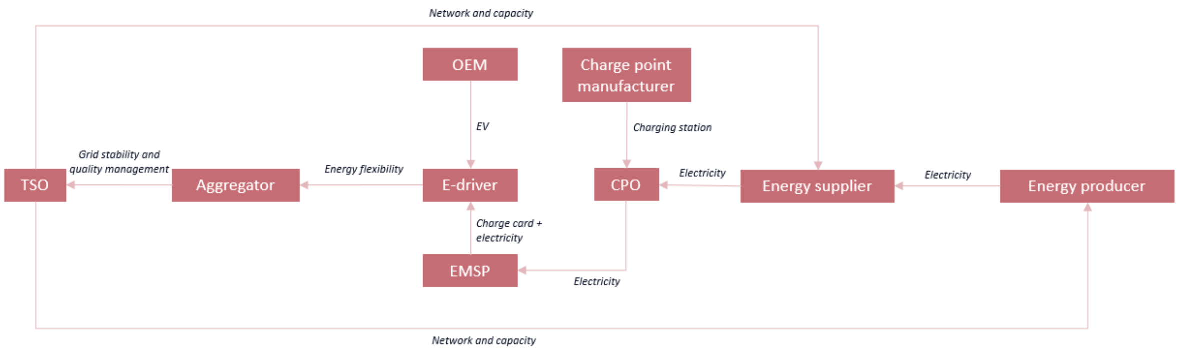


Figure A.6: Flow of goods and services of the public V2G system design

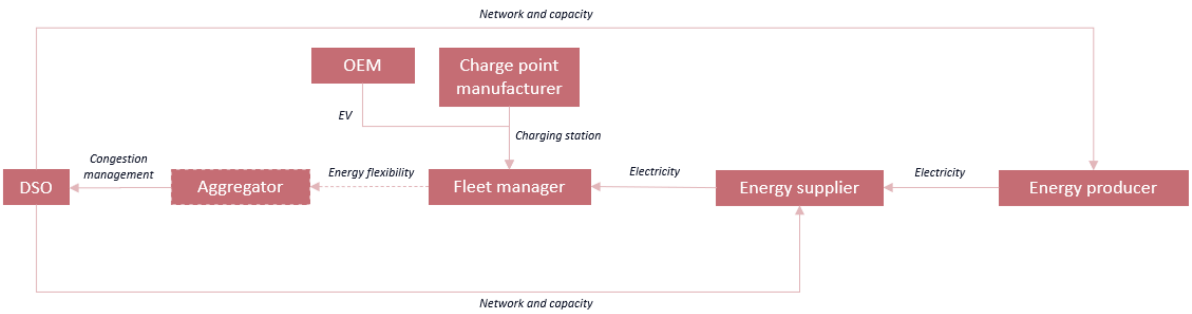


Figure A.7: Flow of goods and services of the commercial V2B system design

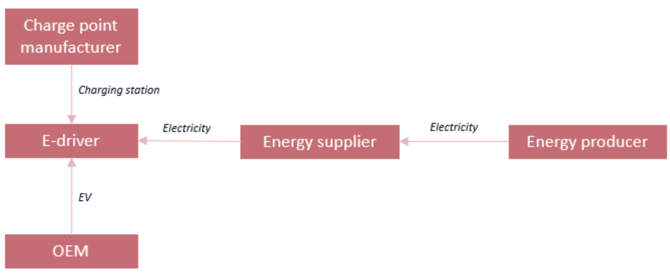


Figure A.8: Flow of goods and services of the islanded V2H system design

In a pilot project, a limited number of stakeholders are involved as only one representative from each stakeholder group is required. However, in the implementation of a large-scale system, collaboration among all potential stakeholders becomes essential. For instance, while a pilot project can be carried out in partnership with a specific OEM like Nissan, a comprehensive system on a larger scale must ensure interoperability among all OEMs that offer bidirectional models. *If you have one set of parties of each role, and they can work with each other, then you have a pilot. But eventually you want large-scale. So you want that one party with that one role to be able to be exchanged for another party in that role. It has to be interoperable –*

INT03. This issue is particularly relevant for the public V2G system design, as all possible stakeholders could be involved. All V2G-compatible EV models from all OEMs must be able to communicate successfully with all types of charging stations from all charging station manufacturers, all types of energy suppliers, and so on. Coordinating all these players makes this network quite complex. In recent years, more and more parties have become involved in the bidirectional charging innovation. In the past, only Nissan and Mitsubishi were involved as OEMs, but in recent years the involvement has broadened (INT03). However, by no means are all stakeholders ready yet to form a successful network (INT03).

The network is less complex for the islanded V2H system design. This is due to two reasons: on the one hand, there are far fewer actors involved in the design (Figure 4.17); on the other hand, it concerns only one charging station that has to work with one vehicle. If certain OEMs refuse to participate in a bidirectional system, the user can choose to purchase another EV that is able to charge bidirectionally. The same is true for the charge point manufacturer and the energy supplier. As the design does not involve feeding electricity back into the grid, the DSO and TSO are not actively involved, which further simplifies the network.

For the commercial V2B system design, the network complexity is somewhere in between. The design does not include a CPO or EMSP, as this is handled by the EV fleet manager. Even the aggregator role could be removed if the fleet is large enough to not require one. The EV fleet manager can decide which OEM and charge point manufacturer to work with, making interoperability easier to achieve. However, as the design involves feeding back to the grid, the DSO is actively involved in the system.

Network collaboration refers to the degree or extent of collaboration and cooperation among various stakeholders within a network relevant for a specific system design. For the public V2G system design, the network collaboration level is by far highest (INT05). Serious network collaborations have been formed through pilot projects such as We Drive Solar. Therefore, there are multiple parties that continuously work together, which stimulates the innovation system design. For the commercial V2B and islanded V2H system design, the collaboration networks are less far along. However, for the islanded V2H system design, there is a less extensive network necessary.

Availability of collaboration platforms refers to the presence and accessibility of platforms or mechanisms that facilitate collaboration and knowledge exchange among stakeholders within the system. This refers mostly to the dimension service provided as this service must be provided through a platform. For the public V2G system design, ancillary services are provided. To provide this service, TenneT has developed the Equigy platform, which aims at lowering the threshold for offering small-scale balancing flexibility (INT09). This platform has been launched in April 2020 [32]. It enables aggregators to seamlessly participate with smaller flexibility devices in electricity balancing markets across Europe while allowing the market to operate within grid limits. The platform's initial focus are the FCR and aFRR markets. The importance of this platform stems from the current threshold for the provision of ancillary services (INT09), which is currently 1 MW (INT04). This threshold is based on the way the grid has been balanced so far: with large generators easily reaching 1 MW. The aim of Equigy is to connect balancing markets in multiple countries in Europe.

The platform is currently in the pilot phase. The main barrier mentioned by [32] is the question whether or not TSOs will allow small-scale, unpredictable flexibility from EVs to fulfil their balancing needs in a significant way. This argument is also used by INT04. However, INT04 mentions the power of quantity: *Say we have 10 gigawatts of V2G chargers at any given time. Then, based on data models, you are able to claim to have 20% availability at any given time as the minimum requirement to participate to FCR.* With an 11kW AC charger, you will need close to a million EVs to reach 10 gigawatts. Therefore, the need for an extremely large scale implementation to achieve the sufficient guarantee is another significant barrier for the public V2G system design.

For the commercial V2B system design, congestion management services are provided. For this service, the GOPACS platform is developed by grid operators (INT03). GOPACS aims to mitigate congestion on the grid in an efficient way. The collaboration between the grid operators also prevents an action performed by one grid operator from aggravating another grid operators congestion issues. *GOPACS is a collaboration platform where parties can offer flexibility and get paid money for it by the grid operators. But I don't think it's nationwide yet. They started once with a small scale-able pilot. And they are now scaling up. It is already quite mature, but not yet available everywhere.* – INT03. The fact that the platform is not yet available everywhere is expressed somewhat more clearly by INT02: *You will find that the mechanism created to be part of the solution to congestion, namely some kind of trading platform, has not yet been made accessible at all.* The collaboration between GOPACS and the EPEX SPOT-market has only been initiated in May 2022 [35], which shows that the platform is still in its early stages of development.

For the islanded V2H system design, none of the above mentioned platforms are needed, as only small-scale energy optimization is the aim. What is relevant, is a platform that enables the shift of electricity-use to off-peak and energy-abundant hours. One well-known platform for such a service is the Stekker App. The three requirements for usage of such a platform are (1) an internet-connected vehicle, (2) a smart charger, and (3) a hourly-dynamic energy contract. Even though all these requirements are not evident, they are certainly not impossible to realize.

A.5. F4: Guidance of the search

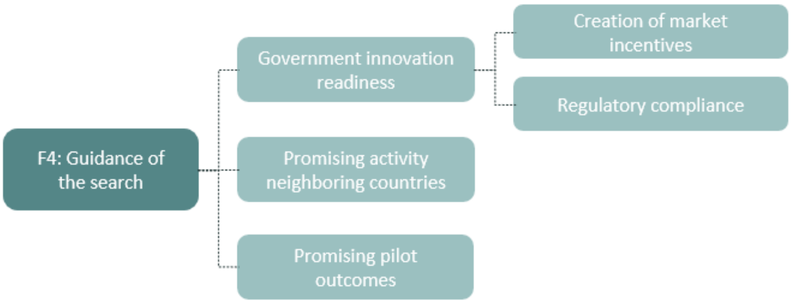


Figure A.9: Themes Illustrating Key Differences in V2X Designs Linked to Guidance of the search

The function *guidance of the search* refers to providing direction and support in the search for V2X innovations and solutions. The identified themes, as depicted in Figure A.9, highlight the key differences observed among V2X designs in relation to guidance of the search. The most important differences in use cases for this function are the promising activity of neighboring countries, promising pilot outcomes, and government innovation readiness. The latter could be subdivided into creation of market incentives, and regulatory compliance.

Creation of market incentives refers to the deliberate efforts and strategies employed to stimulate and promote market demand and adoption for the V2X innovation. For the public V2G system design, a market incentive is created through the addition of the V2G-ready requirement to public charging infrastructure tenders in multiple areas of the Netherlands (INT03, INT09). This is based on the smart charging requirements that are identified by the Nationale Agenda Laadinfrastructuur (NAL) [21]. *So for public chargers in Amsterdam, for example, a tender states that all charging stations must be V2G-ready.* – INT03. Although these requirements are currently focused on hardware requirements, and software requirements are still unclear (INT03, INT07), this will make the current bidirectional charging infrastructure, at least partly, future-proof. The same requirements have been established for the implementation of the forty-six smart charging-squares spread over nineteen municipalities in the Netherlands (INT07) [64]. Solving the uncertainty with regard to software requirements would create even more market incentive for the public V2G system design.

For the commercial V2B system design, a relevant market incentive has been created with the introduction of the energy savings obligation in 2023 [79]. This new regulation obligates companies to rapport each four years on the measures they take aiming at lowering their energy usage. *There is no monitoring of the energy savings obligation. Vehicle-to-building is obviously not an energy-saving measure, but if the government would enforce the energy savings obligation, it forces the entrepreneur to engage in energy consumption. And then the step to engage in vehicle-to-building is smaller. Right now, the entrepreneur is not engaged in energy consumption at all.* – INT04. Enforcing the energy savings obligation would be an easy step toward the creation of more market incentive for the commercial V2B system design, as the regulation is already in place. In addition, where homes in the Netherlands can rely on energy supply security through regulations [91], companies cannot rely on this. This creates an incentive for companies to rethink their back-up energy plan (INT05). This incentive will increase even more when congestion issues rise in the future.

For the islanded V2H system design, there is no active creation of market incentives to be found. This could be because of the little impact this design has on the system as a whole, rather than just the individual. In the Netherlands, the focus is on solving the current grid enforcement issues. Therefore, the public V2G and commercial V2B system design are more relevant. More on this is written under function 5: Market formation.

