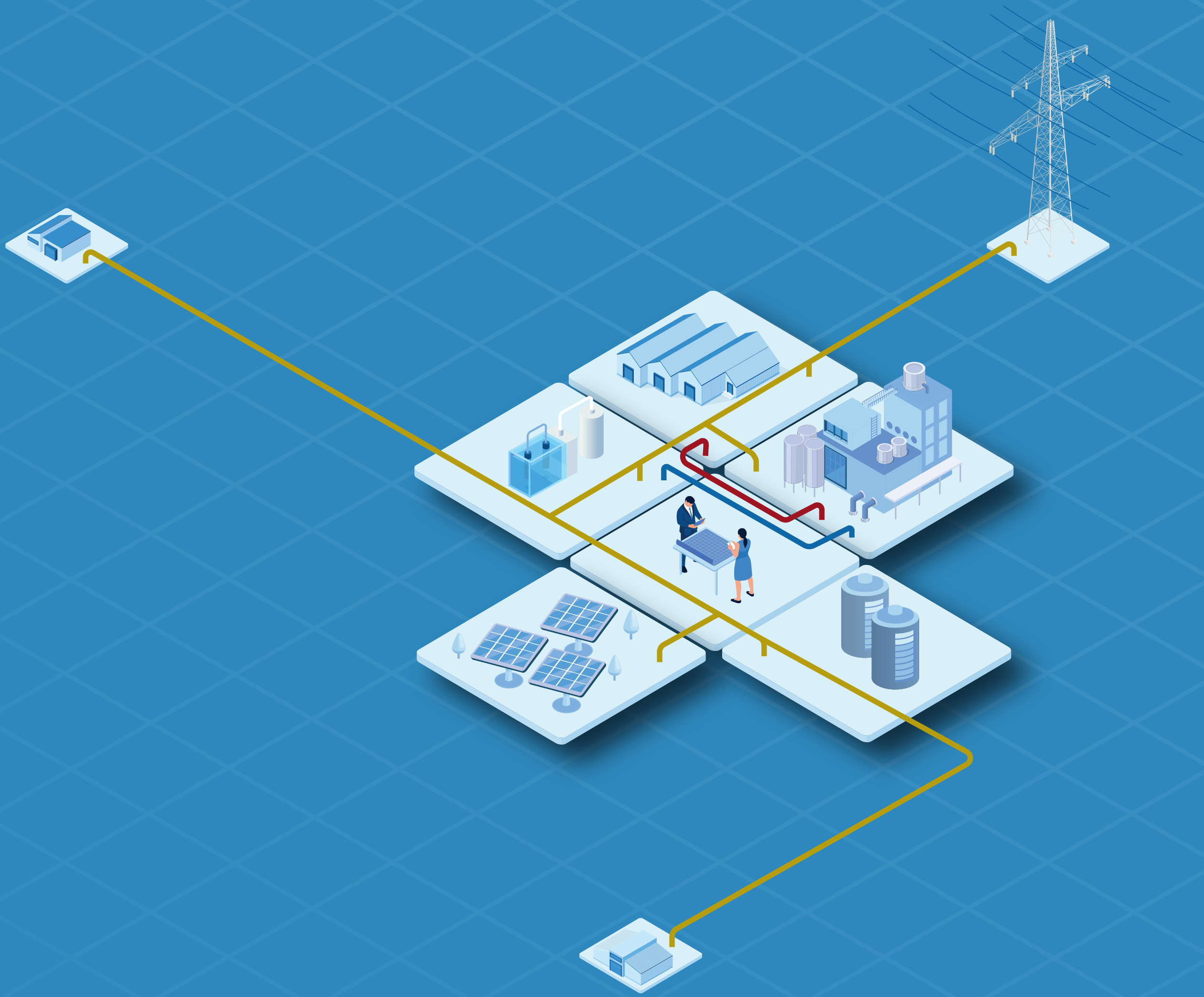
Energy hubs as the solution to net congestion

A governance and innovation perspective on implementing energy hubs



Twan Kramer

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Energy hubs as the solution to net congestion

A governance and innovation perspective on implementing energy hubs

by

Twan Kramer

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TU Delft

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I hope that my thesis will contribute more knowledge about energy hubs to anyone who reads it. I hope you enjoy reading it.

Twan Kramer
Delft, August 2023

Executive summary

The Netherlands is committed to combating climate change. One of the ways to achieve this goal is by transitioning to renewable energy sources and promoting the electrification of the Dutch industry. Inherently, the energy transition changes the energy system from central to decentralised. As the electricity grid was initially constructed based on the centralised system and lower energy demand, these changes result in grid congestion. Traditionally, grid expansion is the way to solve grid congestion. However, grid operators do not have adequate capacity to keep up with the demand for grid expansion. A result is an increasing number of requests for transmission capacity that cannot be honoured. To avoid hindering both the energy transition and economic growth, a solution is needed which can be implemented quickly.

One solution that has recently gained attention is implementing an Energy hub (ehub) in locations with congestion. However, an ehub is an emerging trend about which a lot is still to be discovered and learnt. This research aims to see how ehubs can be introduced into the Dutch energy system from a governance and innovation perspective. To support the research goal, the following main question has been formulated. *What is needed to stimulate the implementation of energy hubs from a governance and innovation perspective?*

Qualitative research was used to answer the main question about congestion in the Netherlands. A case study approach was chosen for a comprehensive national view. Data was collected through desk research and expert interviews, and analysed using four theoretical frameworks. First, the Multi-Level Perspective (MLP) framework provides insight into the current situation of the energy system and the influences that work on the implementation of the ehub concept. Next, the Strategic Niche Management (SNM) framework is applied to understand developments at the level of the niche itself. Third, the Governance of Change (GoC) framework is applied to understand the tools that can initiate change and the legitimacy of that change. Finally, the first three frameworks' findings were applied in the backcasting framework. Using the backcasting framework, a shared future vision was created to put together a follow-up agenda.

Using the MLP framework, it was found that mainly three aspects exert the most significant influence on the development of ehubs. The potential to contribute to a congestion area positively influences the concept. However, the other two aspects are working negatively on the development. First, there is legal uncertainty for implementing an ehub concerning shared grid capacity. In addition, setting up and initiating an ehub requires time and money, making it difficult for pilots to get off the ground. The uncertainty reinforces companies' reluctance to invest. Using the SNM framework, it can be seen that the difficulty initiating pilots also affects the development of ehubs at the niche level. Additionally, it was found that expectations for ehubs are widely shared among stakeholders. However, experiments have not confirmed these expectations, resulting in uncertainty about how the expectations could be achieved in practice. Furthermore, it is found that there is a rich composition of actors active with the concept of both established parties and new parties, which contributes to the development of ehubs. From the GoC framework, it was found that steering for change to develop ehubs further can be perceived as legitimate. The concept is widely accepted, which allows it to be perceived as legitimate. With the findings from the MLP and SNM frameworks, instruments have been established that could contribute to the development of ehubs from the thoughts in the GoC framework. These instruments are presented in Figure 1 on page v. The backcasting framework was used to explore the potential of these instruments in creating ehubs based on a collective future vision. Using backcasting, a collective future vision was formulated as follows: By 2030, local ehubs will be established to facilitate the exchange of energy flows and transport capacity. And thus fulfils a social role in reducing grid congestion issues. This

includes not just electricity but also heat and potentially other energy sources. Additionally, the role of ehubs outside of congestion will be better understood. From this ensues the follow-up agenda presented in Figure 1.

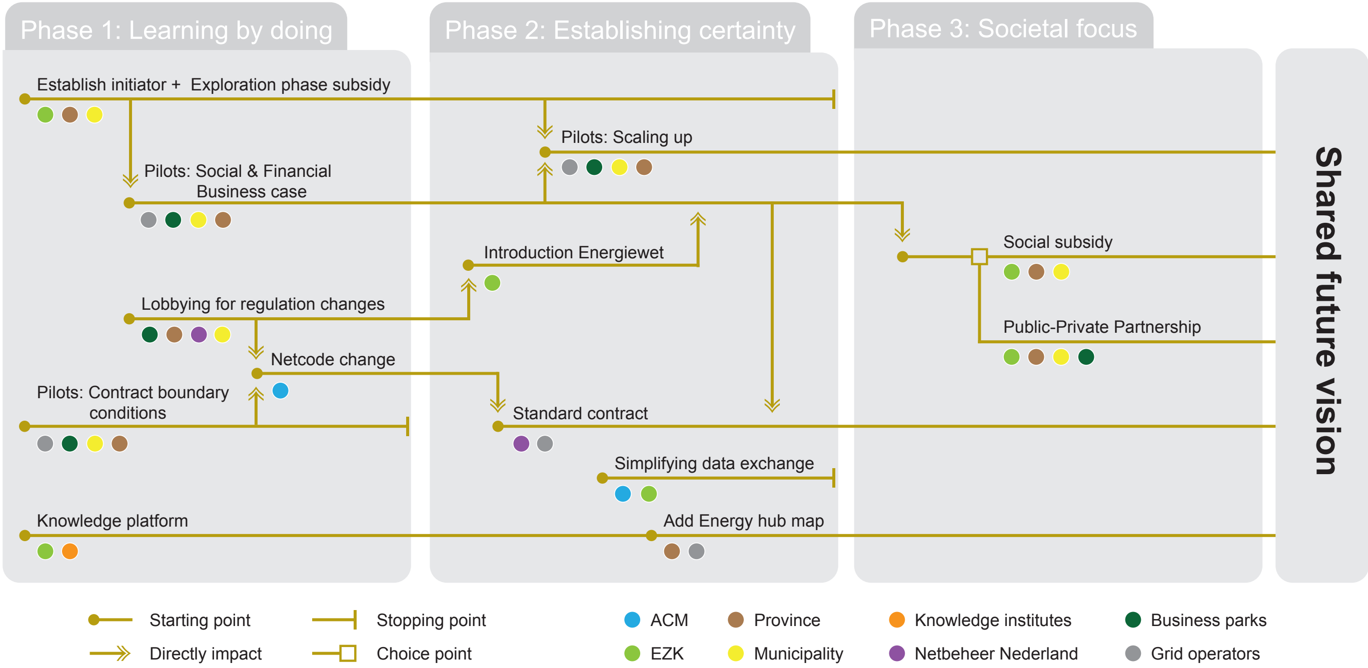

Figure 1: Follow-up Agenda

From the findings above, the main research question can be answered. From a governance point of view, it is advantageous for an established party to initiate the development of ehubs. Moreover, it is crucial to reaffirm expectations from an innovation perspective. This can be achieved by gaining more knowledge through implementing ehubs in pilot situations.

Setting up pilots proves challenging. Knowledge gathered from setting up citizen energy communities could help overcome obstacles. However, there is a question about whether the requirements for citizen energy communities are suitable for ehubs. It is suggested that future research should focus on exploring how citizen energy community requirements can be applied to ehubs, potentially benefiting their design. Another proposal investigates the applicability of frameworks like GoC and backcasting to sustainable transition frameworks, particularly retrospectively. Additionally, it is suggested to replicate the study after a few years to evaluate the evolving expectations and effectiveness of instruments in developing ehubs. This iterative approach ensures adaptability and improvement over time.

The recommendations for the stakeholders revolve around three main changes outlined in the follow-up agenda. The first change emphasises practical learning through pilot projects. The second change involves establishing legal certainty for ehubs. Lastly, the agenda highlights the importance of ensuring ehubs deliver social benefits. Specific measures are proposed to align ehubs with societal goals. The stakeholders within the network are strongly encouraged to consider the earlier changes and reflect on how they can actively contribute to implementing these necessary changes. Their involvement and thoughtful consideration of the changes needed will play a crucial role in effectively shaping the future of ehubs and maximising their potential societal impact.

Glossary

Aansluit- en Transport Overeenkomst An agreement between the DSO and the customer. The agreement concerns agreements made regarding the technical specifications of the connection, the tariffs the customer has to pay for the use of the network and other aspects regarding the connection to the network of the DSO. 15

Backcasting The framework describes an approach to developing sustainable future visions in collaboration with stakeholders. The framework describes steps to define a desired future vision to formulate actions that return to the present (Quist, 2013). iv, v, 4, 5, 19, 29–32, 36, 39–41, 67, 69, 81–84

Distributed Energy Resource DER are small-scale and decentralised power generation and energy storage technologies such as solar, wind, battery storage systems and fuel cells. 14

Energy hub Regional collections of entities that effectively produce, use, and store energy and convert it between energy carriers. iv, 2

Flexibility options Flexibility options refer to possible actions that can be taken on the electricity network for better matching supply and demand. Such flexibility options include storage, DSM, conversion to other energy carriers and curtailment. 10

Innovation The application of novel services, technologies, or methods where none have been employed previously (Eurostat, 2023). 19, 21–26, 29, 55, 56

Acronyms

ATO Aansluit- en Transport Overeenkomst 15–17, 51, 53, 68, *Glossary:* Aansluit- en Transport Overeenkomst

DER Distributed Energy Resource 14, 47, *Glossary:* Distributed Energy Resource

ehub Energy hub iv, v, 2–4, 6, 7, 9–17, 19, 34–37, 39, 40, 43–51, 53–65, 67–72, 74–81, 83–85, *Glossary:* Energy hub

flex options Flexibility options 10, 12, *Glossary:* Flexibility options

ACM Autoriteit Consument en Markt 15–17, 47, 51, 56, 62, 68, 70, 71, 77, 99

CBS Centraal Bureau voor de Statistiek 45–47

DSM Demand Side Management vii, 10

DSO Distribution System Operator vii, 15–17, 37, 56, 57, 71, 99

EC European Commision 45, 46

EP European Parliament 45–47, 80

EZK Ministerie van Economische Zaken en Klimaat 2, 5, 6, 9–11, 14–16, 39, 45, 47, 49, 58, 62, 71, 85

GDPR General Data Protection Regulation 46, 50, 62

GoC Governance of Change iv, v, 4, 7, 19, 27, 28, 32, 36, 39–41, 43, 67, 74, 81–84

kV kiloVolt 99

LAN Landelijk Actieprogramma Netcongestie 57, 58

MES Multi-Energy System 9, 10

MLP Multi-Level Perspective iv, 3–5, 7, 19–21, 23, 26, 27, 31, 32, 36, 39, 41, 43, 45, 52, 67, 74, 81, 82, 84, 102

MW MegaWatt 99

NBNL Netbeheer Nederland 2, 4, 5, 9, 11, 12, 14, 16, 47, 49, 50

NP RES Nationaal Programma Regionale Energiestrategie 2, 5

RVO Rijksdienst voor Ondernemend Nederland 34, 56, 57

SNM Strategic Niche Management iv, 4, 7, 19, 22–24, 27, 31, 32, 36, 39, 41, 43, 54, 67, 69, 74, 81, 82, 84

SQ sub-question 7

st socio-technical 2–5, 7, 19, 20, 23, 25–31, 34, 35, 41, 45, 46, 58, 63, 75, 76, 81

TSO Transmission System Operator 37, 56, 99

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CHAPTER 1

Introduction

As a result of climate change awareness, the Netherlands signed the Paris Climate Agreement along with 195 other countries (United Nations, 2015). The Paris Climate Agreement aims to limit the global temperature increase to one and a half degrees Celsius. It has been scientifically proven that greenhouse gas emissions, mainly CO_2, lead to global warming (IPCC, 2022a). In the Netherlands, the signing of the Paris Climate Agreement resulted in the creation of the climate accord. The Climate Accord is an agreement signed by more than 100 parties (governments, businesses and civil society organisations). The agreement states that the parties are committed to reducing CO_2 emissions by 49 per cent compared to 1990 (Ministerie van Economische Zaken en Klimaat [EZK], 2019). This reduction must be achieved by making the Netherlands more sustainable, on the one hand, by scaling up renewable energy and on the other by countering emissions from existing processes.

Making the Netherlands more sustainable has implications for the electricity network. Initially, the Dutch electricity network has been designed based on the predictable production and consumption of electricity. The rise of renewable energy generators, resulting from the 2013 SDE+ subsidy, created an excess electricity supply on grid sections with thin cables in non-densely populated areas. In addition, the electrification of industrial areas increases the load on the grid (Agentschap NL, 2013; Netbeheer Nederland [NBNL], n.d.-c). Over the next decade, as a result, the capacity of the electricity network will have to increase by a factor of two to three (EZK, 2022d; B. den Ouden et al., 2020). However, electricity grid reinforcement is proving to be a difficult task and grid operators can no longer keep up with the pace of demand (Brinkhof, 2023; NBNL, n.d.-c). More and more regions in the Netherlands are reaching the capacity limit of the electricity grid, resulting in more requests from citizens and businesses for (more) capacity on the grid being rejected (Algemene Rekenkamer, 2022). Despite this, the Dutch government is looking at the electrification of the industry to reduce CO_2 emissions (Hers et al., 2022; EZK, 2019). To meet the set climate goals, alternative short-term solutions are needed to free the electricity grid from the obstacles mentioned earlier (Nationaal Programma Regionale Energiestrategie [NP RES], n.d.; Topsector Energie, 2019).

One of these alternatives is the implementation of an Energy hub (ehub), full definition in chapter 2 (EZK, 2022d; NP RES, n.d.). Ehubs are regional collections of entities that effectively produce, use and store energy and convert it between energy carriers. Instead of behaving as individuals, an ehub will be one local integrated energy system (Van Bracht, 2022). Within an ehub, different energy carriers can be balanced to match the need of all parties. For example, the waste heat of one facility in the cluster can be an input for another facility that needs heat. This high interconnection between parties increases the overall efficiency (Geidl et al., 2007). Another main benefit of the energy system is that it will reduce the burden on the infrastructure outside the ehub. Since less external energy needs to be transported to the ehub over the central grid.

Despite the benefits of ehubs, the implementation is not straightforward. In the Netherlands, ehubs are mostly being tested as pilot projects. However, the realisation of the ehubs proceeds with difficulty (EZK, 2022d). According to EZK (2022d) and Royal HaskoningDHV (2022), some issues need to be addressed to move on with the adoption of ehubs. These include smart spatial integration, reduction of legal barriers, organisation and operation of ehubs, infrastructure construction and clarity of the revenue model. These issues related to ehubs are mainly in the socio-technical (st) domain.

1.1. Knowledge gap

The definition of ehubs mainly flows from a project called ”Vision of Future Energy Networks” presented by Geidl et al. (2007), in which a greenfield approach was applied to future energy systems. Academically, Geidl et al. (2007) still sees knowledge gaps in the system’s technical aspects, such as tools to model the stability of an ehub. Mohammadi et al. (2017) reviews the academic literature to move from an ehub model to a concept. It also identifies the knowledge gaps on the application of ehubs in different consumption areas and how this affects the balancing of the system. The article also identifies the lack of studies on applying ehubs. One article that looks at the application of an ehub is that of Damman and Steen (2021). This study looks at the role of Norwegian ports as ehubs for enabling the energy transition. The study uses a st perspective in analysing the topic by using the Multi-Level Perspective (MLP) framework. This involves looking at the system’s relationship between different factors and processes. The researchers then also highlight the importance of more research into facilitating the many stakeholders in the system and how they operate within the complex system surrounding an ehub.