Regulatory compliance refers to the compliance of individuals, organizations or systems with the rules, regulations and legal requirements laid down by relevant authorities or governing bodies. *You see that in Europe we are still very little concerned with how we are actually going to shift that energy demand. So we are very much focused on the production side of energy, and not focused enough on the demand side. Also from the Dutch government, there is actually still a real lack of vision on what the role of small-scale flexibility is* – INT02. Due to this lack of vision, current laws and regulations are not made to enforce small-scale flexibility. For example, the Dutch government does not require grid operators to offer small-scale flexibility providers to provide services for them (INT02). In addition, the lack of clarity on software requirements which was mentioned earlier could be resolved through directives by the EU or Dutch government. More specifically, an obligation for all relevant stakeholders to implement the new ISO 15118-20 would be a significant regulatory step to take (INT05, INT06, INT07).

On the other hand, INT08 argues that the stakeholders themselves could better clarify this uncertainty about software requirements: *A new standard does not have to be initiated top-down by a the Dutch government or by the EU. In fact, then everyone will sit and wait. And then the EU comes up with something and it's just the wrong thing.* with regard to the public V2G system design, one important regulatory barrier is the current legislation surrounding the quality of electricity that is fed back into the grid (INT01). The deviation percentages that are allowed, are based on the idea of only one entity feeding back into the grid. With V2G, there are many more entities feeding back into the grid simultaneously, which causes the grid frequency and harmonic deviations to accumulate (INT01). The norms need to be accustomed to this situation, which is especially relevant for the public V2G system design as the grid quality could be worse for AC charging (INT04). In conclusion, the Requirements for Generators (RFG) need to be made more stringent. Secondly, the Smart Charging Requirements which were discussed to serve as guideline for public charging tenders, are not legislated (INT09). *We are unable to do so. But, of course, we really want to go there.* – INT09.

Thirdly, the state-of-charge data is currently not regulated and in hands only of the OEM. Some OEMs voluntarily share this data with their users, but not all of them do so (INT09) [45]. For changes in these laws, the Netherlands is dependent on the European Unions legislation (INT09). This is proven to be a sensitive subject for the EU, and will most probably not be handled any time soon (Global EV Charging test Symposium). This forms a barrier specifically for the public V2G system design, as its success is dependent on the market share that is interoperable with the system. For the other two designs, one could more easily choose an OEM that voluntarily shares its data.

Another regulatory barrier for the public V2G system design is the need for a verkeersbesluit, which refers to a traffic decision in the Netherlands. It is an administrative decision made by the local authorities to regulate traffic and transportation in a specific area. This is necessary by law for the placement of a public charging station. *What is somewhat in our way is perhaps much more the implemention of charging infrastructure. Because that requires verkeersbesluiten. Ultimately, placing a charging station requires a lot from a local environment. So if you can do something in your private environment, that would be a lot easier.* – INT09. The last barrier for the public V2G system design is the issue of double taxation (INT05, INT06). As the public V2G system design directly feeds back into the grid, each time charging or discharging is executed, energy tax is charged, even if the energy is not used but just transported back and forth. *If you ask We Drive Solar, can you please provide the evidence, provide the data streams, from which it emerges that there are double energy charges. Then all that is very difficult.* INT09. Therefore, it is also difficult to solve this issue, as the Dutch national government does need evidence of this issue for it to try and solve it.

With regard to the commercial V2B system design, it was stated that the laws and regulations surrounding the use of the GOPACS platform for congestion management services are not fully implemented, yet. *I imagine some of that has been figured out, but a fair amount has not yet.* – INT03. The issue of double taxation of energy is also relevant to the commercial V2B system design, as in this design energy is also (at least partially) injected into the grid for congestion management purposes.

For the islanded V2H system design, the salderingsregeling that is currently in place in the Netherlands forms the largest barrier (INT02, INT03, INT04, INT07). The 'salderingsregeling' refers to a policy in the Netherlands that allows owners of solar panel systems to offset the electricity they produce against their consumption from the grid. Under this scheme, the excess electricity generated by the solar panels is injected into the grid, and the owner receives a credit for the amount of electricity supplied. Due to this, there is no incentive for households to store their own energy supply rather than feeding it back into the grid and receiving credit for that. *The business case won't be there for V2H with a salderingsregeling, but the gap will be closed. And if the gap is closed then you get some of those crazy people like me. Who are just going to buy it. And then mass production will kick in and it will become cheaper.* – INT04. The energy supply security [91] also creates a disincentive for households to think about a back-up energy supply plan. The issue of double energy taxation does not play a role within the islanded V2H system design, as all energy transport takes place behind-the-meter. In addition, there are currently developments for a "use-it-or-lose-it" strategy for grid operators and their energy supply contracts with customers. Currently, it is only possible to offer contracts with power supply only available for a part of the day for businesses [91], but not for households. It could, however, very well be that this will change in the future.

Promising activity of neighboring countries refers to notable and noteworthy initiatives, projects, or developments taking place in countries geographically adjacent to or nearby the Netherlands. It signifies activities in the neighboring countries that show potential, promise, or success in specific areas of interest or relevance. In neighboring countries too, development is taking place in the field of V2X. *There is now another proposal from the European Commission to reform the Electricity Market Directive and that includes a request for member states to set targets on how they are going to reduce peak demand, that is, what they are going to do to ensure that people charge less during that peak* – INT02. The Dutch government has not yet processed the first Electricity Market Directive yet, which dates from 2019 (INT02). *You notice, for instance, in the recent comments on the bill, that the Council of State states that the ambition was actually too high with the bill that was submitted. They wanted to implement what Brussels wants, plus additional wishes. That was all put into one proposal and was too much.* – INT02.

Thus, it seems that the European Union is trying to move toward more appropriate rules on small-scale flexibility, but the Dutch government is currently struggling to implement these rules within its current frameworks. According to INT03, the UK has a more outspoken vision toward a bidirectional charging system compared to the Netherlands. There, the pilot projects are more focused on developing clear business cases. *If you look at the Netherlands, we are really not that far yet.* – INT09. Denmark also does a better job in this regard: *That's where they really actually have created a commercial proposition.* – INT09.

For the public V2G system design, the promising activity mostly occurs with regard to enshrining bidirectional charging in laws and regulations, as the charging takes place on public grounds. *There is quite a bit involved if you want to impose vehicle-to-grid in laws and regulations as well.* – INT09. However, it is possible. In California, all vehicles are obliged to be V2X-compatible by 2027 (INT09) [6]. Therefore, other countries have found methods for stimulating this design.

For the commercial V2B system design, France has already taken some steps, which the Netherlands could use as inspiration. *I think that's where you are going to see that here, like in France, we are going to see a requirement for solar carports over car parks. Then I think you are going to see very quickly that solar panel providers are also going to offer charging stations. And in that way build a proposition that includes both components.* — INT04. Taking inspiration from France in this regard means an additional market incentive for the commercial V2B system design. Another method for stimulating the commercial V2B system design has been found in Belgium, where they decided to focus on energy peak enforcement. This way, more money has to be paid by users of larger grid connections, which stimulates the minimization of the grid connection. So, ways have already been found in neighboring countries to encourage this design.

For the islanded V2H system design, a significant business case was confirmed in the UK with the Octopus project. *In the UK, we were able to make a business case for the end user with Octopus at the time. With a combination of a private lease car and a private charge point. If you then solemnly promised to make your vehicle available 12 times a month, for peak times, and so ended up delaying charging but allowing discharging, that resulted in a saving for the end user of č35 a month.* – INT09. In addition, the Belgian method of putting monetary value on energy peak usage could stimulate the implementation of the islanded V2H system design. *You see that happening in Belgium, where the residential customers are no longer allowed to peak above 4 kW, so they suddenly start buying batteries to stay below that peak.* – INT04. So also for this use case, ways have already been found in neighboring countries to encourage this design.

Promising pilot outcomes refers to positive and encouraging results or findings derived from pilot projects or experimental initiatives. For this, the seventeen V2X pilot projects conducted in the Netherlands were analyzed. For each of the designs, multiple relevant pilot project outcomes were found. Table A.1 shows the pilot projects relevant for each design.

Table A.1: Relevant pilot projects executed in the Netherlands for each configurational design

Public V2G	**Commercial V2B**	**Islanded V2H**
Smart Solar Charging	Hitachi, Mitsubishi and Engie	V2G @ Home
Powerparking	Flexgrid	Flexgrid
Utrecht V2G charge hubs (We Drive Solar)	Direct Solar DC V2G Hub @ Lelystad	Interflex
Newmotion V2G	Powerparking	
	City-Zen Smart City	
	Solar-powered bidirectional EV charging station	
	Amsterdam Vehicle2Grid	
	Interflex	

A.5.1. Pilot projects similar to the public V2G system design

Smart Solar Charging and Utrecht V2G charge hubs (We Drive Solar)

The bidirectional charging pilot project in the Utrecht region comprises five different pilot areas, each with its own unique characteristics and target market. Through these pilot areas, the project aims to explore the different user profiles, customer types and specific market dynamics in order to assess the feasibility and potential of bidirectional charging in different real-world scenarios. The pilot project uses a combination of bidirectional charging with car sharing and solar PV, and is a frontrunner of the We Drive Solar project in Utrecht. Both projects do well with regard to marketing, but struggle to prove themselves on paper. *We Drive Solar cannot yet charge bidirectionally at all. They say they can, but it's not happening yet* – INT03. INT04, INT07 and INT09 agree with this stand point.

Powerparking

PowerParking is an innovative concept aiming to develop (large) parking sites into integrated 'local power plants'. The pilot project has provided valuable insights over the course of 4 to 5 years. A key finding is that system emissions can be recovered and cost savings achieved within this 4 to 5 year time frame. The battery response time was found to be fast enough to support frequency response services that require the fastest response times. However, maintaining the accuracy of the response remains a challenge with an approximate deviation of 4%. The system is less efficient during the discharging phase, with energy losses ranging from 8% to 22%, compared to 0.9% to 16.5% during the charging phase [28].

Newmotion V2G

The aim of the Newmotion V2G pilot was to provide frequency control reserve (FCR) services to the transmission system operator (TSO) TenneT, using charging stations directly connected to the high-voltage grid. A significant adjustment made during the pilot was to reduce the minimum bid size from 1 MW to 100 kW. Despite the challenge most pilot participants faced in providing FCR in the regular market due to the minimum bid size requirement, TenneT and other European TSOs decided to maintain this requirement [25]. It was found that aggregators struggled to make a positive business case for volumes below 1 MW, and accepting smaller FCR bids would significantly increase costs for TenneT. The pilot also highlighted the time-consuming nature of the prequalification process for new FCR providers. In addition, discussions on centralised and decentralised frequency metering in Europe took place during the pilot, and the results contributed to the conclusion that centralised frequency metering is allowed within TSOs in Europe [89]. These results provide valuable insights for the ongoing development and implementation of FCR services, informing decision-making processes and regulatory considerations for future deployments.

With regard to the public V2G system design, multiple pilot projects have provided insights into the practical feasibility of trading EV electricity for the FCR market. Both the Newmotion V2G and PowerParking project concluded it to be feasible. The PowerParking project concluded it to be economically beneficial within 4 to 5 years. However, TSOs have decided to not reduce the minimum bid size to ease the market entrance. Also, it was concluded that the prequalification process for new FCR providers is rather time consuming. Energy losses were also a concern during pilot projects. The We Drive Solar project, which originally started as the Smart Solar Charging project has grown much over the years, which lets to believe the concept has potential. However, during the interviews, many interviewees stated the inability of the We Drive Solar project to actually feed back into the grid. Furthermore, the utilization of shared electric vehicles has been concluded to offer additional benefits in terms of Smart Charging and bidirectional charging capabilities. By leveraging reservation data from the shared vehicles, it becomes possible to anticipate when a car will be driven and when it will be available for charging. This insight enables more efficient management of charging schedules, optimizing the use of renewable energy and supporting bidirectional energy flows between the vehicles and the grid. Based on these pilot project outcomes, multiple academic researches have concluded the same [10].

A.5.2. Pilot projects similar to the commercial V2B system design

Hitachi, Mitsubishi and Engie

The project involved the installation of a bidirectional charger at the ENGIE office in Zaandam, with the aim of increasing the self-consumption of on-site solar PV generation. The primary objective was to enable the building to achieve energy neutrality. This project is a compelling example of the remarkable efficiency of energy storage technology. By using the bidirectional charger, the ENGIE office can store excess energy generated by its solar PV system in electric vehicle batteries, which can then be used to power the building during periods of high demand or when solar generation is insufficient. The integration of energy storage with renewable energy generation increases the self-sufficiency and sustainability of the building, reducing reliance on the grid and contributing to a more balanced and efficient energy ecosystem. This project demonstrates the potential of V2B technology to enable buildings to optimize their energy consumption and make significant progress toward energy neutrality.

Flexgrid

The aim of this pilot project was to develop a DC-DC charger. Connecting DC sources and storage through a DC network has several advantages, including reduced investment costs and increased efficiency [11]. The key to achieving this efficiency gain is the elimination of a conversion step, specifically the AC to DC conversion. By operating on a DC system, the connection of storage becomes more seamless and natural. Compared to similar AC systems in a home, a DC system can achieve 2-3% higher efficiency, resulting in energy savings. In addition, the overall cost of a DC system is typically lower due to the simplified design and reduced equipment required for AC/DC conversion. The use of a DC network enables a more efficient and cost-effective approach to integrating renewable energy sources and storage systems, contributing to a more sustainable and economically viable energy infrastructure.

Direct Solar DC V2G Hub @ Lelystad

This pilot project incorporates both AC and DC systems, and it concludes that the implementation of a DC-DC coupling between the solar carport and the charging points can prevent power losses [94]. The combination of DC coupling and the integration of shared electric vehicles enhances the overall performance and flexibility of the pilot project, contributing to sustainable and smart energy management practices.

Powerparking

Lessons learned from the PowerParking pilot highlight the importance of connecting the bidirectional charging infrastructure to a building, as this maximizes the potential for energy management [28]. This integration provides an additional means of control in addition to tariff settings, charging speed and battery management. The ability to offer services to the Distribution System Operator (DSO) depends on the specific location within the grid. Being connected to a heavily loaded part of the grid increases the likelihood of providing voltage support services compared to other electric vehicles (EVs) connected elsewhere. However, the adoption of vehicle-to-grid (V2G) technology faces challenges due to the limited availability of V2G components from car manufacturers and low market demand, resulting in higher capital costs, which are about five times higher than standard EV equipment.

An economic barrier is the uncertainty of revenue generation and its distribution among stakeholders. In addition, the lack of comprehensive legislation incentivizing energy storage is a constraint. Although DC technology is more suitable, it is currently associated with CHAdeMO, which is not the standard in the Netherlands [28]. In addition, there is currently no market for trading congestion management services, which is another barrier to the widespread adoption of the commercial V2B system design.

City-Zen Smart City

The City-Zen Smart City pilot conducted a small-scale commercial trial of congestion management service. Surprisingly, the acquisition of participants proved to be easier than anticipated, indicating a positive interest in the program [2]. However, the pilot encountered some technical difficulties, particularly with the reliability of the charging stations. Participants involved in car-sharing programs demonstrated a higher willingness to participate, as they were accustomed to certain usage conditions, such as being restricted to using bidirectional charging stations. Additionally, their level of concern regarding potential battery degradation was lower compared to vehicle owners, which reduced the participation threshold for them. These factors contribute to the overall understanding of the dynamics and challenges involved in implementing V2B programs in a commercial setting.

Solar-powered bidirectional EV charging station

The project focused on the integration of PV panels and electric vehicles through the design of a direct PV-EV charger. This innovative approach eliminated the need for power conversion to AC, resulting in increased overall efficiency. Through simulated case studies, the project demonstrated promising results in terms of net cost [70]. The study examined a scenario where four EVs at a workplace were connected to a single EV-PV charger. The results showed a remarkable cost reduction of 118%. When an additional charger and two additional vehicles were added, the cost reduction increased to an impressive 427%. These results highlight the potential economic benefits and cost-effectiveness of implementing a direct PV-EV V2G charging system.

Amsterdam Vehicle2Grid

The Amsterdam Vehicle2Grid project involved the installation of charging stations in people's driveways, with a focus on vehicle-to-building (V2B) applications. The study concluded that V2B has the highest potential compared to vehicle-to-home (V2H) or vehicle-to-community (V2C) applications [2]. The results obtained after two years of operation are encouraging and indicate the feasibility of scaling up the project in the city. Key findings include a significant increase in energy independence or zero-emission energy autonomy for households, with bidirectional charging contributing to the increase from 34% to 65%. There was also a significant 45% reduction in energy exchange with the grid compared to situations without bidirectional charging. The storage size efficiency reached an impressive 93% with a storage capacity of 10 kWh, suggesting that additional storage capacity provides little additional benefit. The operational energy losses in the DC batteries during storage and re-conversion when the energy is consumed were around 80%. Battery capacity loss after two years was relatively limited, around 6-7%. These results highlight the positive impact of V2B systems on energy independence, grid interaction, storage efficiency and battery performance, making them a promising solution for future deployment.

Interflex

The Interflex pilot has highlighted the importance of flexibility procurement, particularly in the early stages of market development when the value of flexibility is low and demand from DSOs is sporadic and difficult to predict. This scenario challenges aggregators' business models, making them potentially fragile, and creates a lack of liquidity in the market [43]. In addition, the current situation in the demonstration areas suggests that the conditions for establishing sustainable business models for local flexibility markets are not yet in place.

The largest number of pilots have been conducted in the Netherlands that are similar to the commercial V2B system design. Much focus has been put on direct EV-PV charging, which is by multiple pilot projects concluded to be energy efficient. Multiple pilots conclude that the connection of the bidirectional charging concept with a building is important, as it optimizes sustainable energy usage behind-the-meter. The integration of energy storage with renewable energy generation increases the self-sufficiency and sustainability of the building, reducing reliance on the grid and contributing to a more balanced and efficient energy ecosystem. The lack of a current trading market for congestion management services is mentioned to be a significant barrier, as well as the fact that DC charging is currently compatible with the CHAdeMO standards, while CCS is more popular in the Netherlands. On the other hand, finding participants for pilots turned out to be easier than expected. The PV-EV combination resulted in one study to a serious energy autonomy, and storage size efficiency increase. It was found that, as the demand from DSOs is still sporadic and difficult to predict, the business model is still rather fragile with a small market share. The combination of V2B and stationary batteries is concluded to be a worthwhile combination with regard to energy reliability.

A.5.3. Pilot projects similar to the islanded V2H system design

V2G @ Home

The V2G @ Home project focuses on open source software solutions that enable the average citizen to actively participate in bidirectional charging technology at home. By adopting this technology, users have seen significant cost savings, paying less than one cent per kilometer driven [95]. The implementation of a user-friendly interface, including a "CHARGE NOW!" button, puts the user in control of their charging and discharging activities, allowing for convenient and efficient management of their electric vehicle's energy. The pilot aims to democratize access to bidirectional charging technology, enabling users to make financial savings while contributing to a more sustainable energy system.

Flexgrid

Connecting DC sources and storage via a DC network offers several benefits, including reduced capital costs and increased efficiency. This efficiency gain is achieved by eliminating the AC to DC conversion step typically required in traditional AC systems. By using DC, the connection of storage becomes more seamless and efficient. In fact, a DC system can achieve 2-3% higher efficiency than a comparable AC system within the same home. In addition, the overall cost of a DC system is lower, making it an attractive option for integrating DC sources and storage in various applications.

Interflex

The InterFlex project has focused on achieving a seamless transition between grid-connected and islanded modes to improve resilience in specific locations such as rural areas, islands and in response to local initiatives such as Local Energy Communities. While significant progress has been made, many battery storage business models still face economic challenges. However, the cost of battery storage systems continues to fall and there are potential cost savings associated with adjusted grid connection fees and reduced tax regimes. In addition, the expected increase in price volatility in global markets creates opportunities for the development of storage systems. These factors contribute to the evolving landscape of storage technology and its potential to become more commercially viable in the future.

With regard to the islanded V2H system design, only a small number of pilots have been conducted. The PV-EV combination is also area of interest for this design, and has been concluded to be more energy efficient than a comparable AC system. The design in general was also concluded to be cost efficient, with participants paying less than one cent per driven kilometer. The Interflex project concludes that the design still struggles with economic challenges. However, these might be diminished in the future with more price volatility as a result of a higher percentage of intermittent energy sources. Also, battery innovation is expected to decrease market prices.

A.6. F5: Market formation

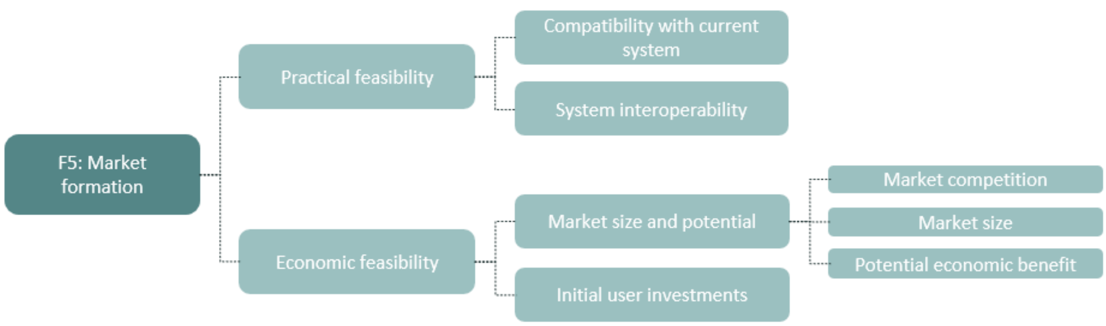


Figure A.10: Themes Illustrating Key Differences in V2X Designs Linked to Market formation

The function *market formation* refers to the process of creating and developing markets for the bidirectional charging technology and its three analyzed system designs. The identified themes, as depicted in Figure A.10, highlight the key differences observed among V2X designs in relation to market formation.

The most important differences in use cases for this function are with regard to the practical and economic feasibility. Practical feasibility could be subdivided into compatibility with the current system, and system interoperability. Economic feasibility could be subdivided into market size and potential, and initial user investments. Market size and potential in its turn could be subdivided into market competition, market size, and potential economic benefit.

Compatibility with the current system refers to the degree to which the new bidirectional charging designs align with and integrate smoothly into the existing system or infrastructure. It measures the ability of the system designs to coexist with established processes, technologies, regulations, and practices without causing significant disruptions or conflicts. As described in Paragraph A.1, the transition toward renewable energy is in full swing. The focus is slowly shifting to renewable energy sources and local energy generation. A combination of generation by rooftop solar panels and storage in EVs fits this landscape development. On the other hand, the Netherlands' present energy infrastructure was not designed for small-scale flexibility. *"It is easier to talk about ten battery systems than a million EVs"* — INT02. Therefore, a bidirectional charging system in general has compatibility issues with the current Dutch energy system.

With regard to the public V2G system design, one of the important barriers is the inability to enter the balancing market with a smaller contribution than 1 MW (INT01, INT04, INT06). As was concluded in the Newmotion V2G pilot, a lowering of the bidding threshold is not desirable due to financial and administrative reasons (see Paragraph A.5). Another issue connected to the provision of ancillary services is the inability of EVs to give the desired guarantee of available power due to their non-stationary nature (INT01, INT06). In contrast to other European TSOs, TenneTs balancing approach is of a reactive nature [89]. This means they only activate balancing products if imbalances actually occur, not in response to forecasted imbalances. This complicates it for EVs to contribute to the balancing market, as they are not guaranteed to be connected to the grid 100% of the time.

In addition, stakeholders, including CPOs, currently have little experience with dynamic pricing (INT03, INT04), which is a must for a successful public V2G system design. The current system is based on tenders with fixed prices. A more technical barrier concerns the noise caused on the grid by AC onboard chargers *Renault had a bad onboard charger that was made in a certain way that made it produce much more harmonics.* – INT01. However, INT01 states: *Renault didn't pay attention to that at the time. Purely because they just had a certain design. And, That is perfectly fixable.* INT04, on the other hand, argues that because of this, it is proven that feeding back into the grid does not successfully work with AC charging.