In the literature search focused on the combination of ehub and st analyses, no additional papers were found. As mentioned above, publications were found that explored the different st aspects individually. Still, there is a knowledge gap in the literature regarding the intersection of these aspects. Furthermore, it is worth mentioning that within the existing literature on ehubs, there is little discussion on implementing an ehub within the Netherlands. While some research touches on ehubs in a broader context, there is a need for a more focused exploration of the challenges and opportunities associated with implementing ehubs in the Dutch context.

1.2. Research goal

The research objective for the master thesis flows from the societal need to create movement space in the electricity grid and from the knowledge gap regarding implementing one of the potential solutions, ehubs. The research objective is twofold. On the one hand, the aim is to fill in knowledge gaps and, on the other, to flesh out aspects regarding the implementation of ehubs. Here, the project aims to highlight the opportunities and barriers to implementing ehubs and provide insight into the necessary follow-up steps.

1.3. Research questions

This thesis will address the research goal from a governance and innovation perspective. With this, the following main question has been formulated as a guiding principle in the research.

What is needed to stimulate the implementation of energy hubs from a governance and innovation perspective?

With the main question in mind, the sub-questions and the research methodology used in the master’s thesis can be formulated. The sub-questions are formulated to answer the main research question.

The first step in answering the main question is to create a clear picture of the definition and characteristics of ehubs. A literature review and expert interviews will be used to answer this sub-question. To acquire a clear picture, the following sub-question will be used.

SQ 1 - *How to define and characterize energy hubs?*

After defining ehubs, its position in the electricity system will be considered and, more precisely, its position as a niche innovation. The position of ehubs will be analysed with the frameworks Strategic Niche Management (SNM) from Kemp et al. (1998) and the MLP from Geels (2002). SNM helps to provide insight into the current position of ehubs as a niche. The MLP looks at the relationship of ehubs as a niche compared to the current st-regime. MLP and SNM are described in section 3.1 and section 3.2 respectively. Knowledge acquired from applying the MLP and SNM framework will help to answer the sub-question below.

SQ 2 - *How is the innovation energy hub currently positioned as a niche in the socio-technical system?*

After framing ehubs, its position in the electricity system will be considered. Specifically, it will examine how the current st system affects the realisation of ehubs, both positively and negatively. The MLP framework will be utilised to examine these influences. A literature review will be combined with interviews with experts on the subject to answer this sub-question. The sub-question that will be used is presented below.

SQ 3 - *How does the current socio-technical system of electricity infrastructure influence the introduction of energy hubs?*

After looking at the positioning and influences on the innovation ehubs, it will be necessary to look into how the system can be changed to enable ehubs. Change in a system arises from its stakeholders, so knowing which stakeholders can initiate change is essential. The change can be created with the available instruments of these stakeholders. What and how instruments are used is based on their interests and opinions; therefore, the legitimacy of the stakeholder's actions will be included in the research. The framework of Borrás and Edler (2014b), Governance of Change (GoC), will be utilised to analyse the above. GoC is further described in section 3.3. This framework will conduct in answering the sub-question below.

SQ 4 - *What does the governance of change entail regarding introducing energy hubs?*

After creating a clear understanding of the different aspects concerning the implementation of ehubs, a future vision will be designed. The future vision will give insight into the follow-up steps for ehubs to develop beyond the niche level. The vision is created for the year 2030 because of the need for such a solution in the short term. NBNL (2023) also states the need for such flexibility solutions by 2030. The backcasting framework methodology of Quist (2013) outlines the steps to establish the bridge between the current state and the desired future vision. Backcasting has further explained in section 3.4. The information gathered from the previous sub-questions and interviews with subject experts will be utilised to answer the sub-question formulated below.

SQ 5 - *What is a possible pathway to encourage energy hub niche development towards the future vision in the Netherlands until 2030?*

1.4. Research flow diagram

An outline of the approaches that will be done to accomplish the research objectives can be seen visually in the presented research flow diagram, Figure 1.1 on page 7, which shows the various parts of a research project. The research flowchart presents the different frameworks that will be used to answer the sub-questions and, ultimately, the main question. The feedback loop shows that initial findings may allow adjustments to previously written work. The master thesis eventually flows through the application of the frameworks in a backcasting analysis to then be able to answer the main question. The figure shows that besides answering the main question, suggestions for future research and recommendations will also be given.

1.5. Relevance to masters program

The topic of this thesis can be seen as a particular problem taught in the master's programme Complex System Engineering and Management (CoSEM). The system in which the problem resides can be considered complex since various stakeholders with different views interact with each other and the technologies in the system. These different aspects will need to be considered during the thesis, and a holistic view of all these aspects will be given. In addition, economic, institutional, technical, and social perspectives must be considered to present this holistic view, making it a st problem. For example, in the course 'Sociotechnology of Future Energy Systems', these perspectives have been used to analyse and compare future energy systems. Furthermore, the course provided methods to create feasible routes for transitioning towards a future energy system and evaluate the capabilities of emerging energy technologies.

The research approach needs a holistic view by involving insights from multiple perspectives. One of the frameworks in the course is the MLP framework. This thesis also employs this framework to analyse and compare the future energy system. Also, this thesis provides a possible pathway towards a desired future energy system, which was also taught during the mentioned course. Concluding these aspects of the master thesis makes it suitable for the master's CoSEM.

1.6. Societal relevance

The Netherlands aims to reduce greenhouse gas emissions to prevent the planet from warming by more than one and a half degrees Celsius (United Nations, 2015). However, achieving this target will be challenging (IPCC, 2022b; McGrath, 2023; United Nations, 2022). One method to contribute is to switch from fossil fuels to renewable energy sources can help decrease emissions. More renewable energy sources lead to a decentralised system. Electricity usage in the Netherlands is increasing as businesses strive to meet sustainability objectives (Hers et al., 2022; EZK, 2019). The electricity grid is becoming overloaded due to decentralized energy sources, hindering economic growth for businesses without sufficient access (Agentschap NL, 2013; Algemene Rekenkamer, 2022; NBNL, n.d.-c). Renewable energy is also affected, so finding a solution to utilise available transmission capacity is crucial for sustainability and economic growth (NP RES, n.d.; Topsector Energie, 2019).

Implementing ehubs at business parks is seen as a promising solution to allow companies to make use of unused transmission capacity (Van Bracht, 2022; EZK, 2022a; Royal HaskoningDHV, 2022). By better utilising the electricity grid, sustainability and economic growth can occur again. The research on ehubs, therefore, focuses on analysing the development of this niche to then offer advice for steps that can contribute to the further development of ehubs in the Netherlands.

Concluding the social relevance of this research is evident. It stimulates the implementation of ehubs, which can play a crucial role in achieving the Netherlands' sustainability goals. By analysing the development of ehubs and offering recommendations, this research contributes to better utilising transportation capacity for businesses and renewable energy, promoting sustainability and economic growth. It is an essential step towards a more sustainable future for the Netherlands and helps maintain a healthy and prosperous society.

1.7. Research structure

Figure 1.1 on the next page shows the thesis structure, which is divided into several chapters. Chapter 2 provides a definition of an ehub, drawing on academic and grey literature. In Chapter 3, the frameworks applied in the thesis are described. Chapter 4 explains the data collection and analysis methodology. In Chapter 5, the niche innovation of ehubs is analysed using the frameworks. Based on the previous chapters, Chapter 6 presents a future vision and a potential way forward. The final chapter, Chapter 7 presents the conclusion along with a discussion and advice for future research and stakeholders in the system.

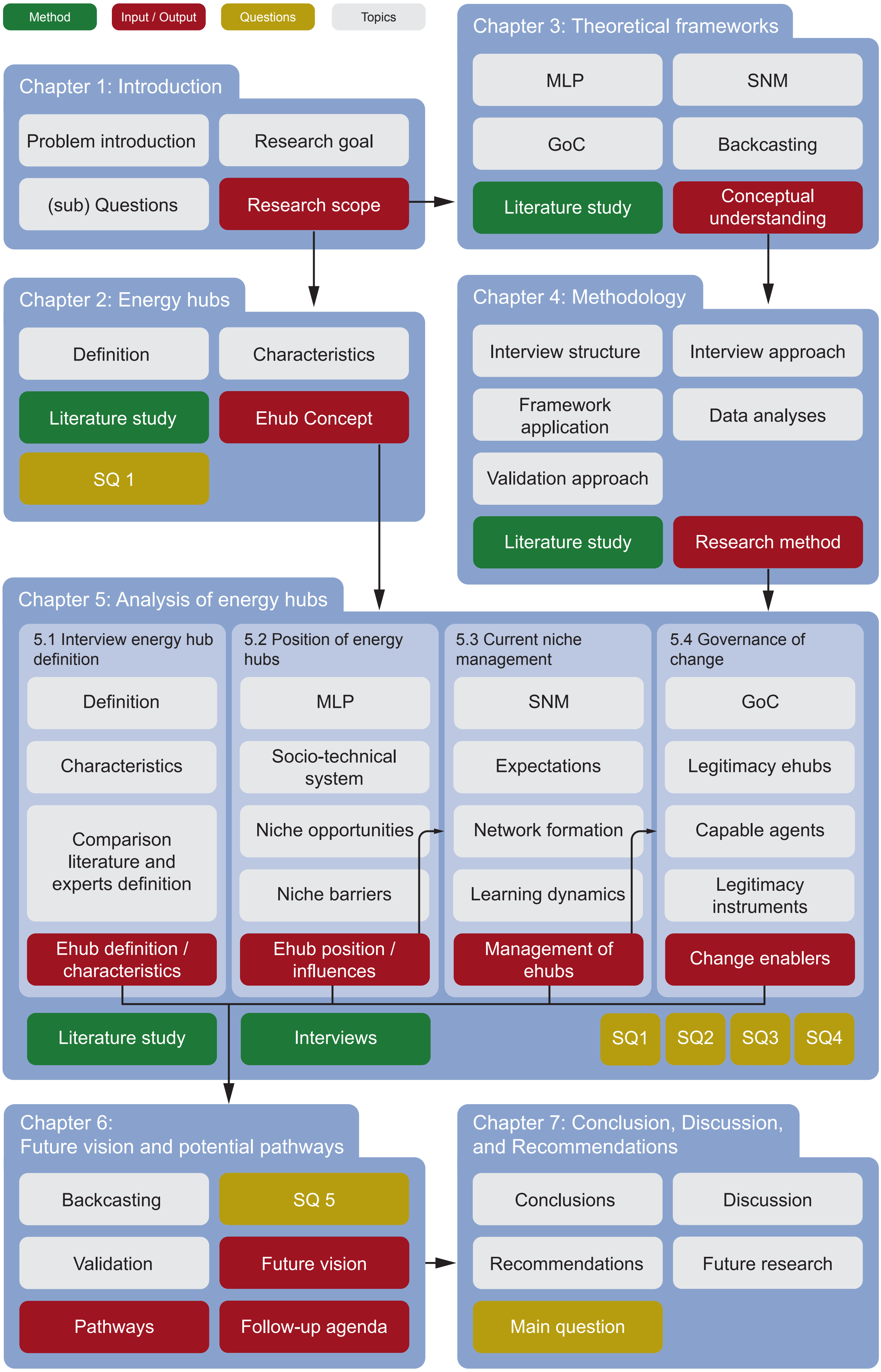


Figure 1.1: Overview of the thesis research structure.
NOTE: MLP = Multi-Level Perspective; SNM = Strategic Niche Management; GoC = Governance of Change; st = socio-technical; SQ = sub-question; ehub = Energy hub

CHAPTER 2

Energy hubs

This chapter will set out the definition and characteristics of an ehub. The various facets of an ehub will thus be highlighted to get a complete picture. The first section will discuss the concept and the difference between the academic definition and the implementation in the Dutch context. The following sections discuss the technical aspects, governance, and legal components. Finally, an overview of current ehub pilots will be presented.

2.1. The concept

The concept of ehubs started with a research project from the University ETH Zurich called 'Vision of Future Energy Network' (Geidl et al., 2007). The project conceptualised a future picture for the energy network where a Multi-Energy System (MES) is used to supply energy. Using different energy carriers as energy sources in the Netherlands is not unusual. Geidl et al. (2007) vision of the future is about integrating different energy carriers into one cooperating infrastructure. The research argues that such an energy system can provide increased efficiency. The increase in efficiency is achieved by exploiting the benefits of all the different energy carriers. For example, using electricity to transport energy and hydrogen can be used for long-term energy storage. The research sees the application of ehubs as a possibility to ensure easier integration and interconnection of the energy carriers, stimulating movement towards the described system.

In the literature, an ehub takes many guises. For example, the studies by Howell et al. (2017, p. 202), Geidl et al. (2007, p. 26–27), Van Bracht (2022, p. 3), Favre-Perrod (2005, p. 14), Mohammadi et al. (2017, Chapter 3), Rakipour and Barati (2019, p. 384), Royal HaskoningDHV (2022, p. 7–8) and EZK (2022d, p. 22–23) provide a variety of definitions for the concept of an ehub. Table 2.1 on the following page presents the different components reflected in the definitions in the literature. It can be seen that there is a clear overlap in the characteristics, but there is also variation in the definition. To further analyse the concept of an ehub in this study, the definition in the Dutch context is given below.

Some studies name a geographic scale when looking at the scale of an ehub. Geidl et al. (2007) named that an ehub is located within different facilities such as an industrial site, large building complexes or rural and urban areas. Van Bracht (2022), EZK (2022d), NBNL (2023) and Royal HaskoningDHV (2022) reports to give a similar geographic scale. These reports state that an ehub occurs in a local geographic area or hub. Therefore, a geographically local area will be assumed when formulating the definition of an ehub. Beyond the geographical scale, Van Bracht (2022) also named the format of an ehub. A difference is drawn between the micro and macro levels. Micro level means the abstraction level of components. The micro level is, for example, a combined heat and power plant since it has multiple energy carriers within a defined system. The macro level is at the local level and corresponds to the stated definition by Geidl et al. (2007). Dutch policy papers and reports mainly mention the relevance of macro ehubs (EZK, 2022d; NBNL, 2023). Therefore, in this thesis, micro-level ehubs will be disregarded after the definition.

Although it is not named explicitly within the academic literature, cooperation between different parties is an essential factor in an ehub. For example, Royal HaskoningDHV (2022) states that an ehub is an organisation representing several stakeholders. EZK (2022d) also named a standard legal form for an ehub. Shaping an ehub into a legal entity makes it easier to conclude agreements with the various parties.

Table 2.1: Summary literature definitions of energy hubs - The check mark indicates that the source names the characteristic in the definition of an ehub. *Only talks about applying heat as another energy carrier.

Sources	Size	Legal entitiy	Optimal energy utilisation	Multi energy carriers	Conversion	Storage	Smart control	Connection external infrastructures
Geidl et al. 2007	Micro-Macro		✔	✔	✔	✔		✔
Howell et al. 2017	Single building	✔	✔	✔	✔	✔	✔	
Van Bracht 2022	Micro-Macro		✔	✔	✔	✔	✔	✔
Favre-Perrod 2005	Micro-Macro		✔	✔	✔	✔		✔
Mohammadi et al. 2017			✔	✔	✔	✔		✔
Rakipour et al. 2019			✔	✔	✔	✔	✔	✔
Royal HaskoningDHV 2022	Local system	✔	✔	✔	✔	✔	✔	✔
EZK 2022d	Local system	✔	✔	✔*	✔	✔		

Beyond geographical scale and stakeholder organisation, an ehub is mainly about using energy better. Within the academic literature, optimal energy utilisation is mainly achieved when an ehub is built as an MES (Favre-Perrod, 2005; Geidl et al., 2007; Mohammadi et al., 2018; Mohammadi et al., 2017; Sadeghi et al., 2019). In a MES, different energy carriers are balanced to meet the energy demand of the parties involved optimally. Within such an MES, using Flexibility options (flex options) capabilities is essential for optimal energy utilisation. Putting the definition of an ehub in the academic literature next to the current pilots in the Dutch context, the importance of multiple energy carriers in the system is less prominent (Bosma, 2023; Enexis Netbeheer, 2022; Firan, 2022; Schuiling et al., 2021). In the current pilots, initiated or in progress, the starting point is to balance electricity. Subsequently, emerging cooperation provides a good starting point to expand to multiple energy carriers. Because of the Dutch focus within the master thesis, the possibility of flex options will be a more prominent factor to consider in defining an ehub. With the above as the reason, the definition set in this thesis deviates from the definition drawn in the academic literature to understand the current situation in the Netherlands better. This includes conversion between energy carriers as one of the options to provide flex options in the system, but it is not a must, as stated in the academic literature. Outside conversion, the flex options options could be Demand Side Management (DSM), energy storage, and supply-side management (e.g. curtailment) are applicable to balance energy optimally (Lund et al., 2015).

Driving flexibility capabilities require a certain level of intelligence in the system. Van Bracht (2022) mentions the importance of a smart control function to ensure balancing is done robustly and efficiently. Several articles speak of a smart ehub, emphasising the importance of smart control function in an ehub (Van Bracht, 2022; Howell et al., 2017; Royal HaskoningDHV, 2022; Sadeghi et al., 2019).

The connection of an ehub to the external infrastructure can have different configurations (Van Bracht, 2022; Favre-Perrod, 2005; Geidl et al., 2007; Mohammadi et al., 2017; Sadeghi et al., 2019). The system can be connected only to the electricity or natural gas networks, but the internal energy flow can also consist of other energy carriers. This provides the freedom to develop the optimal arrangement for an ehub. Geidl et al. (2007) mentions that combining different transport networks can contribute to higher efficiency. However, this combination is not essential to define something as an ehub.

From the text above, the following required limiting criteria will be used:

- Must be spatially demarcated locally;
- Is a single legal entity representing multiple stakeholders;
- Has flexibility options for scaling up or down demand and supply of energy;
- Applies smart energy management system for optimal matching of supply and demand

From these limiting criteria, significant variation is still possible between the different ehubs. As Van Bracht (2022), Favre-Perrod (2005), Geidl et al. (2007), Mohammadi et al. (2017) and Sadeghi et al. (2019) describe, different configurations can be used regarding the energy carriers used as inputs and outputs. The ability to customise these configurations makes it easier to meet specific local conditions and energy issues. Furthermore, there is a variation in the size of ehubs, from micro-size to macro-size (Van Bracht, 2022; EZK, 2022d; NBNL, 2023; Royal HaskoningDHV, 2022). Micro-ehubs can be single components, while macro-ehubs span industrial clusters (Van Bracht, 2022). Finally, the components used to regulate supply and demand are not fixed. Supply, demand, and energy use can be optimised using the right mix of flex options.

All in all, the variation in factors makes the definition of ehubs versatile and adaptable. As a result, there is no standard configuration of an ehub, but there are different build-ups in ehubs. Using limited criteria, the following definition can be constructed for ehub.

> *An energy hub is a cooperation of actors at a local geographic scale. This cooperation results from smartly matching supply and demand with flexibility for optimal energy usage. The flexibility options concern one or more different energy carriers.*

2.1.1. Advantages

The benefits of an ehub can be divided into several categories. Within this study, the benefits of an ehub are divided into benefits to the energy system and to the participants in an ehub.