Lastly, the chicken-and-egg problem is often mentioned. This refers to the challenge of the simultaneous introduction of EVs capable of bidirectional charging and the availability of infrastructure to support bidirectional charging. It is a situation where the demand for bidirectional charging stations is low because there are few bidirectional EVs, and the production of bidirectional EVs is limited because there are few charging stations that support bidirectional charging. This interdependency creates a market dilemma that hinders the widespread adoption and implementation of bi-directional charging technology. This issue becomes particularly problematic in the public V2G system design, as the success and viability of public charging infrastructure depend heavily on user demand. If there are few or no EVs capable of bidirectional charging, the use of bidirectional charging stations will be low, leading to underutilization of the infrastructure. This in turn discourages investment in expanding the public charging network, making it less attractive for EV owners to adopt bidirectional vehicles. However, the public V2G system design benefits from the existing extensive AC charging infrastructure in the Netherlands. *The biggest problem is actually: there are already a lot of AC charging stations In cities. So, what are you going to do with those? Are you going to replace them all, that is a possibility. If you believe DC is more future proof. That is a huge investment. Suppose you replace only half of them, then again you have the hassle that a person has to go on his or her app to see at which charging station he or she can charge bidirectionally.* – INT01.

With regard to the commercial V2B system design, the current nationally organized energy market is a significant barrier for provision of congestion management services. *The signals from a national energy market are not necessarily the same signals as what is desirable for the grid operator at the local level. So then you can get the situation that as a user you are going to optimize on a certain price incentive which actually increases problems elsewhere In the energy system.* – INT02. Organizing the energy market locally is a must-have for a successful provision of congestion management services through EVs [12]. *But I still foresee a big problem. Suppose you start charging at work and discharging at home. What would the tax authorities think about that?* – INT04. Dynamic pricing is also currently not evident for commercial buildings (INT02).

With regard to the islanded V2H system design, less than 1% of Dutch households currently have hourly-dynamic energy prices [9]. However, there are multiple energy suppliers providing these types of contracts, which are EasyEnergy, EnergyZero, Frank Energie, Nieuwe Stroom and Tibber. Other than this, there are no significant barriers with regard to compatibility of the current system for the islanded V2H system design.

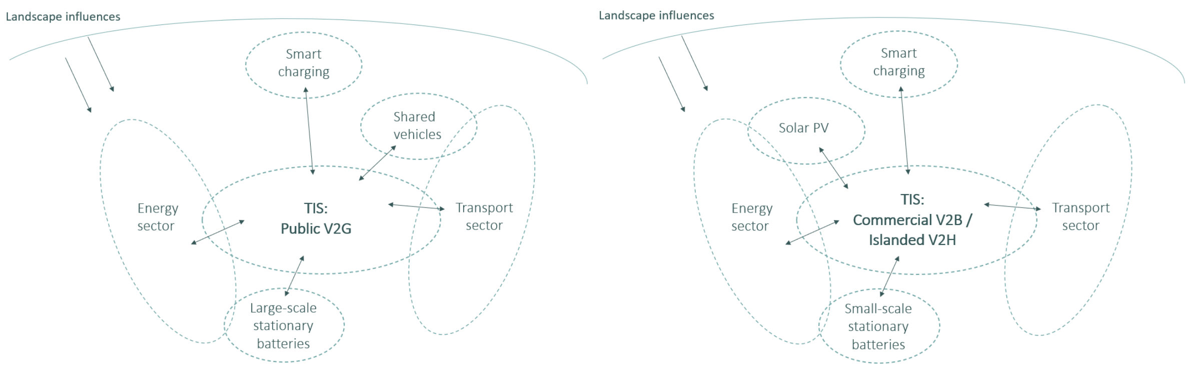
System interoperability refers to the ease or complexity of the exchange of information, data or services between different systems or actors. It examines the ability of different components or entities within the system to effectively communicate, interact and work together without encountering significant compatibility issues or constraints.

When comparing the three designs, the public V2G system design has most system interoperability issues. This is due to the large number of potential combinations of customers and suppliers. *Because those 1,000 separate vehicles might have 1,000 different drivers with different requirements.* – INT02. *I think it is easier with the commercial V2B and islanded V2H system design, that you can make arrangements with your company, or at home. You can communicate more clearly with the charging station. For example: it is fine whatever you do tonight, as long as I can drive 100 kilometers tomorrow. With the public V2G system design, that is a lot more difficult.* – INT04. When OEMs decide to place an onboard charger in the vehicle, they are compatible with both AC and DC bidirectional charging (INT03). However, when they decide to choose the DC route, without onboard charger, these vehicles are not interoperable with public AC charging stations.

Lastly, issues with the implementation of the ISO15118-20 protocol in charging stations and vehicles form a significant barrier, especially for the public V2G system design (INT06, INT07, INT08). *It is still too vague how the protocol must be implemented, which results in different implementations among parties. The protocol leaves space for interpretation, which does not help.* – INT06. As there are many more parties potentially involved in the public V2G system, the differences between ISO implementations are a serious issue. Many parties have not even implemented this protocol at all, yet (INT06), which forms a barrier for all three designs. In conclusion, the need for an integrated solution is greatest in the public V2G system design.

With regard to the islanded V2H system design, an integrated system is a more feasible solution. *You see the same thing happening with solar panels now. People buy a solar panel inverter that can hold a battery. Then indirectly they have already picked the battery that can cope with this inverter. Because there is a vendor-lock in that. But people love that. At least, for now, they think so.* – INT04.

Market competition refers to the degree of rivalry and competitive dynamics within the bidirectional charging market. The competitive and complementary innovations of the three system designs are visualized in Figures A.11a and A.11b, highlighting their distinct characteristics. The analysis reveals that the relevance of different complementary and competitive innovations varies depending on the specific use cases. Notably, smart charging emerges as a crucial complementary innovation across all designs, serving as a transitional step towards bidirectional charging (INT01, INT02, INT05).



(a) Public V2G system design **(b)** Commercial V2B and Islanded V2H system design

Figure A.11: Relevant adjacent innovations of the V2X system designs

With regard to the public V2G system design, shared vehicles have been found to be a relevant complementary innovation from the transport sector [2] (see also Paragraph A.2). On the other hand, the current system leans toward a more centrally organized energy management. For example, market-entering conditions are easier for ten large-scale stationary batteries compared to one million EVs (INT02). There are fewer parties involved and those parties often already have access to the market, which simplifies implementation. INT02 argues that multiple kinds of research have concluded that small-scale, decentralized flexibility is better compared to large-scale, centralized flexibility. Besides, *the advantage of those 1,000 cars over ten huge battery storage units, is the marginal cost. For those 1,000 cars, the marginal cost of using them to provide additional services to the power system is very small. You bought that car primarily to drive it. So you no longer have to include that battery cost for the energy system, whereas, of course, a stationary battery storage does. That requires substantial investment.* – INT02. However, there are still developments occurring in the field of large-scale batteries. CE Delft concluded in their research on the business case of large-scale batteries that they have great potential for ancillary services [14]. They have less potential when it comes to congestion management due to their centralized and stationary position. Therefore, large-scale batteries do not form a competition in the commercial V2B system design.

With regard to the commercial V2B system design and islanded V2H system design, small-scale batteries are seen as the most relevant competitive innovation (INT04, INT05, INT07). *I think that for the commercial V2B system design, by far the most demand is present for small-scale stationary batteries.* – INT07. Small-scale stationary batteries have the benefit that they are able to provide electricity always, as they are never disconnected from the grid. However, in the commercial V2B system design, small-scale stationary batteries could also act as a complementary innovation (INT04, INT07). *I think stationary batteries and vehicle-to-building can complement each other very well. Because with that stationary battery, you can always keep some kind of backup. That you always have that full energy guarantee still.* – INT07. This is because the behind-the-meter optimization of energy use can then be carried out even better. The stationary battery then serves as a backup when vehicles are unavailable or their batteries are empty. The same goes for the islanded V2H system design, but because the energy usage is relatively lower for a household, the need for an additional stationary battery is lower. An average household needs around 8 kWh per day [96], while even the smallest EV models currently have a battery capacity of around 40 kWh. A benefit of EVs compared to stationary batteries is the scarcity of battery materials. Therefore, EVs are more favorable for circularity and cost efficiency (INT05).

Another relevant complementary innovation, for both the commercial V2B and the islanded V2H system design, is solar PV. Solar charging is a well-known concept in the industry, and is especially relevant for visitor locations like office buildings (INT04, INT07). The combination of solar PV panels and DC charging is logical, as solar PV panels produce direct current, which could then directly be stored in the EV battery, without any conversion (INT01, INT04). Thus, owning solar panels increases the incentive to participate in a bidirectional charging system. The incentive to implement the islanded V2H system design without solar panels drops significantly, as there is no local energy to store.

Market size refers to the total value or volume of the bidirectional charging market, indicating the scale and potential of economic activity within that market. Both the supply side and demand side are analyzed. For the demand side, the balancing and congestion management markets are investigated. While the FCR market has a volume of only 130 MW, the day-ahead market has a volume of 4000 to 5000 MW (INT01). This means that the market for ancillary services will potentially saturate in the coming five years (INT01, INT05) [34]. On the supply side, the market size depends on the amount of users that are able to implement a design.

Concerning the supply side of the market, INT03 argues that the largest number of charging stations is located at homes in the Netherlands, while INT08 argues that the largest number is located on public grounds. There is no exact data available on this. INT04 argues that the occupancy rate of public charging stations is much higher, which increases market size for the public V2G system design. *70% of homeowners is not able to charge at home* – INT04. *In Utrecht, I believe 25-30% of the houses in the city have solar panels on the roof. And these are houses that do not have their own driveway.* – INT08. Duurkoop et al. [18] concluded that by 2030 only 25% of homes in the Netherlands has the ability to charge on private grounds at home [18]. With the number of homes in the Netherlands being around 8 million, this means a number of 2 million homes being able to charge on private ground in 2030. Thus, the market for the islanded V2H system design is limited, while the market for the public V2G system design is much larger. Little data is known about the supply market size of the commercial V2B system design, but considering that only a small percentage of office buildings have their own parking facility, the market size for this design is regarded also limited.

Potential economic benefit refers to the total value or volume of the bidirectional charging market, indicating the scale and potential of economic activity within that market. There are two conflicting dynamics influencing the potential economic benefit of a bidirectional charging system. On the one hand, the transition toward more intermittent energy sources results in more fluctuating energy prices, which results in more potential economic benefit. *Last year was a bit crazy with electricity prices with huge peaks and dips. So then you can make plenty of money even in the day-ahead market. But for that to happen, the energy transition has to be further along to go to a more dynamic system with bigger peaks and dips. And then you are able to make enough money.* – INT03. On the other hand, as more vehicles provide energy from their batteries, the economic compensation becomes smaller. *When 1 million vehicles join the bidirectional system, prices are going to drop tremendously.* – INT01. these two developments make it difficult to predict the economic gains to be made by different designs.

With regard to the public V2G system design, the potential economic benefit must be distributed over a large number of involved parties. However, while the market for ancillary services is concluded to be the smallest, the potential revenue for this market is argued to be the highest (INT01, INT08).

The congestion management services in the commercial V2B system design are more predictable, but ensure less potential revenue. However, it is argued that the commercial V2B system design will be economically beneficial automatically when grid operators stop handing out new or larger grid connections due to capacity issues on the grid (INT04). INT07 argues that the reduction of the grid connection is currently the most proven business model, as you are able to reduce energy costs significantly. Also, V2B has more economic potential due to its ability to scale the system to dozens of vehicles, while for the islanded V2H system design, the economic benefit must come from only one vehicle (INT04).

For the islanded V2H system design, it is currently economically more beneficial to feed additional energy retrieved from solar PV panels back into the grid, and buy additional energy back when needed. This is due to the so-called salderingsregeling (INT03, INT04, INT06, INT07, INT09). This is a policy mechanism that allows electricity consumers with solar panels or other renewable energy sources to offset their electricity consumption by exporting excess energy to the grid and receiving credits for the excess electricity supplied. *Suppose you have solar panels on your house and you have a surplus of electricity. Then it is very often cheaper to give that back to the grid and then buy it back at a later time, when you are short of energy. Transporting and trading is currently much cheaper than storing energy.* – INT01. However, once this barrier is conquered, the economic benefits need to be distributed among far fewer parties compared to the public V2G system design, which results in relatively more economic benefit for each party.

Initial user investments refer to the relative financial resources allocated to cover the costs associated with the participation in a specific design. While a simple AC unidirectional charging station could easily be under €500,-, a simple low-power bidirectional DC charger quickly costs over €6.000. *The cost of DC chargers is a serious barrier. Costs have already come down considerably, but they need to come down even further. You need even more scale to achieve a sound business case.* – INT03. The initial investments for the commercial V2B and islanded V2H system design, thus, are significantly higher with regard to the charging infrastructure. For the islanded V2H system design it is especially significant, because of their limited scale of deployment. In contrast, a company in the commercial V2B system design can spread the cost over multiple chargers and potentially benefit from economies of scale, making the investment more cost-effective.

Even if the initial investments could be made, the important question is at which time these investments could be earned back. *If a charger or 3000 euro extra costs, and suppose you want to earn this back within 10 years. Then you need to earn over 300 euros a year. that's not evident at the current time.* – INT03. Just like INT03, INT04 argues that the costs for DC chargers will drop soon. *DC as a charge topology currently suffers mainly from the price of the charger. And of course that does go down hard, because so much is being built and then you get industrialization and so it gets cheaper.* – INT04. INT07 also argues that DC will play a larger role in society in the future, also in the form of DC power grids.

The system designs also differ in the stakeholders that make the investments. Figures A.6, A.7, and A.8 show this. In the public V2G system design, the charging infrastructure investments are made by the CPO, while the vehicle investments are made by the e-driver. In the commercial V2B system design, both investments are made by the EV fleet manager. In the islanded V2H system design, both investments are made by the e-driver.

A.7. F6: Resource mobilization

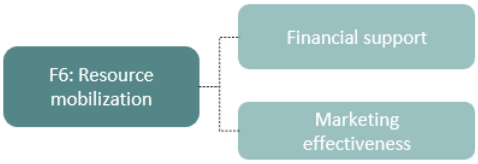


Figure A.12: Themes Illustrating Key Differences in V2X Designs Linked to Resource mobilization

The function *resource mobilization* refers to the process of acquiring and deploying the necessary resources to support the development and diffusion of the bidirectional charging innovation. This includes securing the financial, human, technological and organizational resources that are critical to the successful implementation and advancement of V2X. The identified themes, as depicted in Figure A.12, highlight the key differences observed among V2X designs in relation to resource mobilization. The most important differences in use cases for this function are with regard to the financial support that is offered, and the marketing effectiveness of the use case.

Financial support refers to the provision of financial assistance, incentives or subsidies by governments, organizations or stakeholders to promote and facilitate the adoption and implementation of a particular technology or initiative. Nine out of seventeen pilot projects that have been executed in the Netherlands were supported by a subsidy. These were either the European Region Development Fund (six pilots), the Interreg subsidy Vlaanderen-Nederland (one pilot), the Horizon 2020 program (two pilots), or subsidy by the Dutch government (one pilot).

Table A.2: Subsidized Dutch pilot projects and their associated configurational designs

	Subsidy received	**Associated system design**
V2G @ Home / V2G Liberty	European Region Development Fund	Islanded V2H
Smart Solar Charging	European Region Development Fund	Public V2G
Powerparking	European Region Development Fund	Public V2G Commercial V2B
V2G/V2B at the Johan Cruijff ArenA	European Region Development Fund	Commercial V2B
Share the Sun/Deeldezon	European Region Development Fund Interreg subsidy Vlaanderen-Nederland	-
Utrecht V2G charge hubs	Subsidy by Ministry of I&W	Public V2G
AirQon	European Region Development Fund	-
Interflex	Horizon 2020 Program	Commercial V2B Islanded V2H
Invade	Horizon 2020 Program	Public V2G

Table A.2 shows the variety of pilots that are subsidized, there is no clear preference for use cases with regard to financial support. Another type of subsidy given by the Dutch government, was the subsidy for smart charging living labs. *in December 2019, Stientje van Veldhoven, the state secretary at the time, said, we need to start experimenting with living labs, smart charging squares. And there are nineteen municipalities that have received the grant for that and have delivered forty-six of those living labs, some of which are also vehicle-to-grid. So that includes Utrecht, but it also includes, for example, Culemborg and Lelystad* – INT09. Out of forty-six living labs, only three included bidirectional charging. Most of the financial support then went toward the development of unidirectional smart charging. However, these developments could also support the bidirectional system eventually. For example, subsidies were also given out for the development of software that manages smart charging. *Stekkerapp was a funded project and developed a solution to apply smart charging. And eventually that can also be applied for bidirectional charging.* – INT07.

You do see that, especially in the DC world, the government did contribute with development subsidies. – INT04. However, not all subsidies are beneficial, according to INT04 and INT09. *The question is whether* *they should continue to give subsidies. I always think they shouldn't. Everything that involves subsidy breaks down once the subsidy ends. So instead, let them make sure that incentives arise. That the market develops itself. They should make sure the ACM gets to work on network tariffs.* – INT04. *You also have to be careful now if you're going to subsidize it, that mass production gets up and running too fast. And that you also get junk on the market. So that everything will soon come from China.* – INT04. *Subsidy money should be much more in sharing knowledge and information than offsetting other things. We are about to gain that insight.* – INT09. INT07, on the other hand, argues that currently there is not much financial support directed toward this development. *I think that if you want to do it right, the financial support could be more. Because it is simply very important.* – INT07.

Marketing effectiveness refers to the extent to which a marketing strategy and its associated activities successfully accomplish their intended goals and objectives. One thing that was mentioned by both INT03 and INT05 was the visit of the King to the opening of the We Drive Solar project. They argue that this symbolizes perfectly the amount of marketing for the public V2G system design. *You notice the commercial side of it a lot. So everyone always wants to act like they have it all and like it's all going well. And it sounds like it's all up and running. But there's nothing there yet.* – INT05. *There is a lot of chit-chatting about it. And nice partnerships are being made. The concept is nice, but for now it really sticks to marketing.* – INT09. The commercial V2B and islanded V2H system design, however, do not reach much marketing effectiveness. Very little is spoken about these designs with this regard. For the V2H system design, this is argued due to the irrelevance of the design for the Dutch context. *In the Netherlands, we have little to do with electricity black-outs, especially compared to the US.* – INT01.

A.8. F7: Creation of legitimacy

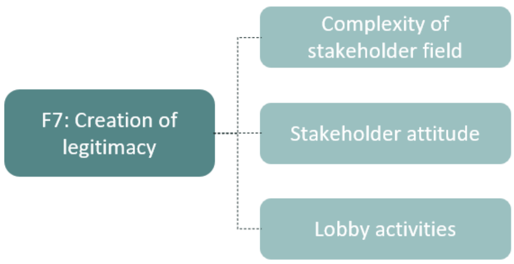


Figure A.13: Themes Illustrating Key Differences in V2X Designs Linked to Creation of legitimacy

The function *creation of legitimacy* refers to the process of establishing and maintaining credibility, acceptance, and support for the V2X innovation. The identified themes, as depicted in Figure A.13, highlight the key differences observed among V2X designs in relation to creation of legitimacy. The most important differences in use cases for this function involve the complexity of the stakeholder field, the attitude of involved stakeholders, and lobby activities.

Lobby activities refer to the strategic efforts made by individuals or groups to influence decision-making processes and policies in order to advance their interests or advocate for specific outcomes. Lobby activities play a prominent role in the public V2G system design, primarily due to the well-established networks within this context. An excellent example of such networks is the We Drive Solar collaborations. This collaboration has facilitated the formation of strong lobbying efforts, aimed at advocating for the implementation and advancement of the public V2G system design. However, in the case of the commercial V2B and islanded V2H system designs, there is currently limited active lobbying. This can be attributed to the relatively early stages of development and fewer established networks within these specific contexts.

Complexity of the stakeholder field refers to the degree of intricacy and diversity in the composition and interactions of stakeholders involved in the context of the various designs, including their various interests, roles, relationships, and dynamics. This is analyzed through the development of a power-interest grid with the aim of creating insight into the most important stakeholder within a specific use case [1]. Four quadrants are formed in which stakeholders are placed. For each quadrant, an alternative management strategy is proposed [1]. The alternatives for strategies are: manage closely, keep satisfied, keep informed, and solely monitor.

Stakeholder attitude refers to the perceptions, beliefs, opinions, and overall disposition of stakeholders toward a particular design. Only stakeholders identified as having significant power in the power-interest grid are assessed for their attitude, examining reasons why they may be either supportive or resistant toward a specific design. Both themes are discussed for each design respectively.

A.8.1. Stakeholder field in the public V2G system design

Figure 4.13 visualizes the stakeholders that are directly involved in the public V2G system design. This is the most extensive list of stakeholders, compared to the commercial V2B system design (Figure 4.15) and the islanded V2H system design (Figure 4.17). These stakeholder are placed in the power-interest grid, which is shown in Figure 4.14. For each stakeholder, their position is shortly explained.

E-driver

The e-driver is placed in the quadrant for stakeholders with both high power and interest. E-drivers, have the authority to provide the battery of their EV as a flexible energy source. Driving range uncertainty and battery health concerns (INT09) have been identified as two major obstacles for EV drivers [55]. On the other hand, e-drivers could see their participation in a public V2G system design as an additional economic opportunity.

Energy supplier

The energy supplier is placed in the quadrant for stakeholders with little power, but high interest. An energy supplier is in support of the public V2G system design since it makes it possible for them to sell more electricity and, as a result, increase earnings. As the system does not function without dynamic pricing, energy suppliers seem to have some level of power. However, this power is mostly regulated by governmental bodies, leaving them with limited power to control the implementation of the design. Energy suppliers are interested in broadening their field of business by facilitating an integrated energy management system.

Energy producer

The energy producer is placed in the quadrant for stakeholders with both little power and interest. This stakeholder is not mentioned in the extensive stakeholder analysis by pilot project SCALE [55]. An energy producer is in support of the public V2G system design since it receives a financial compensation for energy delivery, even in times when there is a surplus of energy supply. They are not involved further, thus their interest is limited. Their power is rather limited as well.

OEM

The OEM is placed in the quadrant for stakeholders with both high power and interest. The OEM is required to make significant additional investments for the EVs compatibility with the system, as the design uses AC charging. *And those OEMs are not pleased with that at all.* – INT06. This means EV models must have an onboard charger, which adds about 10% of costs for the OEM (INT04). As interoperability plays an important role in this design, it is important that most of the OEMs comply with the need for an onboard charger. Currently, charging data like the state-of-charge is in the hands of the OEMs. They do not have to share this with other stakeholders, which makes them a powerful player as this data is essential for an optimal use of the public V2G system design. They also have a high interest, as the bidirectional charging impacts their battery significantly, for which they give out warranty to their customers.

Charge point manufacturer

The charge point manufacturer is placed in the quadrant for stakeholders with high power, and limited interest. Their role is similar to that of the OEM, but focused on the charging infrastructure rather than the vehicle. Charge point manufacturers must provide bidirectional charging compatibility within their charging stations in order for this system to be feasible. As the conversion is handled within the vehicle, there are little additional investments needed to the charging station. However, as there are currently no AC bidirectional chargers on the market yet, development investments are required to make them market-ready.