Energy system perspective

Even though an ehub is mainly a local affair, it brings national benefits to the energy system. As the introduction mentions, the energy transition leads to profound changes in the current energy system. One negative change is the increase of load on the electricity grid, resulting in congestion. The congestion problem is exacerbated as the electricity grid tries to solve local surpluses and shortages. This is solved by exporting the local surplus and importing energy in case of shortage from higher-lying grids of higher voltage. As a result, High voltage grids are utilised less efficiently and suffer from congestion problems. See Appendix A for an explanation of the different levels in the Dutch electricity system. The regular solution to congestion is reinforcing the electricity grid by increasing its capacity. However, due to an acceleration in the electrification of the industry to meet set climate targets, there is not enough capacity to apply the regular solution (Brinkhof, 2023; NBNL, n.d.-c). An ehub helps to reduce this congestion by reducing the dependency of a local area on the regional grids (Van Bracht, 2022; Royal HaskoningDHV, 2022). As the parties involved cooperate to match local supply and demand, this relieves pressure on the regional high-voltage grids. For example, when there are two industrial areas, one of which has a surplus of electricity and the other a deficit, the regular solution will require capacity on a higher voltage grid to move electricity from the area with a surplus to the one with a deficit leading to a balance in both areas. When the individual industrial areas can handle the imbalance themselves using flex options, it will generally reduce the needed capacity on the high-voltage grid.

Another advantage of an ehub arises when using multiple energy carriers. For instance, Geidl et al. (2007) named that various energy carriers can increase the entire system's efficiency. This is a result of the different properties the energy carriers have. For instance, a gaseous energy carrier, such as hydrogen, can be used for long-term storage and electricity for long-distance transmission (Geidl et al., 2007; Hossain et al., 2020; Luo et al., 2015). Geidl et al. (2007) additionally named that coupling different energy carriers with transporting energy can lead to fewer losses during transport. A hollow cable containing a gaseous substance can reduce losses by capturing lost heat. The heat can then be recovered from the gaseous substance and used. Using an ehub encourages the possibility of such an application.

Local perspective

As mentioned in the benefits from the energy system perspective, establishing an ehub can provide relief to the electricity grid. This relief also brings a benefit from a local perspective. There is then more capacity on the electricity grid for business process expansion. Where usually, one would have to wait for the local grid to be extended, an ehub offers a faster solution to prevent local operations from stagnating. The potential for growth helps to ensure the region's economic and environmental sustainability (Royal HaskoningDHV, 2022). This allows better utilisation of renewable energy and offers the possibility of utilising residual heat, for example.

Besides preventing stagnation in the development of participating companies, creating an ehub can also bring financial benefits. The collaborating companies in an ehub can jointly invest in sustainability.

2.1.2. Limitation

In the current legal framework for ab ehub, a group of users collectively share a fixed capacity on the grid. This means that the group's overall capacity must not exceed a predetermined limit over a period of time. Consequently, the assigned capacity may be considerably less than the peak load that the participants currently share.

The decrease in capacity could be due to the strain on the energy grid outside of the ehub. Figure 2.1 illustrates a scenario with two instances of peak usage on the grid. During the first peak, the ehub participants contribute a lot, but it is primarily non-participants using the grids' capacity during the second peak. The amount of capacity that the group can access is determined by the firm capacity available on the grid. Consequently, the allotted capacity during the entire period is much lower post-shared capacity compared to what the ehub participants used during pre-shared capacity.

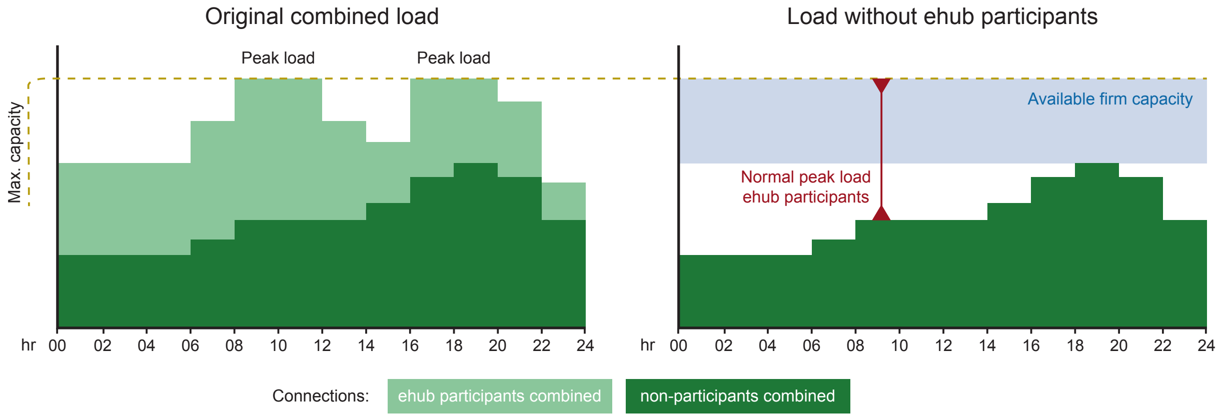


Figure 2.1: Grid capacity peak load - The combined peak load of the group might not be the only peak load of the grids' capacity.

The difference in access to capacity results in more effort that participants in an ehub must put into satisfying the constraints. Therefore, the pooling of grid capacity in an ehub is not desirable in all scenarios, thus limiting the implementation of ehubs.

2.2. Technical aspects

A technology map presents the related technical aspects of an ehub. A technology map is a visual presentation of the different types of technologies that make up an ehub. The technology map is shown in Figure 2.2.

In the technology map, four different energy carriers of the many possibilities have been chosen to be considered. The energy carriers have been chosen based on the research done by Mohammadi et al. (2017). This research sets out the different components of an ehub. From this, the following energy carriers emerge electricity, natural gas, heat, biofuels, hydrogen and cooling. Within this thesis, we look at the Dutch context. When looking within the context of Dutch industry, mainly the energy carriers electricity, natural gas, heat, biofuel and hydrogen emerge (Van Bracht, 2022; EZK, 2019; NBNL, 2023; Royal HaskoningDHV, 2022).

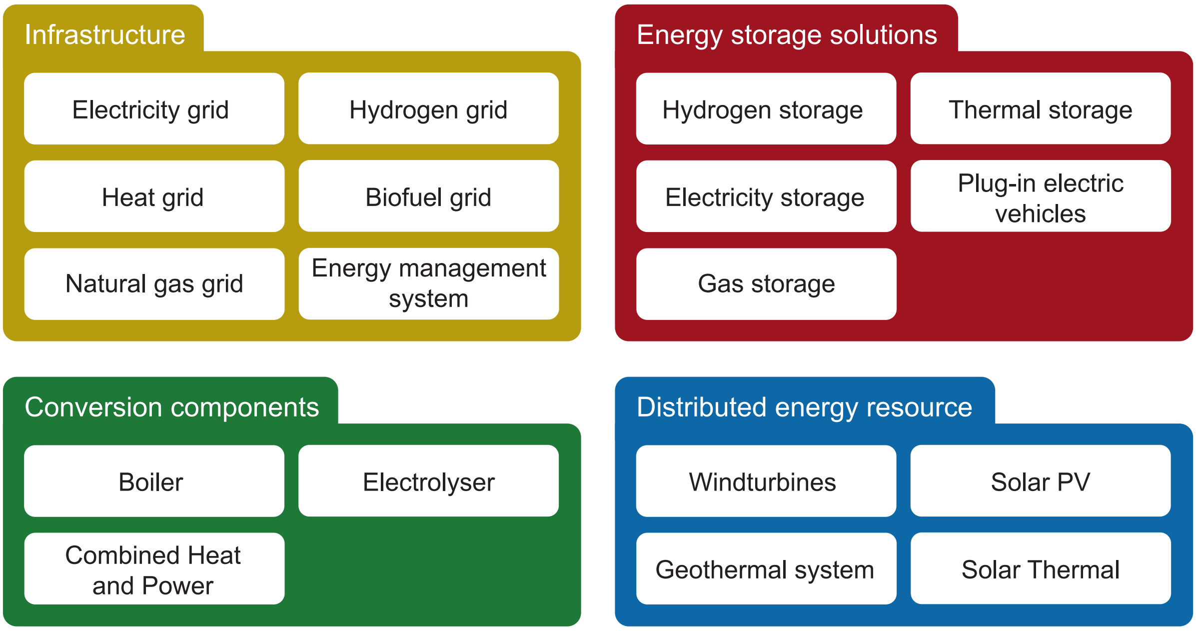


Figure 2.2: Technology map - A representation of multiple technical components that could potentially be located in an ehub.

Energy enters an ehub in two ways. The first way is through the various infrastructure of an energy carrier, e.g. for electricity, the electricity grid. A second way is locally generating energy through Distributed Energy Resource (DER). DERs are energy generation resources connected on the medium to low voltage distribution network instead of a direct connection on the high-voltage grid (Akorede et al., 2010). DER thus involves small-scale generation units that can be applied at the level of an ehub (Cardell & Tabors, 1997; Mallikarjun & Lewis, 2014). Traditionally, energy consumers often receive their energy using the former form. However, the energy transition encourages decentralised energy generation methods (EZK, 2019; NBNL, 2023). As a result, the use of DERs as an energy source at the local level increases. This increase in DER also increases its relevance as a technical aspect in an ehub.

2.3. Governance

Besides the technical aspects of the system, it is also essential to look at the governance of the system. The governance aspects arise from the formal relationships between the parties involved in implementing ehubs. Understanding formal relationships gives a more complete picture of the system's governance. Understanding formal relationships helps to provide insight into the social dynamics and interactions that influence the system and will contribute to the analysis in chapter 5. Using the relevant formal relationships, a visual representation is presented in Figure 2.3.

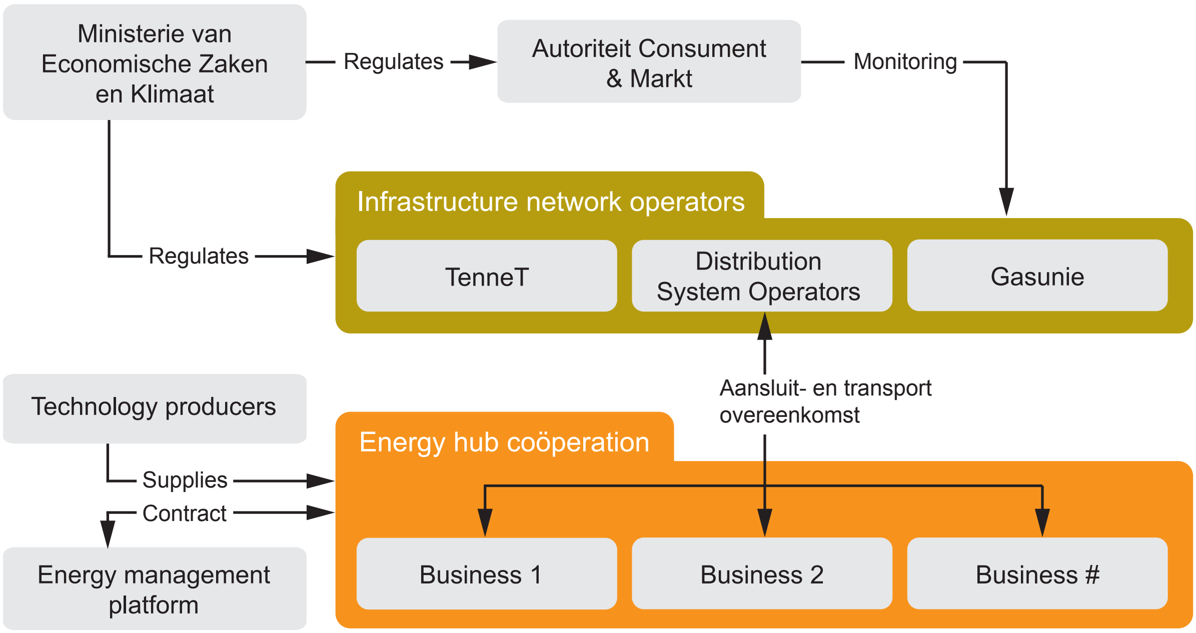


Figure 2.3: Formal map - Visual representation of the formal relationship between different actors in the system.

The Elektriciteitswet 1998 and Gaswet were laws introduced in the Netherlands to regulate the energy market and thereby improve its functioning (EZK, 2022a; EZK, 2022b). Introduced by the Ministerie van Economische Zaken en Klimaat (EZK), these laws regulate the Autoriteit Consument en Markt (ACM) and Distribution System Operators (DSOs) in the Netherlands to create a transparent and sound energy system for consumers. In the Elektriciteitswet 1998 and Gaswet, DSOs are responsible for managing the electricity and gas networks. The DSOs have been tasked with maintaining the grids and ensuring that the grids remain open to both producers and consumers.

In both laws, the ACM has been appointed to supervise the DSOs (EZK, 2022a; EZK, 2022b). They ensure energy networks' fair and proper functioning while protecting consumers' interests. In fulfilling this role, it ensures that DSOs comply with laws and regulations. The ACM has written a set of regulations in the grid code for DSOs and grid users on three aspects: functioning of the grids, transporting energy over the grids and connecting customers to the grids (Autoriteit Consument & Markt [ACM], 2016).

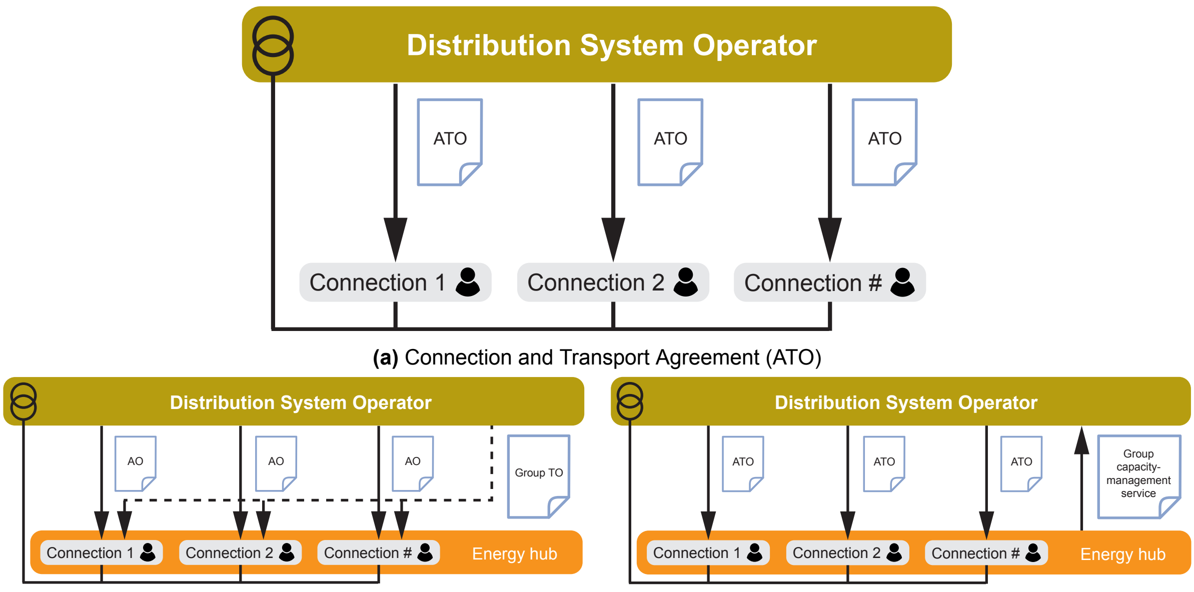
The connection of customers is accompanied by an agreement between the DSO and the customer called Aansluit- en Transport Overeenkomst (ATO). The agreement includes agreements on the technical specifications of the connection, the tariffs the customer has to pay for the use of the network, the responsibilities of the grid operator and the customer regarding the maintenance and safety of the connection, and the rights and obligations of both parties in case of breakdowns or other problems (ACM, 2016).

2.4. Legal component

Within the context of the Netherlands, the development mainly focuses on the legal aspects related to the concept of an ehub. The Dutch energy system is under strict regulation. This regulation mainly relates to the legal obligation of a DSO to provide the required services for connection to the electricity grid and available capacity across the grid. Establishing an ATO could potentially create legal additional capacity on the electricity grid. No contract may be concluded by the DSO covering multiple connections.

As a result, under current legislation, each connection has one ATO (ACM, 2023, Article 3.3). This means that against each physical connection on the electricity grid, there is an ATO between the user and the grid operator, as shown in Figure 2.4a. When there is no grid congestion, a user obtains capacity on the electricity grid via an ATO (ACM, 1999; Ensie, 2017; Groendus, n.d.). This capacity would be available around the clock, regardless of whether it was needed continuously (ACM, 2023). When there is congestion it is not possible to get an ATO (EZK, 2022d; NBNL, 2023).

Through an ehub, the grid operator makes the remaining available capacity accessible to a new entity, such as an energy cooperative. This cooperative allows its members to distribute their capacity, ensuring optimal utilisation. Another completion of an ATO is needed to use capacity on the grid as a group. Currently, two contract forms in circulation aim to make it possible to enter a transmission agreement (TO) as a group. The first form establishes a group TO, and the second is a group capacity management service.



(a) Connection and Transport Agreement (ATO)

(b) Group transport agreement

(c) Group capacity management service

Figure 2.4: Schematic presentation of three different contract types

Figure 2.4b visually presents a group TO. In a group TO, the individual connections abandon their TO for a joint TO. The connections will then use the group TO to access capacity on the power grid (S. den Ouden, 2023). When an ehub is disconnected, the participants must get a new TO from the DSO. Establishing a group TOs is not possible in the electricity grid code of the ACM (ACM, 2023, Article 3.3). A change in the grid code is needed to make a group TO legally possible.

During an interview with an expert, it was mentioned that companies could provide a group capacity management service. Figure 2.4c on the preceding page presents a group capacity management service. This would imply that individual ATOs continue to exist in an ehub. It would be legally possible since the connections provide a service to the DSO. However, this is yet to be confirmed. In addition, it will be possible to fall back on the individual ATO in case of exit. According to the expert, this would make forming an ehub more attractive.

2.5. Conclusion

This chapter introduces the concept of an ehub and provides a definition and description of its characteristics. Existing literature on ehubs has been researched, including their current description in the Dutch context. The main difference between academic and Dutch literature is the focus on multiple energy carriers. In the Netherlands, ehubs are primarily established on the electricity grid. Since the study is about the Dutch context, the multiple energy carriers in an ehub are considered not mandatory despite being essential in academic literature. A definition of an ehub has been formulated based on the research conducted.

> *An energy hub is a cooperation of actors at a local geographic scale. This cooperation results from smartly matching supply and demand with flexibility for optimal energy usage. The flexibility options concern one or more different energy carriers.*

Implementing ehubs brings benefits on two different levels. Despite being mainly a local implementation, an ehub can also impact the national level by contributing to balancing the power grid. In addition, at the local level, an ehub can contribute to congestion relief. Thus, it can contribute to the economic development of the region. Despite the benefits an ehub might bring, implementing an ehub is not attractive everywhere. Depending on the remaining load on the power grid, an ehub can only contribute to capacity release to a limited extent.