Local and regional authorities

The local and regional authorities are placed in the quadrant for stakeholders with both high power and interest. A bidirectional charging system could aid at reaching the set climate goals, which is of the local authorities interest. They are also highly engaged since the charging infrastructure for this design is based on public property. *What is somewhat in our way is the implementation of charging infrastructure. Because that requires traffic decisions (in Dutch: verkeersbesluiten). Ultimately placing a charging station requires so much from a local area.* – INT09. Traffic decisions refer to official administrative decisions made by local authorities regarding traffic regulations and measures. The municipalities' involvement is relevant for this design since they are necessary for the distribution of traffic decisions. However, as the public infrastructure in the Netherlands is already quite extensive with currently over 128.000 (semi-)public charging stations in the country [78], it is likely that the bidirectional system will use existing charging stations that have already been through the traffic decision process.

EU and national regulators

The EU and national regulators are placed in the quadrant for stakeholders with high power but limited interest. A bidirectional charging system could aid at reaching the set climate goals, which is of the local authorities interest. The EU and national governmental bodies have more interest in this design compared to designs that are implemented on private property. However, the government does not seem to be actively involved. However, this design actively helps solving grid balancing issues, which forms a societal issue currently. *The government should have high interest in the concept, but I think they do not understand it enough for that.* – INT05. This could be due to the competing alternatives, such as large-scale stationary batteries. The national regulators also invest time and money in the development of this innovation ([14]) . Whereas this is not an option for congestion management services, this does indeed provide a solid solution for grid balancing issues. Their power is significant. Through laws and regulations, they are able to incentivize key stakeholders in the system to cooperate and participate.

DSO

The DSO is placed in the quadrant for stakeholders with both little interest and power. The DSO is responsible for providing the grid connection for bidirectional charging. However, as the public infrastructure in the Netherlands is already quite extensive with currently over 128.000 (semi-)public charging stations in the country [78], it is likely that the bidirectional system will make use of the existing charging stations. Therefore, their power is limited. Their interest is also limited as the public V2G system design solely provides ancillary services which are directed toward the TSO.

TSO

The TSO is placed in the quadrant for stakeholders with both high interest and power. The TSO has the authority to manage and control the transmission grid. For the transmission grid, ancillary services are relevant. Therefore, the TSOs interest in this design is significant. Their power is also considerable as they have decisive power over the parties able to enter the FCR and aFRR balancing markets. INT01 argues that TenneT will probably make their requirements for entering these markets more flexible. *Then TenneT will say: you don't have to meet some requirements, because we also see that this will be the future.* – INT01. As the TSO has the responsibility to manage the balancing of the grid at 50 Hertz, their interest in the public V2G system design with provision of ancillary services is significant. However, the TSOs issue with a bidirectional charging system as a solution for grid balancing issues, is that there is never a full guarantee of access to the electricity. Also, the standards and protocols are not in place yet, as the market for small-scale flexibility with respect to ancillary services is still underdeveloped.

Aggregator

The aggregator is placed in the quadrant for stakeholders with both high interest and power. The public V2G system design requires an aggregator to bundle all energy of participating vehicles. Without aggregator, the fleets electricity could not be offered for congestion management services to the grid due to current minimum bid regulations. Therefore, the aggregators power is high. Its interest is also high, as the aggregators sole purpose is to be an intermediary between the seller and buyer of flexibility.

EMSP

The EMSP is placed in the quadrant for stakeholders with high interest, but low power. The administration and coordination of the bidirectional charging infrastructure, including services like scheduling, billing, and monitoring, are facilitated by the EMSP. EMSPs are interested in broadening their field of business by facilitating an integrated energy management system. The EMSP sees an additional economic opportunity in managing the energy system. Therefore, their interest in the system is significant. However, their power is limited as they are not authorized to control the implementation of the design. *There are lots of other things we want to do. So it's just not at the front of the queue of what we think is most important.* – INT06.

CPO

The CPO is placed in the quadrant for stakeholder with high interest, but low power. Charge pricing is currently regulated through tenders, which means that CPOs do not have much power over the transition toward dynamic pricing. They are the party that should eventually implement these dynamic prices once tenders allow this. The standardization of local government tendering procedures will provide CPOs clarity on what is expected of them in terms of dynamic pricing models, smart charging, and V2G readiness [55]. The CPOs interest is also rooted in the potential for broadening their field of business by facilitating an integrated energy management system. They have a positive attitude toward bidirectional charging as it provides them with cleaner and cheaper electricity that they could trade with (INT03).

A.8.2. Stakeholder field in the commercial V2B system design

Figure 4.15 visualizes the stakeholders that are directly involved in the commercial V2B system design. These stakeholder are placed in the power-interest grid, which is shown in Figure 4.16. For each stakeholder, their position is shortly explained.

E-driver

The e-driver is placed in the quadrant for stakeholders with high power, but limited interest. The limited interest is due to the lack of economic incentive for the e-driver, as all economic benefit is directed to the EV fleet manager. An interest they do have is the fact that they are asked to give up battery usage control for the sake of the system, which is unfavorable for them (INT09). They do have a reasonable level of power, as are the ones actually having to cooperate and participate in the system. However, as their vehicle is not owned by them, their abilities to be uncooperative are limited.

Energy supplier

The energy supplier is placed in the quadrant for stakeholder with both high power and interest. An energy supplier is in support of the commercial V2B system design since it makes it possible for them to sell more electricity and, as a result, increase earnings. An interesting possibility for suppliers is the use of dynamic pricing for EV charging, which has been made possible by European laws like the Electricity Market Directive of 2019. [26]. As the system does not function without dynamic pricing, energy suppliers have some level of power. Energy suppliers are interested in broadening their field of business by facilitating an integrated energy management system.

Energy producer

The energy producer is placed in the quadrant for stakeholders with both little power and interest. An energy producer is in support of the commercial V2B architecture since it receives a financial compensation for energy delivery, even in times when there is a surplus of energy supply. They are not involved further, thus their interest is limited. Their power is rather limited as well.

OEM

The OEM is placed in the quadrant with both high power and interest. The OEM is required to make limited additional investments for the EVs compatibility with the system, as the design uses DC charging (INT01). This means that there is no onboard-charger needed, instead the vehicle only needs to be compatible with bidirectional electricity flows. For the rollout of this design, there only needs to be one eligible model to be satisfactory, as an EV fleet manager could choose a specific vehicle for bidirectional charging and interoperability little to no issue in this design. Currently, charging data like the state-of-charge is in the hands of the OEMs. They do not have to share this with other stakeholders, which makes them a powerful player as this data is essential for an optimal use of the commercial V2B system design. Through market competition among OEMs, they do not have much power within this design. They do have a high interest, as the bidirectional charging impacts their battery significantly, for which they give out warranty to their customers. Their economic potential for big businesses looking to invest in a bidirectional EV fleet and have a lot of spending power is another reason for a big interest in the system.

Charge point manufacturer

The charge point manufacturer is placed in the quadrant with limited power, but high interest. Their role is similar to that of the OEM, but focused on the charging infrastructure rather than the vehicle. Charge point manufacturers must provide bidirectional charging compatibility within their charging stations in order for this system to be feasible. As charge point manufacturers often sell a variety of DC products (e.g. solar PV panels), a DC bidirectional charger is a relatively easy extension to their product range. There are already DC charging stations available on the Dutch market. In this design, there only needs to be one eligible charging station to be satisfactory, as an EV fleet manager will probably choose one specific charging station for bidirectional charging. Therefore, charge point manufacturers do not have much power within this design. Just like the OEM, they have an interest in attracting big business with a lot of spending power looking to invest in a bidirectional EV fleet.

Local and regional authorities

The local and regional authorities are placed in the quadrant with limited interest, but high power. The local and regional authorities are placed in the quadrant with little power, but high interest. They have little influence on the outcomes of the implementation, as it all occurs on private property. They do have some interest in the system, as it actively helps to solve congestion issues, which are typically regional. Also, a bidirectional charging system could aid at reaching the set climate goals, which is of the local authorities interest.

EU and national regulators

The EU and national regulators are placed in the quadrant with high power but limited interest. The EU and national governmental bodies have limited interest over this design, as it is implemented on private grounds. However, this design actively helps solving congestion management issues, which forms a societal issue currently. *The government should have high interest in the concept, but I think they do not understand it enough for that.* – INT05. A bidirectional charging system could aid at reaching the set climate goals, which is of the EU and national regulators interest. Their power, however, is significant. Through laws and regulations, they are able to incentivize key stakeholders in the system to cooperate and participate.

EV fleet manager

The EV fleet manager is placed in the quadrant with both high power and interest. The EV fleet manager has the authority to direct and coordinate the fleet's charging and discharging activities. The EV fleet manager has an interest in opening up potential income streams by taking part in congestion management services and behind-the-meter energy optimization by carefully managing the V2B system. Another interest lies in postponing the need for a larger grid connection, which takes extremely long currently, and is expected to become even more difficult in the future with increasing grid congestion issues (INT01). *Businesses already have a market that is somewhat more interested in optimizing energy use. You can clearly observe that there are service providers who assist in reducing their energy usage.* – INT02.

DSO

The DSO is placed in the quadrant with both high power and interest. The DSO has the authority to manage and control the distribution grid. Therefore, they also have the authority to manage parties entering the congestion management market. As the DSO has the responsibility to manage congestion on the grid, their interest in the commercial V2B system design is very high. *DSOs could use some help with their congestion management.* – INT03. DSOs have historically been prohibited from actively participating in the electrical market because to the high levels of regulation placed upon them as a result of their natural monopoly position. DSOs are now permitted and encouraged to purchase flexible assets in accordance with the EU legislation included in the Clean Energy Package in order to preserve system security [55]. They have the power to develop the flexibility markets, as they are currently at a relatively lower stage of development compared to the frequency balancing markets [55] The DSO could have an unfavorable attitude toward the design as the characteristics of the design do not allow for 100% guarantee of access. However, it could take some time to implement new technical standards, protocols, and communication interfaces between the grid, charging infrastructure, and EVs during the implemention of a commercial V2B system design. For example, clear congestion management schemes are not yet clarified by the government [55].

Aggregator

The aggregator is placed in the quadrant with both high power and interest. Not all commercial V2B system designs require an aggregator. The company's EV fleet manager can act as its own aggregator if the fleet is large enough by itself. Assuming most EV fleets are not large enough, the aggregator is an essential party for the implementation of the commercial V2B system design. Without aggregator, the fleets electricity could not be offered for congestion management services to the grid due to current minimum bid regulations. Therefore, the aggregators power is high. Its interest is also high, as the aggregators sole purpose is to be an intermediary between the seller and buyer of flexibility.

A.8.3. Stakeholder field in the islanded V2H system design

Figure 4.17 visualizes the stakeholders that are directly involved in the islanded V2H system design. Compared to the public V2G and commercial V2B system design, there is a significantly lower number of stakeholders involved. These stakeholder are placed in the power-interest grid, which is shown in Figure 4.18. For each stakeholder, their position is shortly explained.

E-driver

The e-driver is placed in the most important quadrant for stakeholders with both high power and interest. The e-driver can decide when and how to use the vehicle's energy for domestic purposes. As the users of a bidirectional charging system will currently fall within the early adopters category, it is logical to assume they would want to implement this at their own private property (INT01). *People who are already doing this are the early adaptors and they prefer to do it at home in their own driveway.* – INT01. They also have the power to decide whether to implement the islanded V2H system design at all. An e-driver's interest lies in the desire to optimize their own energy consumption, reduce electricity costs and/or increase energy independence. Sustainability could also be a driver for interest in the islanded V2H system design. A barrier for the e-driver could be the uncertainty on battery degradation effects (INT09). In contrast to other designs, the e-driver in the islanded V2H system design still has a fair amount of control over battery utilization. As a result, compared to the other systems, concern over the battery's condition is less of a barrier. Another barrier could be the upfront investments needed for the implementation of the system.

Energy supplier

The energy supplier is placed in the most important quadrant for stakeholders with both high power and interest. As a user becomes more capable of satisfying their own energy demands, an energy supplier's power may be reduced. However, as it is unlikely that the user would be completely energy independent, the energy provider still has the role and power to offer extra energy services or support. Their interest lies in maintaining a positive relationship with their customers, for example by offering services that allow users to implement the islanded-V2H system design. The islanded V2H-designs asks for an energy management system, which could be supplied by the energy supplier. Without such management software, the e-driver is unlikely to handle all energy flows manually. Their interest is high because their profits are dependent on the specific implemention of such a system. *If you keep your activity behind the meter, it is out of our control. The meter is, of course, our technique of seeing precisely what occurs and what follows immediately after.* – INT06.