In an ehub, many different types of technical aspects can be linked. Several technologies can be part of the concept because an ehub can vary widely in applied technologies and energy carriers. However, the concept is mainly about cooperation between consumers and producers. Therefore, governance in the system is important. The participants in an ehub depend highly on the infrastructure. With that, development is dependent on grid operators that the government tightly regulates. The incorporation of an ehub into the regulated system is still unclear. Two variants are currently circulating. The first is a group TO that replaces the ATO of individual users. This makes it a service provided by grid operators to grid users. The second variant is a service the grid users provide to the grid operators in addition to the standard ATO. This service is called a group capacity management service.

CHAPTER 3

Theoretical frameworks

This chapter will describe the theoretical frameworks used to analyse ehubs. The frameworks are Multi-Level Perspective (MLP), Strategic Niche Management (SNM), Governance of Change (GoC) and backcasting. Finally, this chapter describes how the different frameworks combine to answer the main question formulated in section 1.3.

3.1. Multi-level perspective

The MLP model is a framework used in sustainability research to study st transitions (Geels, 2011). Specifically, the theory is used to understand and explain the transition to sustainable technologies. The model assumes that technological change occurs at three levels: st landscape, st regime and niches. Further in this section, landscape and regime will respectively refer to st landscape and st regime.

3.1.1. Socio-technical regime

The regime refers to the established system of technologies, infrastructure, legislation and markets that support the current way of life. A set of partially coherent rules guides social groups toward maintaining key elements in the st system (Geels, 2002, 2011; Hoogma et al., 2002). The regime is seen as the regular practice of doing things. The current regime remains stable because of a lock-in mechanism that emerges in the system. The lock-in mechanism arises from three different aspects: rules, actors and organisations, and the st systems (Geels, 2004).

Rules: The lock-in created around rules arises from formal rules such as legislation encouraging certain aspects of the current regime or legally binding contracts with partners. The rules also include the non-formal rules of the regime. There are cognitive rules that cause engineers, for example, to focus only on already known directions. As a result, there is a blind spot for development outside the focus of their knowledge. There are also normative rules that networks adhere to, like mentioning the negative impact on the climate from the production is seen as improper behaviour in certain sectors.

Actors and organisations: The current established system hangs together like a web of connections between actors and organisations. Actions of actors and organisations arise from the relationships they have established based on factors such as trust. As a result, organisations try to maintain the network as best they can, and a certain degree of lock-in occurs.

st systems: The systems active in the regime benefit from complementary aspects. Subsystems may depend on other methods to work correctly. Innovations could potentially alter or even break complementary elements of the system. Cohesion in the system allows for economies of scale. If technology is a standard and frequently used, it becomes cheaper per unit and has an advantage over Innovations. These advantages are then achieved through investments already made in the system; these costs are sunk costs. These sunk costs and benefits lead to most actors preferring to use already established technologies for as long as possible since Innovation can nullify sunk costs.

As a result of lock-in, there is a strong system preference for incremental change. The incremental changes thus ensure a stable system. This change generally occurs in the sub-regimes (Geels, 2004). The different sub-regimes are described below. The sub-regimes do not change separately from each other but function together and thus, as a whole, form the regime as discussed above (Geels, 2011). Although minor changes contribute to the system's stability, more significant changes can result in a (temporary) destabilisation of the system. From the whole st regime, there will be caution regarding significant changes. As a result, significant changes in the regime arise mainly from the other two levels in the MLP framework (Geels, 2011).

Individual sub-regimes emerge from a set of rules a group of actors follows. The actors from these different regimes can be seen as separate communities of actors. Geels (2004) presents the following sub-regimes rules:

Technological & product This sub-regime is defined by formal rules such as technical standards, specification of products, the profitability of R&D projects and return on investment. Within the regime, companies act from self-perception, such as in what business the company operates and the type of company. Innovation within the sub-regime arises from expectations, technical problem agenda, specific search methods for solutions, and examples.

Science This sub-regime is defined by formal rules such as research agendas, professional boundaries and limits within government grants. The regime has a shared perception of peer reviews, citation rules, and academic values and norms. Innovation stems from dominant beliefs and assumptions that are tested and changed through methods to generate knowledge.

Policy The sub-regime defines itself through administrative regulation and procedures that shape legislation. Within the sub-regime are adherence to policy goals, interaction norms between industry and governments, and institutional allegiance to existing systems. The policy regime innovates when the perception is that instruments can be more effective, political concepts such as liberalisation or a problem agenda.

Socio-cultural The sub-regime defines itself via the structure of information dissemination determined in media legislation. The sub-regime binds itself to cultural values within communities and sectors. It strives for innovation from the symbolic meaning and ideas of the impact of technology.

Users, markets & distribution networks This sub-regime is shaped by market laws such as property rights, liability, market subsidies, safety regulations and competition rules. Actors in the sub-regime act through interactions between parties and shared expectations and perceptions. Innovation is motivated by perceptions of what the market wants, expected efficiency in the market and interpretation of how technology works.

Although the sub-regimes exist separately, there is an interconnection between them (Geels, 2004). Highlighting a problem in the media can influence the formation of the problem agenda in politics (Piers, 2001). There is also a connection to how engineers base search models on product specifications linked to safety rules (Geels, 2004). In addition to these examples, many more interrelated rules can be identified between the sub-regimes. Geels (2004) describes the st regime as the 'deep-structure' and thus wants to show that the sub-regimes function autonomously from each other but are still dependent on each other.

In short, the regime forms the core of the MLP framework. The regime represents the playing field of different sub-regimes that influence each other and function together. Its stability and resistance towards change characterise the regime. Its stability and resistance towards change come from the vested interests and power structures that benefit from existing technologies and practices. Therefore, change in the regime mainly results from landscape pressure and niche Innovations.

3.1.2. Socio-technical landscape

The landscape is placed above the regime in the MLP framework (Geels, 2004, 2011). The landscape involves a broader context than the regime. The landscape is more rigid than the regime (Geels, 2002, 2004). Where individual actors can influence the regime in the short term, this is impossible for the landscape (Geels, 2011). The landscape is considered the slowest dynamics, and trends are relatively slow (Kamp & Vanheule, 2015). Because of this, the landscape is considered to be the exogenous context of the system consisting of an assortment of deep structural trends (Geels, 2002, 2004).

As an exogenous context forms a framework within which regime change occurs. The landscape context is shaped by demographic developments, political ideologies, social norms and values, among others (Geels, 2011). An example of change in the landscape is the increase in climate change awareness. This has changed the behaviour in norms and values of consumers and policymakers, resulting in an increased demand for renewable energy. This change in perception regarding climate change has, in turn, led to the stimulation of investment in renewable energy sources and technologies.

In conclusion, the landscape is an essential concept in the MLP framework. It shows that not only internal factors, like technical development or market forces, allow changes to occur in the regime but also external factors, such as societal changes and political decisions. Therefore, understanding the landscape and how it develops is essential for understanding the entire system.

3.1.3. Niches

As described in subsection 3.1.1, there is resistance to radical regime change. It is, therefore, difficult for Innovations to develop and become a competitive alternative and enter the established regime (Geels, 2004). Nevertheless, Innovations do enter the regime, but how do these Innovations emerge? This opportunity for development arises through niches.

Niches provide a temporary protected environment for the development and organisation of potential Innovations (Geels, 2004; Smith & Raven, 2012). A niche functions as an 'incubation space' and usually arises from government subsidies or a strategic investment by companies (Geels, 2002, 2004). When creating a niche, it arises from the expectation that Innovation can continue to develop and then be used in the regime (Geels, 2011). The protected environment provides conditions that contribute to improving Innovation in that environment. These improvements should lead to becoming competitive under the conditions present in the current established regime (Smith & Raven, 2012). It also provides the opportunity to form a network around the Innovation, which helps adoption into the regime.

Geels (2011) named three core processes in niche development: articulation of expectations, building social networks and the learning and articulation processes. The SNM framework builds further on this; therefore, these three core processes will be discussed further in section 3.2. A niche gains traction when expectations are more precise and widely accepted, the learning process results in a dominant structure and the networks of Innovation become larger. In addition, Innovations break out of the niche level when tensions in the regime or shifts in the landscape put pressure on the regime resulting in a 'window of opportunity' (Geels, 2002). Kamp and Vanheule (2015) refer to the 'window of opportunity' as an indirect influence of the regime on the niche. Internal factors like network formation and learning process, described in subsection 3.2.1, are direct influences.

To summarise, a niche is an alternative market in which Innovations such as new technologies, products or services can develop outside the regime. A niche is usually created when an actor expects that an Innovation can enter the regime. Through a 'window of opportunity', an Innovation can enter the regime, and it may contribute to or result in regime change.

3.1.4. Representation of level interactions

Figure 3.1 on the next page represents the interaction between the three levels in socio-technical developments as described in the previous subsections. The figure presents a possible course for introducing new Innovation into the regime. Over time, from below, an Innovation develops at the niche level. Through expectations and networking from the other two levels, internal pressure builds. Changes at the landscape level create pressure on the regime. When enough pressure is built up, resulting in the regime's destabilisation, a 'window of opportunity' can arise that allows Innovation to enter the regime. With the entry of the Innovation, an opportunity arises for the regime to stabilise itself again.

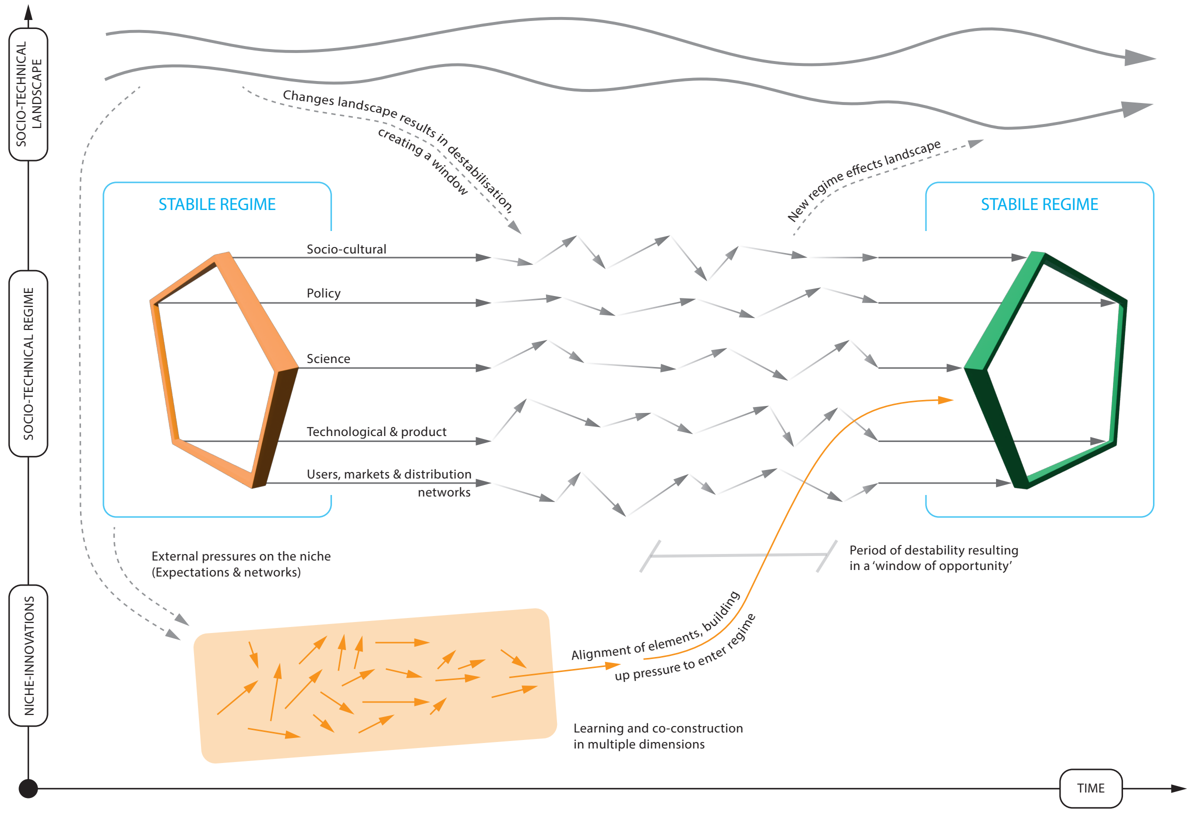


Figure 3.1: Multi-Level Perspective framework based on Geels (2011) - A representation of the dynamics between the levels of the MLP framework. The vertical axis presents the degree of structure of activities, and the horizontal axis represents time.

3.2. Strategic Niche management

The MLP framework described above is adopted in the SNM framework for analysing Innovations and their dynamics (Van Eijck & Romijn, 2008; Raven, 2005; Schot & Geels, 2008). The SNM framework was developed to understand the emergence and diffusion of Innovations. Hoogma et al. (2002) see the SNM framework as a policy tool to create a niche for Innovations successfully. Specifically, SNM creates and manages a niche for a promising Innovation to learn about the characteristics and implications of the application. With this knowledge, parties crucial for further developing the Innovation can then be informed (Kemp et al., 2000). SNM looks at how innovations can evolve through experiments. Experiments are projects to learn about the characteristics of a niche innovation (Weber et al., 1999).

The definition of a niche in the SNM framework corresponds to the description given in subsection 3.1.3. This section defines a niche as a protected environment where Innovations can develop with real users (Geels, 2004; Smith & Raven, 2012). A niche is already somewhat developed in a laboratory environment before Innovations is nurtured in a niche (Weber et al., 1999). A niche exits the protected environment when a 'window of opportunity' arises in the st regime (Geels, 2002). If no radical change occurs in the stable regime, as described in subsection 3.1.1, there is no room for an Innovation to enter the regime (Weber et al., 1999).

In addition to being used for developing a niche, the SNM framework is also used to look at how Innovations can continue to evolve from a niche. An essential aspect of SNM is the scaling-up of an Innovation. Van den Bosch and Rotmans (2008, p. 34) define scale-up as the progression of a sustainable practice from a pilot situation to mainstream use. The flow-through into the mainstream results from various internal processes of a niche (Raven, 2005; Weber et al., 1999).

3.2.1. Three key internal processes

In the SNM literature, the success or failure of an Innovation is described using three internal processes (Raven, 2005, p. 39; Weber et al., 1999, p. 17; Kemp et al., 1998, p. 189–191; Schot et al., 1994, p. 1074). The three internal processes are 1) Voicing and shaping of expectations; 2) Network formation; 3) Learning processes.

Voicing and shaping of expectations

According to Van der Laak et al. (2007), Raven (2005) and Raven et al. (2016), participation in an experiment can be legitimised based on the expectation of an actor. The expectations are particularly important when the innovation does not have clear functionality and performance (Van der Laak et al., 2007). It is, therefore, essential to clearly understand the expectations of different actors and how an actor group can influence the development of an Innovation. Experimenting with niche Innovations can change actors' expectations. According to Hoogma (2000) as cited by Raven (2005), three characteristics can be influenced by experimentation: Robustness, quality and specificity. When these characteristics are present, voicing and shaping expectations is considered good (Van der Laak et al., 2007). An expectation can become more *robust* when a diverse and more extensive set of relevant actors share similar expectations (Raven et al., 2016; Weber et al., 1999). The *quality* of an expectation increases when more experiments confirm an expectation. Weber et al. (1999) consider the quality to result from expectations supported by facts and tests. *Specificity* increases when it becomes clear what steps are needed to realise the expectations of the Innovation. Hoogma (2000) argues that an increase in all three characteristics increases the probability of an Innovation advancing into the mainstream. However, Raven (2005) appointed that there is not much evidence that experiments result in changing expectations. In contrast, external change concerns appear to cause a change in expectations. The external changes are, for example, policy changes or the development of alternatives.

Network formation

The second process of the SNM framework is the dynamics in social networks. A niche emerges accompanied by a network of, for example, users, producers, regulators and interest groups (Raven, 2005). The actors in the network are an essential factor which drives the development and shapes expectations. When a network expands, it contributes to the development of Innovation since more actors in a network often mean more resources are available for development. Usually, a network of an Innovation starts relatively tiny. As a result, the common interest in being successful is still tiny and pulling back ensures fewer consequences for the actors. In a small network, the division of roles is often not yet apparent.

Hoogma (2000) as cited by Raven (2005) presents two characteristics in network formation. The first characteristic is composition. When creating a new social network, it is crucial to consider the participating actors. If a participating actor has interests in an alternative option, participation may be motivated from a defence perspective (Kemp et al., 1998). These parties participate in the network not to encourage but to hinder or even stop it. For this reason, it is crucial to build a network with actors beneficial for the new Innovation. A heterogeneous network will be beneficial to develop the Innovation (Kamp & Vanheule, 2015). The network must not consist only of established actors to encourage radical change in the system. These actors are interested in incremental Innovation, as described in subsection 3.1.1. New actors will bring a new perspective on the innovation and may be better at developing it (Weber et al., 1999). However, incumbent actors are essential for supporting Innovation. As new entrants tend to be limited in the availability of resources and the extent of their network, Innovation is difficult to sustain. Hess (2016) suggests that a lack of established parties can be overcome by involving social movements, building political coalitions, and gathering investments. In addition, in the composition of a network, users are essential to involve, not only as a source of information but for active participation. In addition, non-users are also essential to involve in the network. Non-users experience the consequences of implementing an Innovation. Involving non-users could include the immediate neighbours or could be represented by interest groups (Hoogma, 2000, cited by Raven, 2005).

The second characteristic is the alignment of actors' activities. Alignment refers to the extent to which actors have equivalent visions, expectations and strategies. The composition of the network plays a significant role. Raven (2005) argues that generally, the same type of users maintains a similar direction. In addition, Hoogma (2000), as cited by Raven (2005), argues that if there is substantial history in the network, the parties are better aligned. With a higher degree of alignment, the scope of development in a niche will be more significant.

Learning processes

When introducing a niche, learning is key. In a niche, experiments are designed to learn specific aspects of an Innovation (Raven, 2005). Learning is important to gather knowledge about different barriers to introduction and about ways to overcome the barriers (Weber et al., 1999). Ideally, stakeholders can learn and adjust the Innovation based on the experiment's results. Learning should ensure the alignment of the st factors of an Innovation. Hoogma et al. (2002, p. 28) name five different aspects of learning:

1. **Technical development and infrastructure**
   Involves learning about design aspects and required complementary technology and infrastructure.
2. **Development of user context**
   Involves learning about the user. Aspects such as important values and barriers to Innovation but also characteristics of the users themselves.
3. **Societal and environmental impact**
   These include safety, energy and environmental aspects.
4. **Industrial development**
   Is involved in producing the Innovation and maintaining the social network.
5. **Government policy and regulatory framework**
   Turns to institutional aspects and the role of government. It involves how the government can encourage entry, for example, through incentives.