Energy producer

The energy producer is placed in the least important quadrant, with lower power and interest. The energy producer has little to no power over the system. Their interest is not high, but also not non-existent. With behind-the-meter energy optimization, e-drivers are incentivized to become their own energy producer by integrating the charging of the vehicle with the production of electricity through rooftop solar PV panels. This constitutes competition for energy producers. Since the EV that is linked to the home will not always be connected, some form of supplementary energy storage device is required for the default "energy producer" to no longer be a part of this system. This could for instance be accomplished with the use of a stationary home battery. However, it is not evident that users of this design would completely be self-sufficient. Therefore, the most probable scenario for the energy producer is that it loses a share of the amount of energy their customers normally consume through their generation. However, as they have little to no power over the system, their potentially negative attitude toward the system is not threatening.

OEM

The OEM is placed in the quadrant for stakeholders with both high power and interest. The OEM is required to make limited additional investments for the EVs compatibility with the system, as the design uses DC charging. This means that there is no onboard-charger needed, instead the vehicle only needs to be compatible with bidirectional electricity flows. For the rollout of this design, there only needs to be one eligible model to be satisfactory, as an e-driver chooses a specific vehicle for bidirectional charging and interoperability is no issue in this design. Currently, charging data like the state-of-charge is in the hands of the OEMs. They do not have to share this with other stakeholders, which makes them a powerful player as this data is essential for an optimal use of the islanded V2H system design. Multiple OEMs, like Ford and Volkswagen, put emphasis on the V2H system design with regard to their developments (INT03). This is because they see an opportunity to sell an integrated charge system, including a charging station and charging pass (INT03). Through market competition among OEMs, they do not have much power within this design. They do have a high interest, as the bidirectional charging impacts their battery significantly, for which they give out warranty to their customers. The spending power of private individuals is limited, which is why the OEM has less interest in the islanded V2H system design compared to the commercial V2B system design.

Charge point manufacturer

The charge point manufacturer is placed in the quadrant with little power, but high interest. Their role is similar to that of the OEM, but focused on the charging infrastructure rather than the vehicle. Charge point manufacturers must provide bidirectional charging compatibility within their charging stations in order for this system to be feasible. As charge point manufacturers often sell a variety of DC products (e.g. solar PV panels), a DC bidirectional charger is a relatively easy extension to their product range. There are already DC charging stations available on the Dutch market. In this design, there only needs to be one eligible charging station to be satisfactory, as an e-driver chooses a specific charging station for bidirectional charging. Therefore, charge point manufacturers do not have much power within this design. The spending power of private individuals is limited, which is why the charge point manufacturer has less interest in the islanded V2H system design compared to the commercial V2B system design.

Local and regional authorities

The local and regional authorities are placed in the quadrant with little power and little interest. Therefore, they are not very interesting for the implemention of the islanded V2H system design. They have little influence on the outcomes of the implementation, but also do not have much interest in it, as it all occurs on private grounds.

EU and national regulators

The EU and national governmental bodies have limited control over this design, as it is implemented on private grounds. They are interested in solving congestion management issues. As behind-the-meter energy optimization is executed, there is a lower demand of energy from the grid, which could help relieve congestion on the grid. However, since this design only reduces energy demand, but is unable to inject energy back into the grid, the added value is limited. Therefore, their interest is not very high. Their power, however, is reasonable. This is mostly due to the current salderingsregeling that disincentivizes e-drivers to enter the system and implement an islanded V2H system design.

B
Interviews

This appendix provides a comprehensive overview of the interviews conducted as part of this research study. The interviews were conducted with both field experts and stakeholders. The purpose of these interviews was to gather valuable insights, perspectives and first-hand experiences related to the research topic. This appendix provides detailed information on the selection of interviewees, the interview protocol and the saturation of insights.

B.1. Interview protocol

The interview protocol encompasses pre-established requirements and guidelines that govern various aspects of the interview process, including the selection of interviewees, interview location, interview structure, and the nature of the questions asked. A set of specific criteria was established to ensure the inclusion of appropriate interviewees, comprising experts and stakeholders. Varying requirements were established for the expert- and stakeholder group. The requirements for the *experts* are defined as:

- At least two years of experience in the field of V2X in the Netherlands;
- An active role in some type of V2X development in the Netherlands;
- No direct benefit from boosting V2X technology in the Netherlands.

The objective of the interviews is to obtain an unbiased understanding of the current situation and the interplay among various stakeholders. Therefore, it is essential that the participating experts do not have personal agendas that could influence their perspectives. While the stakeholder-interviewees are also considered experts, their views on the stakeholder landscape may not necessarily be objective. The requirements for the *stakeholders* are defined as:

- At least two years of experience in the field of V2X in the Netherlands;
- Is currently or has been within the last two years in a position focused on V2X as one of the following stakeholders:
  - CPO
  - EMSP
  - Grid operator (TSO / DSO)
  - Energy supplier
  - OEM
  - Charge point manufacturer
  - National / local government

Table B.1 visualizes the characteristics of the interviewees. A theoretical insight saturation can be found when plotting the cumulative number of insights through the conducted interviews, which is visualized in Figure B.1. All interviewees are considered to be experts, as this is one of the requirements for stakeholders as well. Interviewee references are abbreviated to 'INT01' through 'INT09'.

Table B.1: Overview of interviewee stakeholder type

	Expert	Government	CPO	EMSP	Grid operator	OEM	Energy supplier
Interviewee 1	X					X	
Interviewee 2	X						
Interviewee 3	X		X				
Interviewee 4	X						
Interviewee 5	X						
Interviewee 6	X		X	X			X
Interviewee 7	X						
Interviewee 8	X				X		
Interviewee 9	X	X					

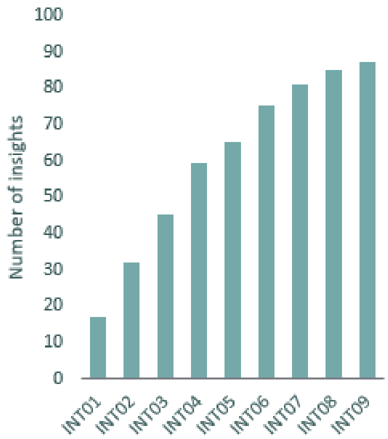


Figure B.1: A visualisation of the saturation of insights through the conducted interviews

B.2. Interview guide

A scripted beginning and ending helps to share critical details and provide sufficient background information on the research to the interviewee. Consent is asked to each interviewee for recordings and incorporation of retrieved information into the research report. All interviews have been conducted in a quiet, private place to make sure the interviewee is focused and feels free to say anything they want. The interview script starts with information on the aim of the research and the interview. More basic questions are asked in the beginning, in order to make the interviewee comfortable. It is made sure only open-ended questions are asked. The interview script is only used as guideline and, as it is a semi-structured interview, is open for changes during the interview itself. Some prompts are prepared per question to help the interviewee when they do not know how to answer a question. The interview guide is written in Dutch, as all interviews were conducted in this language.

Table B.2: Interview guide

Interview Guide	
Opening word - 5 min.	
Personal introduction	Dank u dat u tijd heeft gemaakt voor dit interview. Ik ben Jolijn van Dijk, student aan de TU Delft en ben momenteel aan het afstuderen bij EVConsult voor mijn master Complex Systems Engineering and Management. Mijn onderzoek zoomt in op de verschillende configuratie-keuzes die er zijn bij het concept Vehicle-to-Everything. Ik ben benieuwd wat de beweegredenen zijn om een bepaalde configuratie-keuze wel of juist niet te maken.
Goal of the interview	Het doel van het interview is om uw perspectief en ervaringen omtrent V2X en de verschillende configuratie-mogelijkheden te verzamelen. Het interview zal ongeveer 1 uur duren.
Confidentiality & Consent	Alle informatie die u mij verteld zal geanonimiseerd in het onderzoek komen, uw naam wordt dus niet genoemd, enkel uw functie en het type bedrijf waar u werkt. Ik zou graag het interview opnemen zodat deze later getranscribeerd en geanalyseerd kan worden voor mijn onderzoek, heb ik hiervoor uw toestemming?
Context	In mijn onderzoek analyser ik drie verschillende design opties van V2X: 1. Het public V2G system design 2. Het commercial V2B system design 3. Het islanded V2H system design Deze zal ik kort toelichten aan de hand van een visual. Ik zoek naar drijfveren en/of barrières van deze designs voor een grootschalige implementatie in Nederland. Voor de analyse kijk ik naar acht verschillende functies waarbij ik voor iedere functie een aantal vragen heb voorbereid. Deze loop ik graag met u door.
Start of the interview - 55 min. (Start recording)	
Subject 1: Personal information	- Zou u uzelf kort kunnen introduceren, naam, waar u werkt en uw functie/ expertise?
Subject 2: Starting questions (5 min.)	- Wat zijn volgens u de belangrijkste barrières voor grootschalige implementatie van [design]?
Subject 3: TIS questions (50 min.)	
System Functions	
SF1: Entrepreneurial activities	- Welke configuratiekeuzes worden gemaakt voor pilots? Wie bepaalt deze configuratiekeuzes? - Welke productontwikkelingen vinden op dit moment plaats, en welke zijn nog nodig voor [design]?
SF2: Knowledge development	- Op welke manier vindt er kennisontwikkeling plaats om de mogelijkheden en problemen van [design] in kaart te kunnen brengen? - Welke onzekerheden bestaan er over de concrete implementatie van [design]?
SF3: Knowledge diffusion through networks	- Op welke manier vindt er uitwisseling van kennis plaats tussen de betrokken partijen voor [design]? - Hoe ziet de communicatie-keten eruit voor [design]?
SF4: Guidance of the search	- Op welke manier ondersteunt overheidsbeleid de implementatie van [design]? - In welke mate is de overheid klaar voor de grootschalige uitrol van [design]?
SF5: Market formation	- Op welke manier zou [design] economisch winstgevend kunnen zijn? - Op welke manier zou [design] praktisch haalbaar kunnen zijn?
SF6: Resource mobilization	- Welke middelen (financieel, materieel, menselijk) worden er ingezet om [design] succesvol te maken?
SF7: Creation of legitimacy	- Op welke manier wordt er gepleit of gelobbyd door belanghebbenden voor of tegen de uitrol van [design]? - In welke mate hebben betrokkenen belang bij de uitrol van [design]? - Zijn er tegenstrijdige belangen tussen belanghebbenden? Zo ja, welke?
Subject 4: closing questions	Zijn er onderwerpen die niet in dit interview besproken zijn, maar wel relevant voor dit onderwerp of gezien vanuit uw functie?
Thanking interviewee	Hartelijk dank voor het interview en de inzichten die u heeft geboden, dit is het einde van het interview.
Finishing the interview - 2 min. (Stop recording)	
Next steps	Ik zal het interview transcriberen en opsturen ter controle van uw antwoorden. Als er nog dingen te binnen schieten die u graag wilt toevoegen kunt u mij altijd bereiken via mail. Zou ik u nog mogen contacteren als ik nog resterende vragen heb? Daarnaast kan ik het onderzoek met u delen wanneer deze is afgerond.

C
Codebook

Seven initial function-codes were used based on the TIS functions by Hekkert et al. [40]. This coding structure is shown in Figure C.1. An example quotation out of one of the interviews is given for each theme in Figure C.2. For a clear overview, the definitions of each theme as understood in this research are summarized below.

Themes linked to F1 Entrepreneurial activities:

- *Configurational focus pilots:* the specific emphasis or orientation of pilot projects in terms of their configurations or design aspects.
- *Fleet captivity:* the degree of control or influence that a specific entity or organization has over a fleet of vehicles within a given context.
- *Product availability:* he readiness and accessibility of viable bidirectional charging products or solutions in the market.