Besides learning about the different st aspects, it is also crucial to know how learning takes place in niche development. Hoogma (2000) as cited by Raven (2005) recognised a difference between first-order learning and second-order learning. With first-order learning, the focus is on how effective an Innovation is in achieving its predetermined goals. First-order learning focuses on 'how to do things better' within the current ambitions, expectations, and principles (Van Mierlo et al., 2010). Second-order learning looks at the underlying norms and expectations. Second-order learning allows users to formulate their norms and present them to the designer to develop a product in which their needs are fulfilled (Raven, 2005). Second-order learning is more demanding compared to first-order learning. Second-order learning involves returning to the basic norms and expectations, which might result in a complete re-design of the innovation (Van Mierlo et al., 2010). Hoogma et al. (2002) emphasises that both variants are needed in the learning process for niche development to result in a regime shift.

According to Raven (2005), it is not apparent that all enumerated aspects are included in the learning process. For this, the parties involved must be enabled to formulate their values and ideas. A social network that encourages an open structure contributes to the degree of interaction between those involved (Van Mierlo et al., 2010; Raven, 2005). An open structure can contribute to articulating the values and ideas for an Innovation. However, learning about the st configuration of an Innovation is not self-evident.

3.2.2. Interaction key processes

Schot et al. (1994) found in their research that applying all three processes is mutually reinforcing. Therefore, looking at the interaction between the three processes is essential. Raven (2005) describes the dynamics between the processes as follows. Based on the expectations of a system, actors may decide to participate in experiments within a niche. For designing an experiment, the expectation and the network are important. The results of an experiment provide a learning opportunity. How learning occurs depends on the properties of the social network. Based on intermediate conclusions from the learning process, expectations can be updated. As a result of an adjustment in expectations, the composition of the network may change. The adjusted expectation may make participation no longer attractive to certain parties involved or, on the contrary, becomes attractive to parties not yet involved in the process. Thus, the change in composition and expectations can, in turn, contribute to the shape of the experiment. The abovementioned process results in several cycles in which the innovation will develop. Eventually, the development will improve the design of the innovation, and the invention will be mature enough to advance to the st regime.

Adjustments to the expectations of the niche innovation which do not arise from the learning process arise mainly from external developments in the st landscape or st regime. In Figure 3.1 on page 23, it is visible how the two levels described in the MLP framework influence niche development.

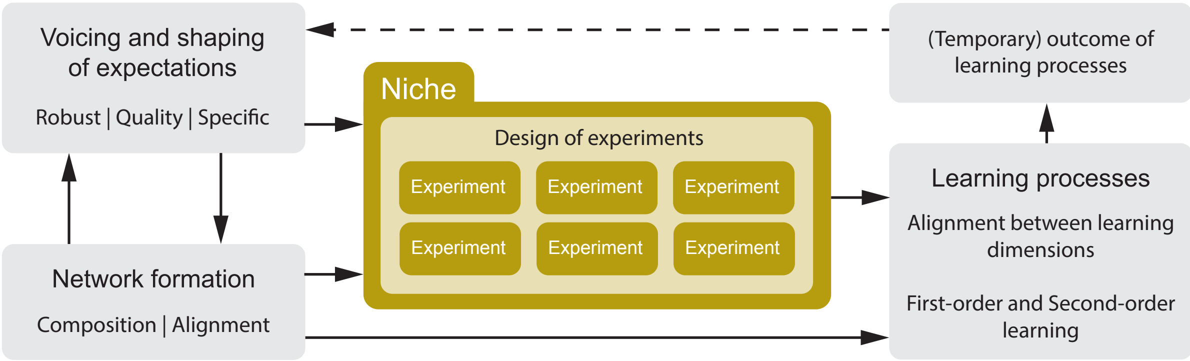


Figure 3.2: Strategic Niche Management framework - Representation of the dynamic interactions between the internal processes in the SNM framework based on Raven (2005).

Conducting experiments and the cycles around the experiments do not, by default, result in regime change. As described in subsection 3.1.4, change requires several aspects. SNM contributes to one of the crucial aspects of a complex system. It stimulates the path to change and contributes to sustainable development.

3.3. Governance of Change

The GoC framework was created by Borrás and Edler (2014b) to look at the patterns and dynamics that take place in st systems and innovation systems. The governance of the systems is an essential factor in analysing the patterns and dynamics. The framework is based on three pillars to provide a comprehensive picture of governance-related change in a st system, shown in Figure 3.3 (Borrás & Edler, 2014a). The three pillars are (1) Capable agents and Opportunity structures; (2) Instrumentation; (3) Legitimacy. The first two pillars examine the ”who and what” and ”how” of governance. As a result, the first two pillars focus on actions in GoC. The third pillar is the ”why” and is used to look at system and process support.

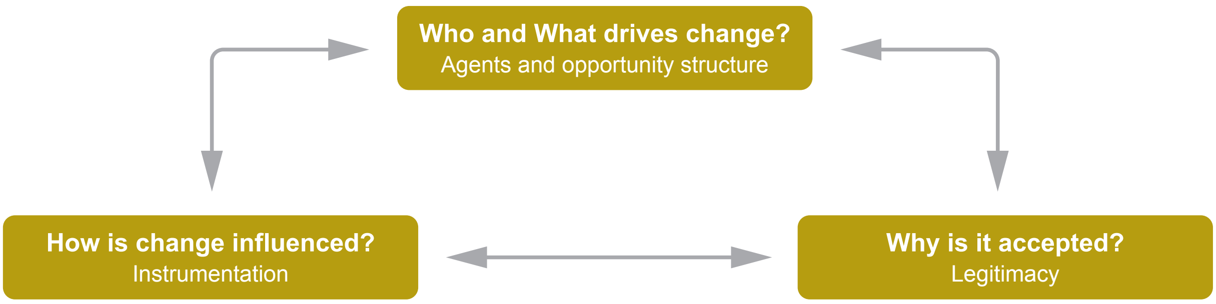


Figure 3.3: Governance of Change framework - The pillars of GoC from Borrás and Edler (2014a).

3.3.1. Capable agents and Opportunity structures

The first pillar is who and what; it examines the interaction between the capable agents and opportunity structure (Borrás & Edler, 2014a). The opportunity structure refers to the development of technology and social institutions. Borrás and Edler (2014a) describe opportunity structure as the possibility for change. The concept of Borrás and Edler (2014a) corresponds to the idea of the ”window of opportunity” in the MLP framework described in subsection 3.1.4. The role of capable agents is seen as an essential factor in activating, directing and suppressing change (Borrás & Edler, 2014a). The degree of capable agents in the system provides variation in how far use is made of an opportunity structure, as described in subsection 3.2.1. How capable an agent is will depend significantly on the number of resources and the agent's interpretive ability (Borrás & Edler, 2014a). Therefore, the distribution of available agents within the network in the system is crucial.

3.3.2. Instrumentation

The second pillar is the how question and focuses on the instruments that agents can apply to initiate change in the st system and help to design and direct change. Borrás and Edler (2014a) refer to a general concept of instruments, focusing on instruments that can bring about change. This includes both policy instruments of government agents and instruments of social agents. As an umbrella term, Borrás and Edler (2014a) therefore use the term 'governance instruments'. There are three reasons why such a broad term is needed to understand GoC in a st system. The first reason given is that there is an empirical question of to what extent a government policy instrument can lead to the governance of change. So it needs to be questioned, to what extent can the government provide the direction towards change and motivate agents? As a second reason, the design and implementation of most governance instruments (using both types of instruments) are essential to explain the change process. The final reason is that traditional policy instruments are increasingly supported and accompanied by social agents' instruments. And the design of the two varieties of instruments differs but works complimentary to each other. In summary, a mix of instruments is used where they jointly lead to change in some situations but not always; therefore, studying both is necessary (Borrás & Edler, 2014a).

In studying instruments, it is essential to look at their design, application and use (Borrás & Edler, 2014a). With the broad definition of instruments in mind, studying the interaction between the two types of instruments is necessary. As mentioned earlier, the two types can complement each other, but there can also be tension between the two and cause the instruments to deteriorate. Therefore, it is necessary to look not only at the effectiveness of the instruments but also at their overall effect on, for example, public values. In addition to the effectiveness, it is essential to understand how agents shape, or reform instruments during and after the design phase of an instrument is essential to understand. The influence of agents is extra significant when the issue is controversial. This often increases the likelihood that agents will not act neutrally (Borrás & Edler, 2014a).

3.3.3. Legitimacy

The third pillar is about the why question and looks at legitimacy. Authorities' preferences may make some innovations stand out more than others. It is, therefore, essential to consider the legitimacy of the actors who bring about change. Borrás and Edler (2014a) therefore use legitimacy as the third pillar and see it as the core concept in the discussion on GoC. Change is perceived as legitimate when there is widespread social acceptance and support. Borrás and Edler (2014a) named three reasons for the focus on legitimacy in the GoC framework. The first reason is the uncertainties associated with a transition. A transition tests the function of established rules, and new activities are accompanied by uncertainty. In times of uncertainty and contestation of institutions in change, call for legitimacy in decisions that shape the change. A second reason is that change is political. Politics thus influences technology, science and innovation and thus affects the value and interest of all stakeholders regardless of whether they participate in the process or not. The third reason is that new governance approaches will ensure binding decisions and thus provide a socially shared direction. Based on the socially shared direction, actors make choices that may be undesirable because it is seen as a normative obligation. Borrás and Edler (2014a) describe two variants of legitimacy output and input. Output legitimacy involves the success achieved with the governance of change. Success can be considered the effectiveness of solving a problem or governance as achieving a goal that aligns with general social preference. These forms of success also work in opposite directions. If the governance cannot effectively achieve a goal, it can lead to a reduction in legitimacy. Input legitimacy is about the role of citizens and experts in the decision-making process. When citizens and experts can give more input into the process, it can increase legitimacy. In a change process, both will be important. When a majority is satisfied with the governance outcome, the minority will look at how the process has gone for the time being. Besides, governing change in a st system is complex. The complexity requires the involvement of citizens and experts to govern change successfully.

3.4. Backcasting

Backcasting is formulated as follows by Vergragt and Quist (2011) ”generating a desirable future, and then looking backwards from that future to the present to strategise and to plan how it could be achieved.”. Despite a relatively simple definition, several variations of backcasting exist in the academic literature. This study applies Quist (2013)’s view of backcasting to creating a future vision and the possible paths that may result in this vision. The study of Quist (2013) combines insights from prior backcasting methods into the participatory backcasting framework. The framework allows a diverse set of actors to extract a shared future vision to gather policy recommendations, follow-up or short-term actions (Quist & Vergragt, 2006). The framework achieves this by combining the following three aspects. 1) Involving a broad field of stakeholders from diverse groups such as companies, government agencies, knowledge organisations and interest groups; 2) Not only using sustainability aspects but also looking at social and economic aspects; 3) Looking at the future of the system in question and related systems.

3.4.1. The five steps

Quist (2013) reviews the various academic literature regarding the backcasting method. From the literature review, Quist (2013) formulates a methodological framework. The framework is intended for application to technological development and sustainable Innovations. Therefore, specifically, the five steps of Quist (2013) are used in this research.

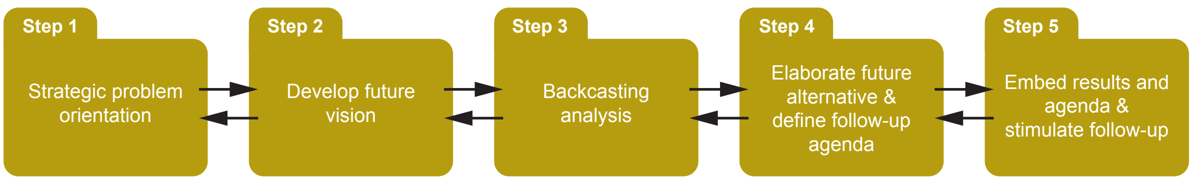


Figure 3.4: Backcasting framework by Quist (2013)

The five steps formulated by Quist (2013) are presented in Figure 3.4 on the preceding page. Although the framework is divided into five steps and thus suggests a certain degree of linear sequence, nothing could be further from the truth. Indeed, iterative cycles can occur between the steps and have a mutual influence. In Figure 3.4 on the previous page, this is represented by the arrows between the steps.

Step 1: Strategic problem orientation

The first step focuses on setting normative expectations and goals. This is done by exploring the problem from a systematic angle and formulating a problem definition, unsustainabilities, possibilities, and solutions while involving the right stakeholders. In exploration, it is essential to identify the problem's perception from the stakeholder's lens. From this lens, it is essential to consider the stakeholder's position towards the system and how it currently functions.

Step 2: Develop sustainable future visions

The first step functions as the starting point for the second step. The second step aims to solve the problem formulated in the first step by creating a sustainable future vision. How societal needs or functioning can be achieved sustainably is essential in the vision. Quist (2013) herein assumes that in a backcasting study, it is always possible to formulate a societal need or function. A single future vision and a set of scenarios can be generated as a product of the second step. The vision, feasibility or creativity can be considered in creating the future image or scenarios. Furthermore, it is essential to create a detailed picture of the desired future vision in this step. It is essential to consider the various st factors such as technology, users and market, culture and policy.

Step 3: Backcasting analysis

As the name suggests, the third step is where backcasting happens as articulated by Vergragt and Quist (2011). This step looks at what changes are needed to achieve the future vision ultimately. According to Quist (2013), there is no agreement in the academic literature on the best method for determining what changes are needed. Suggested methods to apply include describing the future vision, exploratory research, various forms of workshop sessions, or writing an essay (Quist, 2013; Vergragt & Quist, 2011). Furthermore, using guiding questions for the backcasting analysis is mentioned as a method for the third step. Quist (2013) suggests the following guiding question ”What are the necessary changes to make this future vision or scenario become true?”. For more specific questions, are used by Quist et al. (2001) as shown in Quist (2013):

- Which technological changes are necessary?
- Which cultural and behavioural changes are necessary?
- Which structural-institutional changes are necessary?
- Which organisational changes are necessary for realising the desirable sustainable future state?

Step 4: Elaboration and defining follow-up agenda

Like the previous steps, the fourth step will build on the results from the earlier steps. Quist (2013) describes the fourth step as elaborating and defining the actions needed to bridge the gap between the current situation and the formulated future vision. How exhaustive the elaboration of the follow-up agenda depends on the available capacity, budget and time. In the first part, elaboration, assessment, and feasibility are mainly important. The second part defines the follow-up activities and agendas to get from the current situation to the future vision. It is essential to make the follow-up agenda as concrete as possible so that it is clear what steps need to be taken to achieve the desired future vision.

Step 5: Embedding of Action Agenda and Stimulating Follow-Up

The final step of the backcasting framework expresses the importance of following the follow-up agenda. The framework's goal is to make changes in the system towards sustainability. It is, therefore, essential to ensure that the relevant stakeholder takes up the agenda. Stakeholder acceptance is encouraged by involving the stakeholder in developing the preceding steps (Quist & Vergragt, 2006). The agenda should not be translated literally because of that application in a complex st system but should be seen as a guideline (Vergragt & Quist, 2011). In addition, it is essential to evaluate the impact of the implementation. By evaluating the impact, you can gain insight into which actions were successful and which were not. The evaluation can help adjust the follow-up agenda and thus achieve the formulated future vision. Repeating this evaluation process regularly is essential to ensure the implementation stays on track and gets closer to the goal.

3.5. Conclusion

This chapter has described the frameworks which will be utilised to answer the research questions. How and why the frameworks have been used in the thesis is described in section 1.3. In brief, the frameworks can be described as follows. All four frameworks are used in the literature for sustainability research and transitions in st systems. The MLP framework aims to understand transitions from a st perspective. Geels (2004, 2011) makes transitions clear by dividing them into three levels. These three levels comprise st regimes, the st landscape, and niche innovations. A transition is a regime change that follows from a period of instability. The instability may be caused by tensions in the regime itself or by pressure for change from the landscape. A period of instability provides a 'window of opportunity' for innovations to enter the regime. These innovations arise at the niche innovation level.

The niche innovation level can be analysed using the SNM framework. The SNM framework looks at how a niche can be created for innovations. A niche is a protected environment where innovations can develop with real users. SNM named three processes that determine the success of an innovation, Voicing and shaping of expectations, Network formation, and Learning processes. The first two are essential for setting up innovation experiments. Then, the third process describes how learning is done from the experiments, thus shaping the first two processes. This creates a cycle that determines the further development of innovations.

Where the MLP and SNM frameworks look at the change in the system, the GoC framework looks at the governance of change described in the previous two frameworks. Borrás and Edler (2014a) describe the interaction between three pillars. The pillars are capable agents and opportunity structures, instrumentation, and legitimacy. The framework states that competent actors influence the system. By doing so, they can influence the opportunity structure and thus encourage, hinder or drive change. This influence is a consequence of instruments deployed by capable actors. The instruments can be both government instruments and instruments of social actors. According to Borrás and Edler (2014a), combining both instruments is essential in initiating change. Actors do not inherently act neutrally when deploying instruments. Therefore, it is crucial to consider the legitimacy of the instruments. The potential bias in instruments is essential because of the instrument's impact on the system.

The previous three frameworks mainly look at how to change forms and what factors and processes influence change. The backcasting framework of Quist (2013) supports creating a shared future vision to create a policy agenda towards that vision. The backcasting approach is divided into a few steps. First, it looks at the specific problem. Then a sustainable future vision can be created from this problem. The third step looks at what changes are needed to achieve the future vision. Based on the necessary changes, the fourth step looks at a policy agenda to drive the changes. The final step focuses on ensuring the embedding of the agenda and a follow-up agenda.

CHAPTER 4

Methodology

This chapter serves the purpose of explaining the research methodology. First, the research approach will be presented in section 4.1. Next, the choice of frameworks will be presented. The frameworks provide the lens through which data is gathered to examine the research objective. Finally will be described how the data will be analysed in the thesis

The methodology describes how the following research questions are answered in this master thesis. How the different frameworks are used to answer them is articulated in section 1.3 on page 3. The following main question was formulated *"What is needed to stimulate the implementation of energy hubs from a governance and innovation perspective?"*. To answer the main question, the following sub-questions were formulated.

SQ 1. How to define and characterize energy hubs?
SQ 2. How is the innovation energy hub currently positioned as a niche in the socio-technical system?
SQ 3. How does the current socio-technical system of electricity infrastructure influence the introduction of energy hubs?
SQ 4. What does the governance of change entail regarding introducing energy hubs?
SQ 5. What is a possible pathway to encourage energy hub niche development towards the future vision in the Netherlands until 2030?

4.1. Research approach

This thesis uses a qualitative approach to answer the research questions. A qualitative approach helps gather information about experiences, meaning and perspective from the participant's point of view and is useful for investigating systems of change (Busetto et al., 2020; Hammarberg et al., 2016). Bhattacherjee (2012) argues that a qualitative approach is mainly used for understanding phenomena and making sense of a subject. This master thesis looks at the phenom of ehubs and attempts to make sense of the playing field in which the niche innovation ehub plays out. A quantitative approach mainly emphasises understanding and prediction, which is not the focus of this thesis (Bhattacherjee, 2012). Therefore, a qualitative approach is used for this master thesis. A case study is used for the qualitative approach in this master thesis. A case study can be defined as an intensive analysis of a person or community with a focus on developmental factors concerning the environment (Flyvbjerg, 2011, p. 301; Bhattacherjee, 2012, p. 93; Baarda et al., 2018, p. 69–71).

The research is approached from a socio-technical perspective, including both the technical aspects of the innovation and the social and cultural context in which it is applied. For the development of ehubs, this research focuses on factors affecting the acceptance, adoption and diffusion of innovation.

4.2. Case selection

The country of the Netherlands was selected for the case study. The Netherlands in its entirety was selected because the problem of congestion occurs throughout the Netherlands and is expected to increase in the future (Enexis, n.d.; Joulz, 2021; Liander, 2023; Rijksdienst voor Ondernemend Nederland [RVO], 2020; Stedin, n.d.). Therefore, looking at niche innovation at the national level is relevant. In addition, in the Netherlands, ehubs are only deployed in pilot form since it is not an option legally. Even though it is not legally possible, interest in the Netherlands for establishing an ehub is high. Interest in ehubs is high because of the congestion problem, but their realisation is proving difficult in the Netherlands.

4.3. Data collection

This section describes how the data used in this report will be gathered. This will be done through a desk study and expert interview. Combining these two research methods creates a better understanding of ehubs. In addition, the concept of ehubs can be viewed from different perspectives and experiences.

4.3.1. Desk research

The desk study collects information on ehubs from different online sources. These sources include scientific articles, reports, regulations, policy documents and other relevant publications. Based on the literature, the st system can be defined around ehubs. This can be used to describe the different elements of the frameworks presented in Chapter 3. A desk study helps understand the aspects of ehubs. According to Nelson (2009), desk research helps to understand the subject's cultural, social, and political influences. For instance, policy documents can provide insight into the perceptions of government agencies on the ehubs.

4.3.2. Expert interviews

One of the research methods in a case study is conducting an interview (Bhattacherjee, 2012). Bhattacherjee (2012) named that an expert interview can be used to look at a particular phenomenon and understand behaviours within a broader context. This study will use a face-to-face interview to access the interviewees' knowledge, experience, and perspective (Bolderston, 2012; Bourgeault et al., 2010; Nelson, 2009). A face-to-face interview is a qualitative research method allowing flexibility during the interview (Baarda et al., 2018; Bourgeault et al., 2010). A face-to-face interview provides the opportunity to conduct a semi-structured interview. In a semi-structured interview, the topics are prepared in advance with the questions being asked. However, it is possible to go further into the interviewee's answers during the interview (Bolderston, 2012; Nelson, 2009). Going into further detail during the interviews makes it possible to gather information about aspects that might not have been considered before.

Interview protocol

The interview protocol, presented in Appendix B, describes the different topics and questions to be covered during the interviews. The researcher and interviewed experts are Dutch-speaking; therefore, the choice was made to formulate the questions in the interview protocol in Dutch as well. This choice has been made to make the interview as natural as possible. Using the native language makes it easier for the interviewer and the interviewee to interpret the questions and answers (Welch & Piekkari, 2006). The interview protocol is divided into seven parts to create a logical flow.

Part I: Introduction In this part, the interviewee is thanked, the subject and purpose of the interview are explained, and informed consent is discussed.

Part II: General questions This part includes questions about the interviewees and their understanding of the concept ehub. Using these questions, it becomes clear from which perspective the interviewee is looking.

Part III: Innovation development The third part includes questions on how an ehub is influenced and developed as an innovation.

Part IV: Governance This section looks at the parties involved and their role in the process. It also asks whether there is a vision between the different parties.

Part V: Future vision & pathways In the fifth part, the interviewee is asked to outline a future vision for 2030 and elaborate on what will be needed to achieve the described vision.

Part VI: Concluding As concluding questions, the interviewee is asked to name any important topics that were not covered and have any suggestions for potential interviewees and relevant sources.

Part VII: Finishing the interview After the interview, the participant is thanked and informed where the master thesis would eventually be published.

The parts are built from elements from the frameworks described in chapter 3. Questions in part II were designed to gather information to understand how the interviewee views ehubs. Part III then focuses on aspects of the MLP and SNM framework. Part IV continues on aspects from the MLP and SNM framework but also relates to the GoC framework. The final part flowing from a framework is part V which asks the interviewee to formulate a future vision and is applicable in the backcasting framework.

The parts in the interview are divided so that the current situation is discussed first, and then we look at the future vision. By asking about past experiences in the first instance, it is easier for participants to be aware of underlying necessities and values. This awareness serves as a basis for discussing the future and contributes to a more creative future vision (Sanders & Stappers, 2012, p. 56).

Going through the parts described above took about an hour. Asking the questions to the experts, parts II to V, took about 40 minutes. A summary has been made using the transcript automatically generated by Microsoft Teams. The summary aims to stay as close as possible to the interview context without writing it down word for word. It repeatedly occurred that the experts replied with an answer relevant to a previously asked or pending question. To keep the analysis of the data clear, these answers were added under the best-matching question. Experts, for example, mentioned barriers after providing an answer regarding the benefits. Instead of including those answers behind the question about the benefits, it was placed under the question about barriers in the summary. If a question had been answered earlier, the question was asked again, and a summary of the answers given earlier was given. Writing a summary was chosen because of the limited time of the thesis and the high amount of experts interviewed. Since the analysis is based on the insights from the experts and not the literal wording of the answers summarising the interviews is considered to give clear insights into the system. Based on the summary, the experts could see and modify their answers where necessary.

Interviewees

This study chose to call on experts in the ehubs field. The reason for expert interviews is because of the novelty of the concept. Interviewing experts can gather more knowledge, and the information can be considered more credible (Bhattacherjee, 2012, p. 69). To avoid gaining insight from a one-sided perspective, the interviewees were selected to include experts from different sectors. The proposed multi-actor network by Geels (2002) is considered for the different sectors. Besides avoiding a one-sided narrative, interviewing respondents from different sectors also brings more insight into the dynamics present in the system. Geels (2002) named the groups following groups; user group, producer network, public authorities, research network, financial network, suppliers, and societal groups.

Not all domains are present among the interviewees. No respondent was found for the societal groups, which the topic's novelty could explain. In addition, direct users in an ehub were not interviewed. However, park managers of business parks were interviewed, representing the users. Table 4.1 shows an overview of the number of experts interviewed in a specific sector. Respondents were approached in three different ways. Initially, experts within Stedin were approached for an interview. From these interviews, they were asked if they had any suggestions for other respondents within their professional network. Based on this, the majority of respondents were obtained. The third way is through online sources. The authors of relevant sources were approached with an invitation to participate in an interview. Appendix D presents the invitation mail sent to the possible participants for an interview. The consent form is attached to the email. See Appendix C. This explains the rights of respondents and seeks approval for processing the information obtained. Besides processing their data, respondents also agree on how their data will be treated. The treatment of their data involves the retention period and privacy of the respondent. In addition, explicit consent was requested from the interviewee in case of quotes. To this end, an e-mail was sent to the interviewee with the relevant quote written in Dutch and its English translation. Subsequently, the interviewee was asked whether he or she agreed to use their quote, name, and position in the thesis.

Table 4.1: Overview of the organisations participating in the interviews.
The grid operators include both DSO and Transmission System Operator (TSO) **Both knowledge institute experts were part of a single interview.

Type of organisation	#
Grid operator*	8
Province	1
Energy service company	1
Business park	2
Municipality	2
Bank	1
Consultancy	1
Energy supplier	1
Knowledge Institute**	2
National government	1

The search for more respondents stopped at the point of content saturation. According to Baarda et al. (2018, p. 120–122), content saturation occurs when enough matching answers are given. The goal of content saturation is not necessary to get all the information but the vital information (Weller et al., 2018). Weller et al. (2018) suggest that between 10 and 20 respondents are needed to reach saturation. However, it may vary between research domains. Therefore, the degree of similarity in the answers given will be considered within this study. Saturation occurred in around 14 respondents for this study. A few more interviews were conducted after that to include multiple sectors, but saturation also occurred between sectors.

Data processing and storage

The research uses expert interviews; thus, the research uses human participants. To ensure that the rights of the participants remain protected in the research, the research was vetted by the Human Research Ethics Committee from the TU Delft. Based on the data management plan and informed consent, the design for data processing was approved.

The study primarily collects data of a qualitative nature. Personal data is collected from the interviewees. The personal data includes name, email, profession and which organization they work for. Furthermore, the interview is recorded using Microsoft Teams or an audio recording. The personal data will not be published in the master thesis. Using summaries of all interviews, qualitative data is applied in the thesis. The summary is anonymised and only available to this thesis's supervisor. The data is stored in TU Delft storage SurfDrive. This data will be kept for a maximum of two years after completion of the thesis. By taking the above measures, it is assumed that the chance of re-identification is minimal and thus, the rights of the participants are protected.

4.4. Data analyse of interviews

This section presents how the qualitative data obtained during the interviews will be processed in the following chapters. The expert interviews were recorded, and the responses were summarised in text. The summaries were then categorised according to the pre-formulated questions. Since these were semi-structured interviews, more in-depth questions were also asked. The in-depth questions will be summarised under the best-matching question. The summary of the interviews will then be analysed.

A thematic analysis is used for the analysis. Jason and Glenwick (2016) describe thematic analysis as a method of not seeing qualitative data as static. The thematic analysis involves identifying common interview patterns and integrating them with theoretical frameworks. The themes in these frameworks are then used for analysis. This study employs multiple frameworks, making thematic analysis the preferred method. Based on the different frameworks, a set of codes was created to relate the recurring patterns to the frameworks. As described in subsection 4.3.2, the questions were drafted with the frameworks in mind. Therefore, which theme is relevant to each question will vary. Appendix E indicates which thematic code is kept in mind when analysing the answers given in the interview. The qualitative analysis uses the software 'ATLAS.Ti', (2023). The software makes it possible to apply codes to the summaries conveniently. Applying the codes will be done per interview.

Questions two and twelve are coded with more specificity regarding the other questions. These particular questions focus on the differences and similarities between the given answers. The answers are then coded based on the characteristics or future visions of the experts in comparison to the other answers. This aids in the analysis process by formulating a combined definition and vision for ehubs using the given answers. The increased coding specificity enables clear identification of similarities between the answers. The codes concerning the definition and future vision are presented in section E.2.

4.5. Framework application

The frameworks from chapter 3 are applied to analyse the data and answer the questions. Combining all four frameworks has not been done before in the academic literature. The following describes how and why the frameworks have been used to answer this thesis's main question and sub-questions.

The combination of the MLP and SNM frameworks is used frequently in the academic literature (Van Eijck & Romijn, 2008; Kamp & Vanheule, 2015; Li, 2016; Schot & Geels, 2008). According to Kamp and Vanheule (2015), the MLP framework adds the externalities to SNM. Van Eijck and Romijn (2008) describe the importance of identifying multi-level influences on developing a niche innovation to get a clear picture of the whole picture. The MLP framework will be used in the thesis for the same reason, to reinforce the analysis with SNM. MLP will be used to examine the barriers and opportunities for niche innovation. The aspects affecting the niche will be overlaid on the framework for a clear overview of the influences on the niche. In addition, the niche innovation of ehubs takes place in a highly regulated domain (EZK, 2022a). This makes the 'rules' of the sub-regimes interesting. Development is still early; therefore, identifying the system's rules is relevant. 'Filling in' the MLP framework thus makes it easy to see the interactions between the different levels.

Following the MLP framework, the analysis will look at the SNM framework. The SNM framework, described in section 3.2, is mainly based on earlier literature on the framework. Recent SNM literature emphasises using additional factors related to shielding, nurturing and empowering (Sengers et al., 2019; Smith & Raven, 2012). Underlying this change is that experimenting with niches is not world-changing (Sengers et al., 2019). Instead of adding the three aspects mentioned above, this thesis proposes to expand the sustainable transition literature of SNM and MLP to include GoC and backcasting frameworks.

Sengers et al. (2019) mentioned that doing experiments is often legitimate since no significant changes are made. As a result, organisations often prefer staying in the experiments phase of innovation. Legitimising actual change is often experienced as complex and is therefore left behind. The GoC framework looks at the legitimacy of seeking change in the system combined with the necessary instruments and capable actors towards change. The backcasting framework is used to identify the change needed to achieve the future vision.

Using GoC, the analysis will first look at the legitimacy of the innovation. Next, instruments contributing to reducing or exploiting influences will be examined. For these instruments, their capable actors and legitimacy are considered. Considering the legitimacy of the innovation, it is assumed it will benefit the process towards change by supporting action besides experimentation.

After the GoC framework, backcasting is applied. Most of the backcasting steps are already answered by applying the other frameworks. The future vision and how to get there will be explored by further applying the framework. This study will not apply the last step of backcasting because it is a mainly theoretical study. Performing this step will lie with the parties active in the domain.

4.6. Validation

This section describes how validity is maintained within qualitative research. Validity is how accurate the findings reflect the data gathered (Noble & Smith, 2015). The first step in increasing validity is making recordings during the interviews. Making a summary from a few notes taken during the interview provides a huge scope for researcher bias. Thus, recording the interviews takes much of the researcher's interpretation (Bourgeault et al., 2010; Noble & Smith, 2015). As described in subsection 4.3.2, in this study, the interviews will be recorded, which helps reduce the study's bias. Another way is to apply triangulation in obtaining data. Triangulation involves multiple sources of information in substantiating the findings (Bourgeault et al., 2010, p. 94–96). In this study, a desk study is used in addition to interviews to assist the insights from the analysis. The last way to increase validity is through expert consultation. By consulting experts, they can give an opinion on the study's validity. The experts can assess the results' realistic and thus judge validity (Baarda et al., 2018, p. 94–96). In this study, an expert will be consulted after the data analysis. The expert will be presented with the follow-up agenda shown in section 6.3. In addition, the influences on the niche innovation, network, learning process, and expectations on which the follow-up agenda is based.

4.7. Conclusion

This study has formulated five sub-questions to answer the main question. The main question is *"What is needed to stimulate the implementation of energy hubs from a governance and innovation perspective?"*. The questions will be answered in a qualitative case study research. A qualitative study is used to research the phenomenon of ehubs. The case study chosen in the thesis concerns the geographical scale of the Netherlands. The Netherlands has been chosen because of the novelty of ehubs and the unique regulatory situation. In addition, the Netherlands suffers from congestion for which ehubs are a possible solution.

The thesis uses two data-gathering methods, desk research and expert interviews. The desk research involves academic and grey literature. The grey literature consists of policy articles, legislation, and knowledge articles. The interviews are conducted with experts from various sectors related to ehub innovation. The interviewees took part in a one-hour-long interview divided up into seven parts. These parts were the introduction, general questions, innovation development, governance, future vision and pathways, concluding, and finishing the interview. The questions formulated in these parts were based on the frameworks used. After the interview, a summary was made from the recording. The recording was sent to the participants to allow them to review the information given during the interview. Afterwards, all the information, like recording, summary, and informed consent, was stored on TU Delft-approved servers. The analysis was done by coding the interviews based on the elements of the frameworks used. However, questions about the definition, future vision, and pathways were coded more specifically to ensure the experts broadly shared the conclusions.

The frameworks used are MLP, SNM, GoC, and backcasting. Applying MLP and SNM is common practice in the sustainable transition literature. However, newer SNM literature adds additional factors to encompass the development of the innovation towards the st regime. This has been done since early SNM frameworks mostly look at developing experiments and do not enable world-changing innovation. This thesis uses the GoC and backcasting framework to steer towards experimenting and changing the regime to encompass innovation.

While gathering data, validity is considered. There are three main actions taken to increase the validity of the data. For the summary of the interviews, a recording is used to decrease the bias in the summary. In addition, the summary is sent to the interviewees to allow them to provide extra insights or make comments on the correctness. Besides interviews, data is also gathered using desk research. Therefore, applying triangulation which helps to increase the validity of the findings. The last main action to increase the validation is a validation session with an expert. During this session, an expert is presented with the main findings and is allowed to give feedback.

CHAPTER 5

Analysis of energy hubs

This chapter will present the analysis of the gathered data. In section 5.1, the definition of the interviewees will be presented and compared to the previously given definition about ehubs. After this section, the MLP will be used to give insight into the influences on the niche innovation in section 5.2. After the influences, section 5.3 presents the SNM framework looking at interactions on the niche innovation level. At last, in section 5.4, the GoC framework will present the innovation's legitimacy and the instruments that can be used to promote the introduction of the niche innovation.

5.1. Experts energy hub definitions

This section looks at the definitions of ehubs given by the interviewees, after which the shared definition will be examined for consistency with the definition stated in chapter 2.

In the experts' formulation of a definition of ehubs, several functions and properties emerged. The most frequently mentioned property is that an ehub occurs within a local area, with 13 mentions. When naming a local area as characteristic, there is generally no further indication of the size of the local area. In some cases, however, a more specific criterion has been attached. Examples of this could be that the participants must be physically connected to the electricity grid or an ehub is located within a business park. In the definition, a local area is frequently accompanied by the property of self-regulation. Self-regulation has been mentioned a total of 9 times, of which a local area is mentioned in combination eight times. Regarding self-regulation, the experts mainly name the regulation of energy by the group itself. One expert specifically mentioned the self-regulation of energy using an intelligent system. In self-regulation, for most experts, it is not important how it is done as long as it is done. Self-regulation involves using energy optimally or balancing supply and demand, or both. Both are mentioned seven times in 11 unique interviews. For energy self-regulation, the expert mentions aspects such as mutual energy trading and flexibility options. Options include balancing energy optimally on a local grid between supply and demand. Local trading and balancing on energy supply and demand have been mentioned five times. Of which six times unique mentions with self-regulation and eight times with balancing and optimal utilisation.

Five experts mentioned having flexibility options to self-regulate over energy. Flexibility options allow an ehub to use energy optimally and balance supply and demand. Examples of flexibility options that recurred in the interviews are storage, conversion and curtailment of supply and demand. Regarding energy conversion, 11 interviewees mentioned using multiple energy carriers in their definition of ehubs. In these 11 definitions, 5 experts included that the focus is on electricity. The experts stressed that focusing on electricity is for the foreseeable future but that applying multiple energy carriers is eventually desirable.

When it comes to electricity, optimising utilisation capacity in the grid has been named. This means that the various participants collectively stay below a set capacity. If the group manages to stay below capacity, it can contribute to the grid congestion experienced on the electricity grid. In 6 definitions of ehubs, grid operators mentioned grid capacity four times. The naming of grid capacity by mainly grid operators can be explained by the fact that grid congestion and its reduction is their responsibility as grid operators.

In the expert interviews, the question has been asked to define the concept of an ehub. Most experts expressed varying definitions for ehubs. Nevertheless, it was noted that the distinctions between the experts' definitions were primarily in the level of specificity. For instance, a concise definition mentioned the necessity to balance supply and demand, while more detailed definitions included incorporating flexibility options. During the interview with Jorian Bakker, policy advisor, he comprehensively defined an ehub, offering a clear understanding of the concept.

> "An Energy Hub is a semi-autonomous, decentralized energy system where you connect as much local energy generation and consumption as possible through smart control, flexible storage and or conversion." ≪Translation≫
> – Jorian Bakker | Policy advisor central government

The definition given in Chapter 2 is compared below with the functions and properties given in the interviews. The limiting criteria from Chapter 2 are indicated in bold, followed by how the interview definitions compare to the limiting criteria.