Themes linked to F2 Knowledge development:

- *User behavior predictability:* the degree to which the user patterns, like charging behavior and preferences of EV owners can be accurately anticipated or forecasted.
- *Use case specific knowledge*: he understanding, expertise, and insights that are specific to a particular use case within a given context or domain.

Themes linked to F3 Knowledge diffusion through networks:

- *Network complexity:* the number of actors involved, the diversity of their roles and relationships, and the intensity of interactions among them.
- *Network collaboration:* refers to the degree or extent of collaboration and cooperation among various stakeholders within a network relevant for a specific system design.
- *Availability of collaboration platforms:* the presence and accessibility of platforms or mechanisms that facilitate collaboration and knowledge exchange among stakeholders within the system.

Themes linked to F4 Guidance of the search:

- *Creation of market incentives:* the deliberate efforts and strategies employed to stimulate and promote market demand and adoption for the V2X innovation.
- *Regulatory compliance:* the compliance of individuals, organizations or systems with the rules, regulations and legal requirements laid down by relevant authorities or governing bodies.
- *Promising activity of neighboring countries:* notable and noteworthy initiatives, projects, or developments taking place in countries geographically adjacent to or nearby the Netherlands.
- *Promising pilot outcomes:* positive and encouraging results or findings derived from pilot projects or experimental initiatives.

Themes linked to F5 Market formation:

- *Compatibility with the current system:* the degree to which the new bidirectional charging designs align with and integrate smoothly into the existing system or infrastructure.
- *System interoperability:* the ease or complexity of the exchange of information, data or services between different systems or actors.
- *Market competition:* the degree of rivalry and competitive dynamics within the bidirectional charging market.
- *Market size:* the total value or volume of the bidirectional charging market, indicating the scale and potential of economic activity within that market, for both the demand and supply side.
- *Potential economic benefit:* the total value or volume of the bidirectional charging market, indicating the scale and potential of economic activity within that market.
- *Initial user investments:* the relative financial resources allocated to cover the costs associated with the participation in a specific design.

Themes linked to F6 Resource mobilization:

- *Financial support:* the provision of financial assistance, incentives or subsidies by governments, organizations or stakeholders to promote and facilitate the adoption and implementation of a particular technology or initiative.
- *Marketing effectiveness:* the extent to which a marketing strategy and its associated activities successfully accomplish their intended goals and objective

Themes linked to F7 Creation of legitimacy:

- *Complexity of stakeholder field:* the degree of intricacy and diversity in the composition and interactions of stakeholders involved in the context of the various designs, including their various interests, roles, relationships, and dynamics
- *Stakeholder attitude:* the perceptions, beliefs, opinions, and overall disposition of stakeholders towards a particular design.

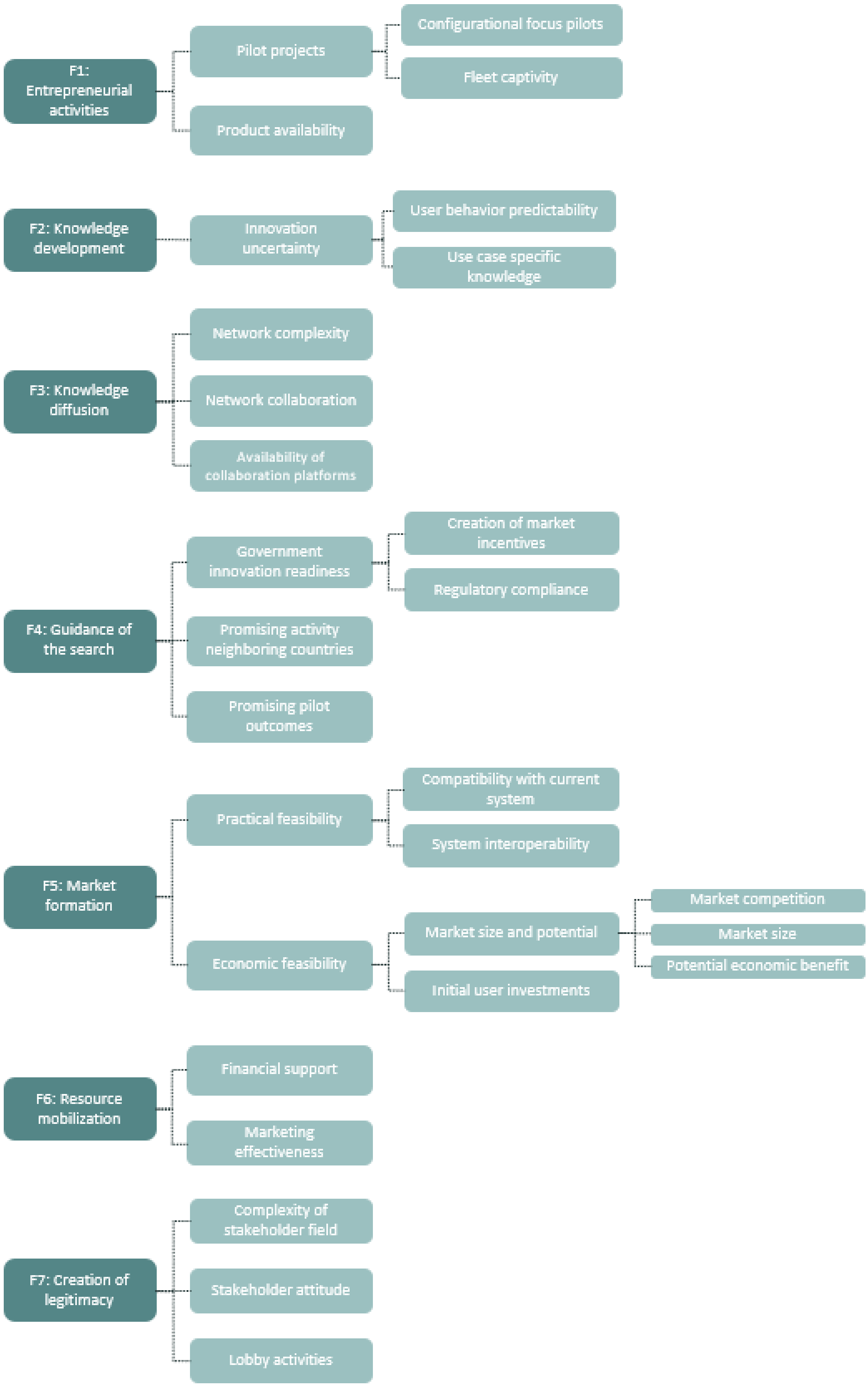


Figure C.1: Research codebook uncovering main themes describing differences between V2X designs

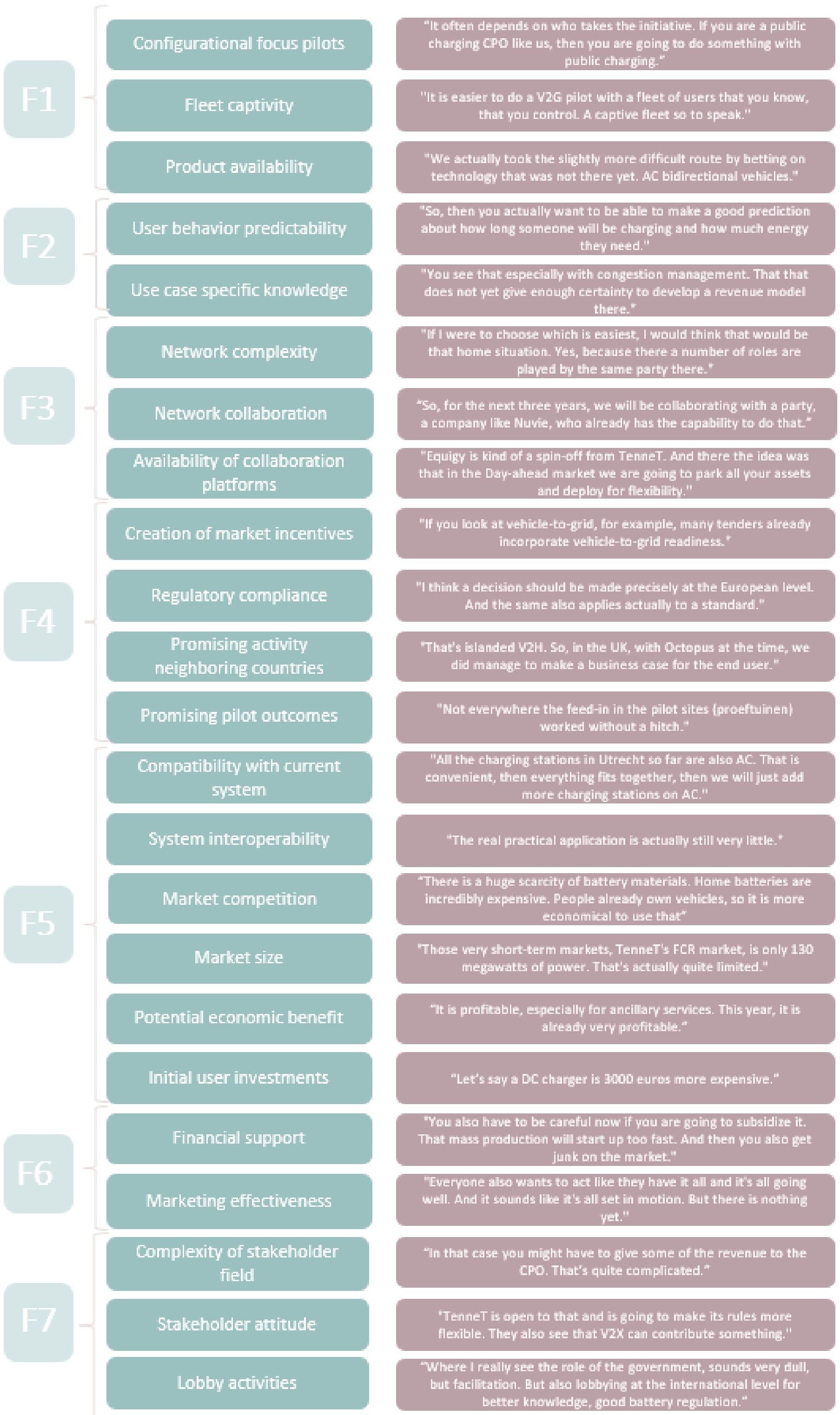


Figure C.2: Main codebook themes and corresponding example quotes

D
List of events attended

Table D.1: Events attended during the research

Name of event	Date	Speaker(s)	Aim
Webinar V2G implementation, regulation and grid requirements - California and the Netherlands	8-2-2023	Lonneke Driessen (OCA), Jeffrey Lu (California Energy Commission), Sebastian Kaluza (Lucid Motors), Chris Moris (Pacific Gas and Electric)	Learn more about the ambitions and ideas regarding V2X, includingtheir application, regulations, and grid code barriers.
Webinar "How will V2G revolutionize the EV industry?"	28-2-2023	Asmund Moll Frengstad (Current)	Discover the benefits, challenges and possible future use cases of vehicle-to-everything
Global EV Charging test - V2X Symposium	28-3-2023	Ben Wender (CEC), Lonneke Driessen (OCA), Matthijs Kok (Utrecht City), Yasmine Assef (AFRY), Robin Berg (We Drive Solar), Thijs van Wijk (Elaad), Diego Manuel Cebreros (Stellantis), Thomas Neuman (AVERE), Christiaan Pielkenrood (Hyundai), Oren Halevi (Driivz), Tomoko Blench (Chademo Association), Antonio Bonvento (Terna SpA), Glenn Cezanne (CharIN), Franc Buve (OCA)	Key note speakers and an international panel of experts on the current status of V2G projects in Europe, Asia and the US. Learn about new insights in open standards, experience demonstrations by leading experts and workshops on specific topics.
Webinar large-scale battery power systems and off-grid congestion	19-4-2023	Maarten de Vries, Jan van der Voet (Ministerie van EZ&K), Lucas van Capellen (CE Delft)	Webinar following a study conducted by CE Delft on the role of large-scale battery systems in solving and preventing off-grid congestion.