Must be spatially demarcated locally A local area often appeared in the definitions given by the experts. Thus, this boundary condition fits the experts' definition.

Is a single legal entity representing multiple stakeholders In the definition of ehubs, a few experts mentioned that forming a legal entity is necessary. Under the heading of local area and self-regulation, several experts did mention that it is about a group of participants doing something together. Although the experts do not mention it, forming a single legal entity is necessary for an ehub, as described in chapter 2.

Has flexibility options for scaling up or down demand and supply of energy Having flexibility options were explicitly mentioned by a small group of experts. However, energy balancing is mentioned repeatedly by experts. The fact that balancing within an ehub should also exist, implies that flexibility options should be included. Therefore, together with the literature from chapter 2, including flexibility is a necessary precondition.

Applies smart energy management system for optimal matching of supply and demand Experts repeatedly mention the need for self-regulation within an ehub. This mainly involves the self-regulation of their energy system. Therefore, having an energy management system within an ehub is important. One expert mentioned the need for an intelligent system to handle energy management.

After comparing the definition from Chapter 2 with those provided by experts, it was found that only the last criterion was not explicitly mentioned. However, it is still considered essential based on current literature and therefore included in the definition. To conclude, the definition in Chapter 2 matches the definition given by experts in the interviews.

5.2. Position of energy hubs

In this section, the concept of ehubs will be positioned as a niche in the Dutch energy system. This will be done by looking at the interactions between different levels presented in the MLP framework.

5.2.1. Landscape

Since this research focuses on the Dutch energy system, the landscape factors that set the scene of the Dutch energy system will be discussed. In the current landscape, some factors nowadays exert a significant influence on the Dutch energy system. These landscape factors then influence the current st regime.

The first landscape factor ❶ influencing the Dutch energy system is the need for sustainability. The urgent need to reduce negative environmental impact and combat climate change has triggered a change that has led to a change in the energy sources used. More sustainable alternatives slowly replace traditional energy sources with high CO_2-emissions. This is supported by European legislation, such as the European Green Deal and the Renewable Energy Directive, which set targets for reducing greenhouse gas emissions and increasing the share of renewable energy in the energy mix (European Commision [EC], 2021b; European Parliament [EP], 2022a). The Renewable Energy Directive states that in 2030, it is required that the Union's gross final consumption of energy from renewable sources is at least 32%, for which the Member States must work together to achieve. The Green Deal covers various initiatives and policies in different areas, including energy, transport, agriculture, industry and buildings. In addition, the European Green Deal aims to transform Europe into the world's first climate-neutral continent. This means balancing greenhouse gas emissions through measures to reduce them and offset the remaining emissions. To do this, making energy more sustainable is one of the pillars.

The second landscape factor ❷ is the growing desire for autonomy at different levels. At both European and national levels, there is an increasing demand for self-sufficiency and reducing dependence on external energy sources. One of the main drivers has been the Russia-Ukraine war. Russia regularly turned off the gas tap, creating an energy crisis in Europe. The threat of shortages caused the gas price to hit record highs (Koster, 2023). The European Union took steps to become independent from Russian gas and oil imports after the start of the war and aims to continue to do so (De Jong, 2022). Furthermore, measures are also being taken at the national level to reduce energy sources from Russian soil (Centraal Bureau voor de Statistiek [CBS], 2023a; EZK, 2023a). At the European level, the Energy Efficiency and Renewable Energy Directive contribute to becoming independent from external energy sources such as gas from Russia (EC, 2022). The Energy Efficiency Directive aims to reduce consumption, and the Renewable Energy Directive promotes the build-up of renewable energy sources and, thus, the need for fossil resources from external actors (EP, 2022a, 2023).

The third landscape factor ❸ is the security of supply and reliability of the energy supply. This third factor can be considered closely related to the first and second factors. However, the security of supply and reliability of the energy supply is considered vital to the acceptance of the transition towards a sustainable and autonomous energy supply. Therefore, this thesis will consider it an individual factor of the landscape. People have become accustomed to the copperplate principle in developed countries like the Netherlands. The copper plate principle assumes enough capacity to transport the desired energy. Until recently, the principle also held with the result that people have become accustomed to the current grid's security of supply and reliability (Kuiken & Más, 2019; Zohuri & McDaniel, 2019). In addition, a stable and reliable energy supply is essential for economic growth, the well-being of society and the operation of vital sectors (Le & Nguyen, 2019; Zohuri & McDaniel, 2019).

A fourth landscape factor ④ playing an increasing role in the energy sector is the data privacy of grid participants. With the emergence of smart energy grids and advanced metering and control systems, more and more data is being collected on individual users' energy production, consumption and behaviour. European legislation, such as the General Data Protection Regulation (GDPR), provides rules and regulations to protect individuals' privacy and ensure that their data is treated securely (EC, 2021a; EP, 2016). It is crucial to safeguard the privacy of this data and ensure that participants have control over their personal energy data. Therefore, participants' privacy in the energy system must always be considered.

A fifth landscape factor of importance is the rise in the price of fossil fuels ⑤. The European Union has set up the emissions trading scheme to reduce greenhouse gases (Stoefs, 2022). The approach is to price greenhouse gases (DG Climate Action, n.d.). The system works by allocating a limited number of allowances to companies which can trade in them. The scarcity of allowances incentivises companies to reduce emissions or buy more allowances (DG Climate Action, n.d.). This has led to higher costs of using fossil fuels as companies have to buy emission allowances to continue their operations (IEA, 2020a). Furthermore, geopolitical changes, especially military aggression by Russia in Ukraine, have led to significant price increases in fossil fuels, such as oil and gas (European Council, 2023). Energy supply disruptions and market uncertainty have pushed prices to record highs. This has directly impacted the electricity market, as Dutch electricity generation relies on fossil fuels (CBS, 2023b; Energie Beheer Nederland, n.d.).

To conclude, there are several landscape factors related to the Dutch energy system; see Figure 5.1. The need for sustainability, the growing desire for autonomy, energy supply reliability, grid participants' data privacy, and energy prices are essential to landscape factors affecting the Dutch energy system. These factors, therefore, have important implications for the st regime and hence the niche innovation ehubs in the Netherlands.

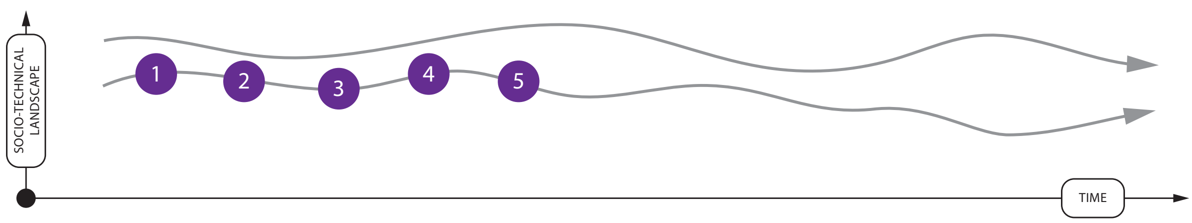


Figure 5.1: Landscape factors - The figure shows the various landscape factors applicable to the Dutch energy system.

5.2.2. Regime

For decades, the Dutch energy landscape has consisted mainly of fossil fuels, such as coal, oil and natural gas. These sources have played an essential role in energy supply (Rijksdienst voor het Cultureel Erfgoed, n.d.; Van de Weterring, 2022). Today, the Dutch energy landscape consists mainly of fossil energy sources, but the share of renewable energy is starting to increase (CBS, 2022; IEA, 2020b). The change to renewable sources due to the desire for sustainability to combat climate change (EP, 2018a). The landscape factor, sustainability, is driving a shift from the energy landscape (regime) that relies mainly on fossil fuels to a renewable system (1). When it comes to renewables, they consist mainly of DER. With the growth of distributed energy sources, such as solar panels on rooftops of houses and wind turbines in different locations, electricity is generated at scattered locations in the grid. The power grid was initially designed for unidirectional power flowing from centralised production to consumers. The current Electricity Act 1998 and Gas Act are outdated and no longer meet the landscape trend of sustainability (EZK, 2023b) (1). However, a new energy law is being drafted to promote energy transition. This law has just passed the Council of States and still needs to go through the necessary steps until the law takes effect (Tweede kamer der Staten-Generaal, 2023). Within the regime, legislation designed for the fossil regime is still active, while new legislation is an insight. In addition, several policy goals seek to make the Dutch energy system more sustainable. For example, the 'Klimaat akkoord' and the various goals set in the 'Regionale Energie Strategieën' (EZK, 2019; Nationaal Programma Regionale Energiestrategie, n.d.). Within the sub-regime policy, there are tensions between legislation and policy goals (1).

In addition, more DER generate power flow back to the grid, increasing the load on the grid. This challenges the grid operators as their grids are not designed for such changes in grid load (Kuiken & Más, 2019; NBNL, n.d.-c). The grid is not made for the unpredictability of DER and cannot cater to peak loads in generation and offtake. In addition, the electrification of companies contributes to the increasing demand for transmission capacity. Companies are increasingly switching to electric equipment and vehicles, increasing their electricity consumption. The upsurge in electricity is a result of the sustainability goals of the Dutch government (2+). This increases demand for electricity transmission over the grid (Van Cuijk et al., 2023). The abovementioned results in net congestion on the electricity infrastructure (2). The problem of net congestion can be considered as reversed saliency. Reverse saliency happens when the development of an aspect of the whole system fails to develop, hindering the system (Dedehayir, 2009). Most experts consider net congestion the main driver for developing ehubs.

In cases of grid congestion, the primary issue is the peak load, where the grid's capacity becomes overwhelmed at specific points in time. To address this, grid operators may implement alternative transportation contracts. This entails offering contracts limiting a grid user's capacity use during specific periods. However, market legislation does not allow for this type of contract (3). When parties willingly accept the alternative, it is tolerated by the ACM (Duijnmayer, 2022). The ACM must modify the different codes concerning electricity to allow alternative transportation contracts. The ACM sees more value in allowing alternative transmission contracts. The ACM has exclusive authority to adjust the relevant codes (ACM, n.d.). But even though they see the benefit of an adjustment, it has not yet happened (ACM, 2023).

Although the 'Klimaat akkoord' seeks the electrification of businesses, for many companies, making their energy needs sustainable is a lower priority (4) (EZK, 2019). The interviews revealed that only a few companies are actively working on their energy supply and its sustainability. These companies are mainly those whose business models heavily depend on energy usage. Additionally, experts indicate that companies with high energy demands require a clear and profitable return on investment before investing in sustainability measures (4). Because the return on investment is important, the price of energy affects the willingness to develop alternatives to access cheaper energy (3+) (Popp, 2002).

When looking at the Socio-cultural sub-regime, there is a growing focus on sustainability. Consumers are increasingly aware of environmental issues and expect companies to contribute to sustainability solutions actively (Essent, 2021). Companies ahead of sustainability can benefit from a positive reputation and customer and employee loyalty. In contrast, companies lacking in this area can suffer reputational damage. Consequently, sustainability is becoming increasingly important in the public image of the Netherlands 5.

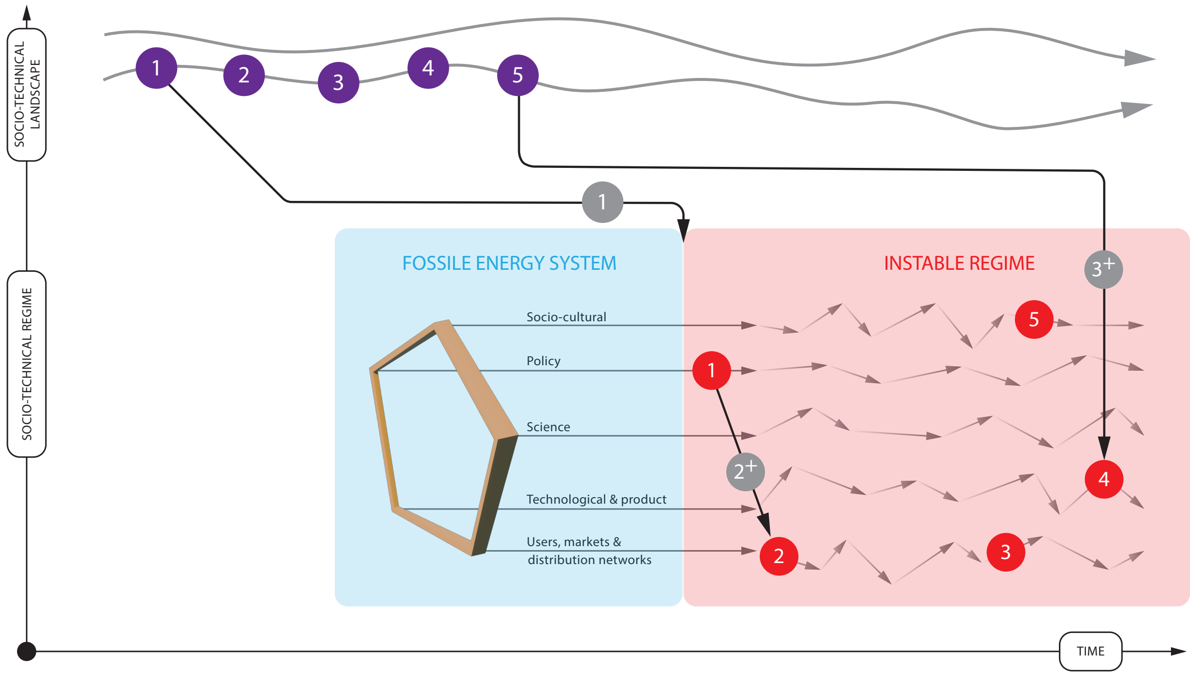


Figure 5.2: Regime factors - The figure shows the various regime aspects and landscape factors influencing the regime applicable to the Dutch energy system.

5.2.3. Niche interactions creating opportunities

The text below discusses the positive influence of these factors on ehubs. The landscape factors discussed are the drive for sustainability, EU legislation, local autonomy targets, and reliable energy supply. In addition, we will cover regime factors, including interaction with grid congestion, socio-cultural perceptions of ehubs and the quest for cost reduction and profit maximisation by companies. Figure 5.3 on the next page builds on the interpretation of the Dutch energy system by adding positive expectations and influences. The text below describes the various interactions presented in the figure.

Landscape-niche interactions

The first interaction is with the landscape factor of sustainability 4+. Experts, therefore, cite sustainability as a personal incentive to develop ehubs. Ehubs are seen as a means to enable sustainability. Although ehubs may contain fossil components, they do not emerge in any interview as part of an ehub. Harnessing renewable energy sources and facilitating sustainable energy supply are crucial aspects of ehubs.

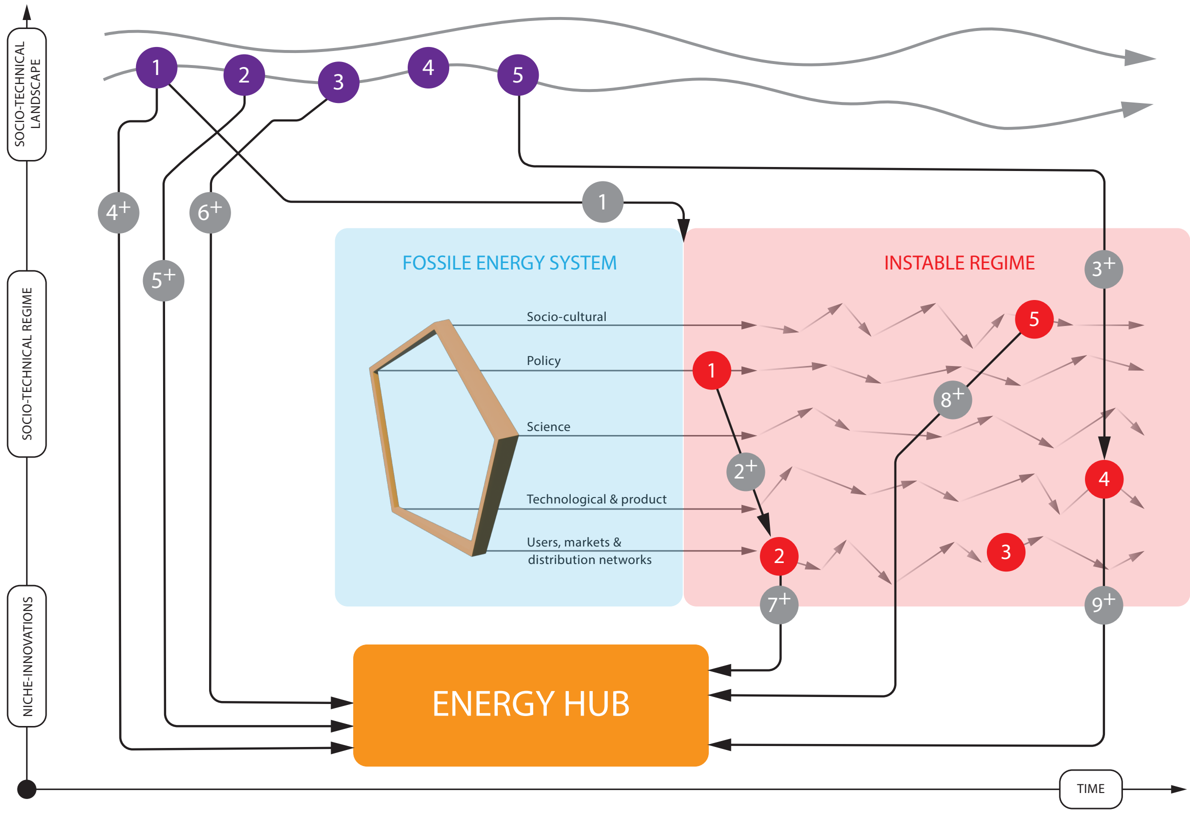


Figure 5.3: Niche interactions creating opportunities - The figure shows the positive influences from the upper levels applicable to the Dutch energy system.

A second landscape-niche interaction is with the landscape factor autonomy 5+. EU legislation and targets seek to promote local autonomy. This mainly involves reducing energy demand and increasing renewable energy production. This benefits ehub development as it can contribute to both areas. For instance, renewable energy can be better utilised locally, and residual heat can increase energy efficiency.

A third interaction with a landscape factor is the factor of reliable and secure energy supply 6+. Ehubs reduce dependence on the national power grid, reducing the negative effects of power cuts and national energy supply problems (Lifeport, 2022). By facilitating local energy production and storage, ehubs can provide a stable energy supply even during grid failures or other challenges. However, this does not emerge as one of the benefits during the interviews. This can be explained by the Netherlands having the most reliable grids in Europe (NBNL, n.d.-b). In 2021, the energy network had a 99.99 per cent reliability (NBNL, 2022a).

Regime-niche interactions

The first interaction from the regime is with the second regime factor, grid congestion 7+. Almost all experts mention that grid congestion issues cause an ehub to be initiated. Companies experience obstacles in their sustainability and expansion because of grid congestion, which inhibits both economic development and sustainability efforts. Traditional methods such as grid expansion are insufficient to meet the increasing demand for transmission capacity (EZK, 2022d; NBNL, 2022b). Therefore, alternative solutions, such as ehubs, are being sought to deal with the current electricity grid more efficiently.

A second interaction between the regime and ehubs can be found at the socio-cultural sub-regime level 8+. Ehubs are often seen as the solution to grid congestion, so several experts point out that ehubs have become a buzzword nowadays. Because it is seen as the solution to grid congestion, the development of ehubs brings positive media attention, which contributes to a positive image for an ehub participant (De Bree, 2022; Dijk, 2022; Jager, 2023; Laconi, 2023).

A third interaction between the regime and ehubs comes from companies' search for innovations that reduce costs and generate profits 9+. With the rising cost of fossil fuels, companies are looking for alternative ways to meet their energy needs. Some experts also agree that higher energy prices are a motivating factor. Harnessing local renewable energy sources, enabled by ehubs, allows companies to reduce energy costs. Besides this, a few experts mention cooperation in an ehub will make it easier to make joint investments in a storage solution, for example. With the higher cost of fossil energy, there is more likely to be a return on investment. Moreover, in some cases, companies can buy renewable energy from neighbouring companies, which is both cost-effective and sustainable.

5.2.4. Niche interactions creating barriers

The implementation of ehubs is influenced by landscape and regime factors. The following text will focus on the landscape and regime factors negatively impacting ehub implementation. Specifically, the negative influences of landscape factors, including reliable energy supply, data privacy and autonomy, will be discussed. In addition, the negative influences of regime factors, such as market codes and profit priorities, are discussed.

Landscape-niche interactions

The first interaction is with the landscape factor of reliable energy supply 10-. Although ehubs can contribute to additional capacity, during the interview, some grid operators doubted its ability to create room on the grid. The main question then is how much space is freed up before it has a significant effect, and is it then still attractive to participate in an ehub. One grid operator emphasized that other characteristics of the power grid must also be considered, such as balancing at the 50-hertz frequency (NBNL, n.d.-d). How frequency balancing can be achieved within an ehub remains unclear.

A second landscape-niche interaction is that between data privacy and niche 11-. Data collection and sharing is an important aspect of utilising the available capacity of an ehub. However, almost all experts mention that sharing the right data is not always possible. The GDPR currently hinders data sharing with third parties. In addition, experts stress that obtaining approval under the GDPR is time-consuming, and companies may be reluctant to share data (NBNL, n.d.-a). However, some experts highlight that this reluctance disappears when companies are hampered by net congestion. Trust among themselves in a business area is also beneficial. Moreover, some data cannot be shared by grid operators themselves.

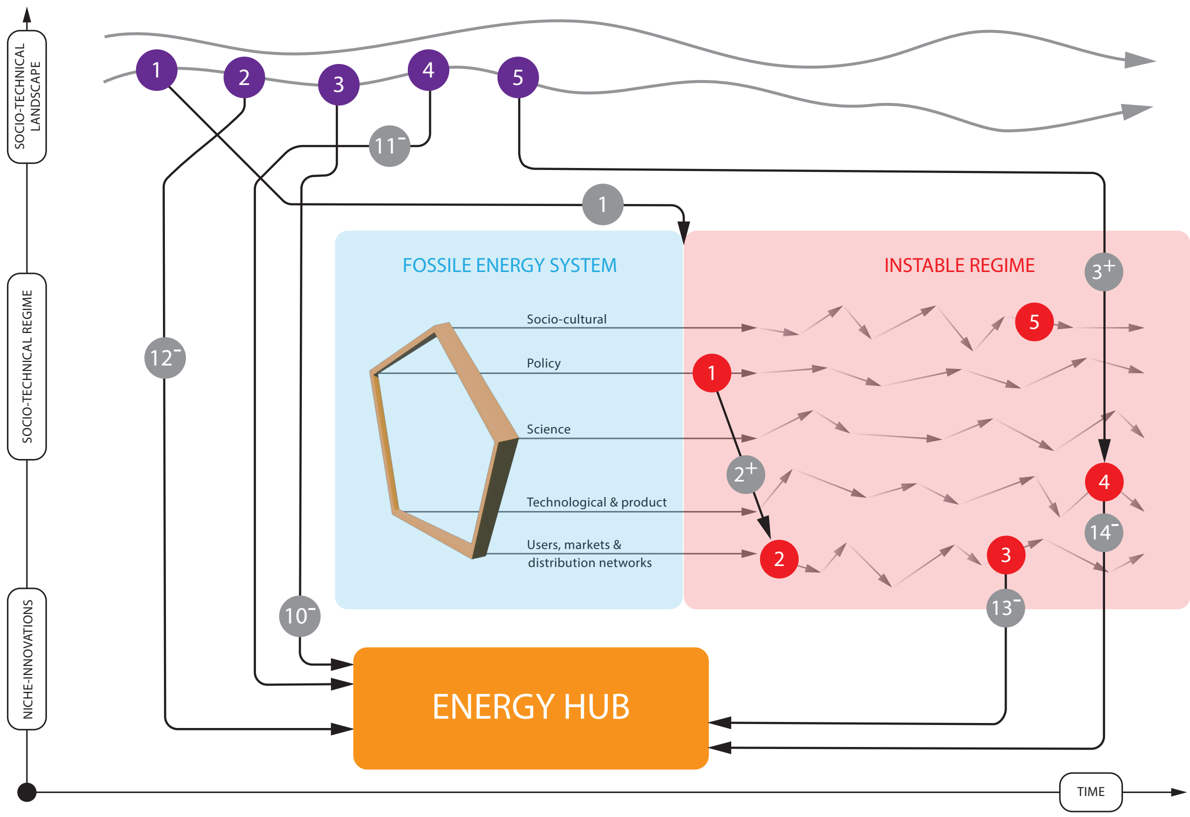


Figure 5.4: Niche interactions creating barriers - The figure shows the negative influences from the upper levels applicable to the Dutch energy system.

A third interaction is the degree of autonomy (12-). Although most experts perceive that autonomy increases with the implementation of an ehub, some experts stress that the personal autonomy of individual companies may decrease. Instead of making their own choices about energy consumption, the energy within an ehub is managed collectively. Experts emphasize the trade-off between dependence on a larger system and local dependence.

Regime-niche interactions

The first interaction between regime and niche comes from the current market codes (13-). Currently, alternative transmission contracts are not permitted, and only the standard ATO is possible. As section 2.4 describes there might be a currently legal way to implement ehubs. However, the ACM has no guidelines or tolerance policy for group ATOs. So, if the grid users voluntarily participate in the contract, it is tolerated by the ACM. Thus, there is ambiguity regarding incorporating ehubs into the codes related to the electricity grid. This creates a degree of uncertainty that hinders the development of ehubs.

A second interaction concerns companies' priority for profit, and investment recovery (14-). Most of the experts mention that getting companies on board and organizing them for an ehub is perceived as a difficulty. Some experts mentioned that energy-focused companies are more likely to participate in the process despite obstacles. In addition, several experts say it is mainly the initial investment determining whether the business park is suitable for an ehub, which often acts as a brake. The current business model without grid congestion is still uncertain, making companies less likely to participate in initiating an ehub.

5.2.5. All niche interactions

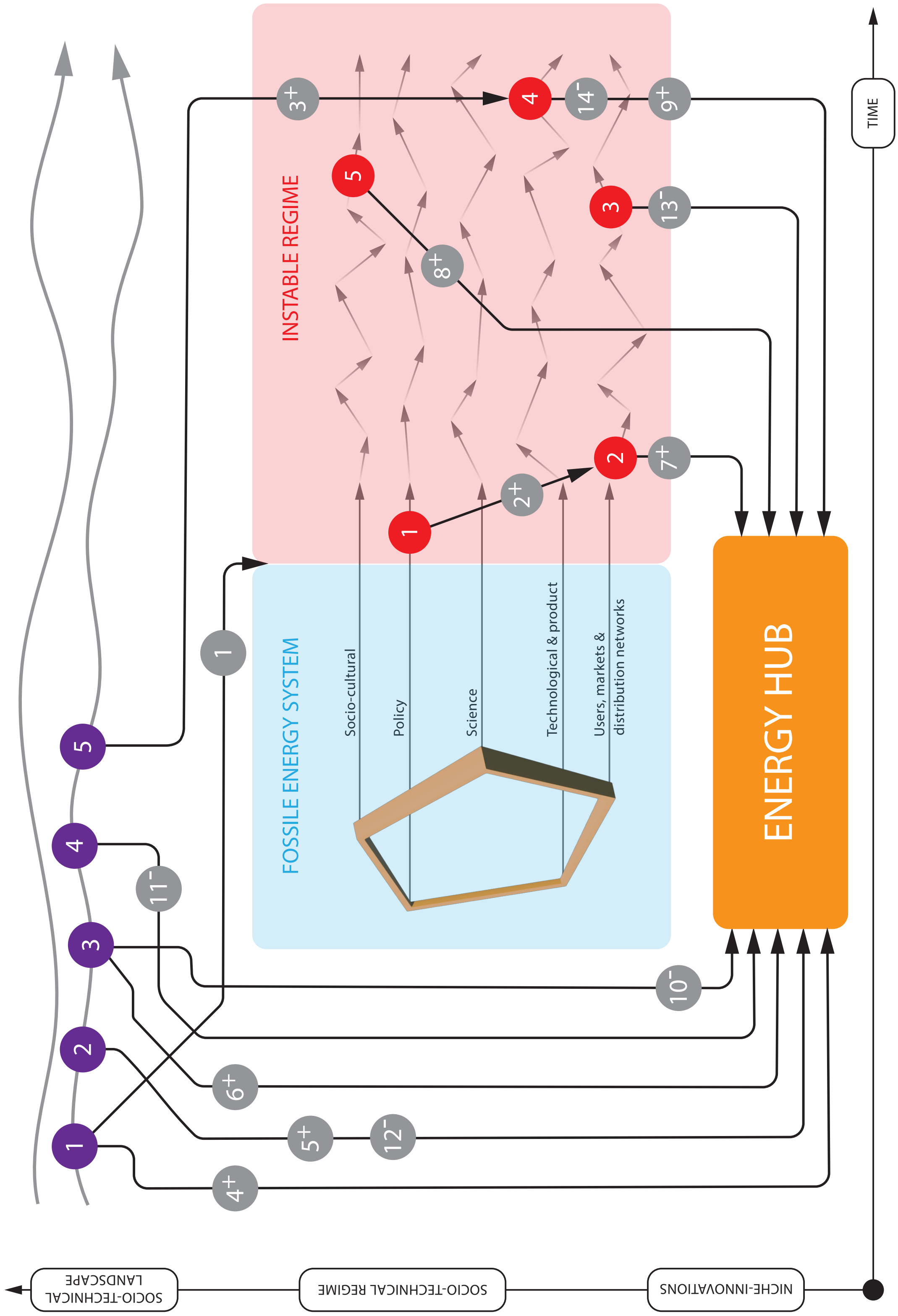


Figure 5.5: Multi-level interactions for niche development of energy hubs - The figure shows all influences between the landscape, regime, and niche innovation based on the MLP framework.

- 1 Sustainability
- 2 Autonomy
- 3 Security of supply and reliability
- 4 Data privacy
- 5 Rise in the price of fossil fuels
- 1 Climate legislation and policy goals
- 2 Net congestion
- 3 Market legislation
- 4 Sustainability requirements and return of investment
- 5 Public image sustainability solutions
- 1 Pressure on the regime to steer towards sustainability.
- 2+ Stimulans for renewable energy sources resulting in more load, creating congestion.
- 3+ An increase in energy prices stimulate the market to look for ways to access cheaper energy.
- 4+ ehubs seen as sustainable innovation. Creating a positive incentive to implement ehubs.
- 5+ Local endeavours, like ehubs, are stimulated since it is considered to increase local autonomy.
- 6+ Security and reliability of energy supply are increased with the application of an ehub.
- 7+ The implementation of ehubs is considered to be beneficial for net congestion. Therefore, increasing the desire for implementation.
- 8+ Positive media coverage about the potential of ehubs stimulates implementation.
- 9+ The increased willingness to innovate stimulate the niche innovation of ehubs.
- 10- Uncertainty about the impact on the grid results in hesitation for implementation of ehubs.
- 11- Implementation of an ehub needs vast amount of data. Participants can be hesitant to participate. Therefore, hindering the implementation.
- 12- Although ehubs increase local autonomy, it decreases individual autonomy, which can be seen as negative.
- 13- Ambiguity regarding the legal acceptance of alternative an ATOs creates uncertainty. The uncertainty hinders niche innovation.
- 14- Companies mainly focus on their own sector. It is considered difficult to involve companies in developing an ehub.

5.3. Current niche management

This section will take a look at the current management of niche innovation. The SNM framework will be used for this purpose.

5.3.1. Voicing and shaping of expectations

The expectations surrounding the benefits of ehubs validate the parties' participation in developing the innovation (Raven, 2005). It is therefore essential to have a clear picture of the current expectations is essential. In developing the innovation, participants will then strive to meet their expectations. It can also work the other way around; expectations can change based on experimentation.

Robustness

When shared by multiple relevant actors, the expectation or vision is more robust (Raven, 2005). When discussing expectations related to the form of an ehub, it is noticeable that most experts used an equivalent definition during the interviews. This is detailed in section 5.1. All experts stressed that an ehub could contribute to increased energy off-take in situations with congestion on the electricity grid. Some experts added that ehubs could also help prevent congestion by using the grid more efficiently. There is thus a robust consensus among stakeholders as to precisely what an ehub is and what its main function is. Regarding a future vision, most experts share an equivalent view on the future of ehubs. The shared vision is further outlined in section 6.1

Currently, the main business case for ehubs, according to all experts, is network congestion. They expect that ehubs can help solve or prevent congestion, allowing companies to expand their electric operations. Moreover, several experts expect that participants in an ehub can also make joint investments in energy assets. Buying, for example, a neighbourhood battery is more likely to be possible. However, experts have different ideas about the future business opportunities of ehubs. These expected business scenarios can be divided into three variants:

1. Ehubs are only relevant when congestion occurs without an ehub. There is then no business argument beyond congestion.
2. High grid investment costs are expected to lead to increased connection tariffs. This will make sharing transmission rights financially attractive. With that, implementing an ehub.
3. Owning an ehub also enables local mutual energy trading between participants. Experts expect this to make a business case for ehubs.

When asked about a future vision for ehubs in the year 2030, there were two types of responses among the experts. Some thought it was still very far away, while others considered it very near. Those who considered it far away often linked this to the goal of making the Netherlands congestion-free by 2029. They concluded that a solution had to be found by then, of which ehubs could be one. So in that respect, 2030 is still far away. Moreover, some experts noted that it would probably take longer to reach the goal of congestion-free networks.

Quality & Specificity

The quality of expectations increases when experiments confirm the expectation (Raven, 2005). The number of experiments currently in progress throughout the Netherlands is small. The largest number of ehubs are starting in the eastern Netherlands. OostNL (n.d.-b) is doing this to position the region as a living lab for ehubs. Ten sites have currently been identified in the region for pilots. These pilots are currently in the research stage of implementation (Oost NL, n.d.-a, n.d.-c). There is a similar level of development of ehubs in other regions in the Netherlands. No fully realised ehub exists in business parks. The quality of expectations is therefore on the low side.

Specificy increases when it becomes clear what steps are needed to realise the expectations of the Innovation. The niche specificity is currently not high. Although the big picture is clear what is needed to harness the potential of an ehub, it is currently unclear how it plays out in specific situations. This is illustrated by the experts' responses on what it will take to realise their future vision. In this, experts directly or indirectly only indicate that the obstacle must be overcome with hardly any specific suggestions. Some experts mention specific instruments, like public-private partnerships and knowledge platforms. Generally speaking, they then indicate that the instrument is now just a quick thought and think it may benefit the innovation. The business case varies so much from one location to another. As a result, it is not scalable between different locations. A standard business plan is needed for full deployment.

5.3.2. Network formation

It is important to have a wide selection of parties in a niche. The broad selection does not just involve many parties; it is also important that the different parties come from different sectors related to the topic.

The network around energy hubs consists of various actors involved in developing these innovative systems. Although still relatively new, the network has recently gained traction, mainly from the "bottom-up" approach. Below, the different actors in the ehub network will be identified. This will include an explanation of the actor's role in the network.

Individual companies from business parks Individual companies participate in the ehub mainly because of their business interests. The problem of congestion, which leads to limited electricity capacity expansion opportunities, hinders their business operations. Companies are motivated to participate in an ehub to gain excess to more capacity on the grid.

Business park management Business park managers are part of the network to ensure the business park can continue developing economically. The expectation for an energy hub is that it can contribute to this and might offer additional financial opportunities. The management often functions as an intermediary for the companies. As such, it plays a facilitating role.

Municipalities and provinces Municipalities and provinces are involved in developing ehubs in two ways. The congestion problem hinders achieving sustainability goals and limits the region's economic development, making it difficult for companies to establish or expand.

National government The national government recognises the potential of ehubs and sees similar benefits as municipalities and provinces. Because of the still limited understanding of the true potential of an ehub, the national government invests mainly in research in this area (RVO, 2023a, 2023b; Topsector Energie, n.d.).

Distribution System Operator DSO connect users to the grid with the desired capacity. However, congestion arises due to the increasing need for capacity on the electricity grid. The DSOs cannot meet this demand of capacity. An ehub offers a possible way to contribute positively. With that, it is a new way for the DSOs to deal with their electricity networks. Since ehubs change how DSOs need to handle capacity requests, it is important to participate in the network.

Transmission System Operator The TSO follows the developments around ehubs but is not directly involved in the creation of various pilots. Nevertheless, the national grid operator must be included in the development of the concept, as ehubs potentially affect the electricity grid at a national level.

Autoriteit Consument & Markt The ACM is presently taking a wait-and-see approach towards ehubs. There is no active participation yet, but it is to be expected that the ACMs grid codes will have to be amended to enable the actual implementation of ehubs. Given their role and responsibilities in regulation, the ACM must be involved in developing the concept of ehubs.

Banks Banks see a potential business model in the ehub. This makes providing loans in the pre-phase of ehubs to recoup their investment attractive.

Energy service companies The Energy service companies have a business model for providing operational services for the ehub. It will help to integrate the aspects needed to balance the energy flow in an ehub.

The network around ehubs includes various actors with different interests and motives. The need for capacity expansion, economic development, sustainability goals and the exploitation of new business models drives the participation of these actors. To successfully implement ehubs, all relevant actors must be actively involved in the development process.

Composition

The composition of the network around the ehubs must include a variety of actors. In the composition, it is also important to consider the motivation for participation in the Innovation network (Kemp et al., 1998; Raven, 2005).

The composition of the social network of ehub innovation development currently shows a striking bottom-up approach. The bottom-up nature of the current composition of the ehub network reflects the challenges arising from recent developments and congestion in the system. To date, ehubs have only been initiated by provinces, municipalities or business parks, with the companies in these business parks mainly forming the user group (ECUB, n.d.; Langenhorst, 2023; OostNL, n.d.-b).

Moreover, some companies are joining this innovation because they see opportunities for a revenue model. Experts from a bank, an energy service provider and an energy supplier have indicated that an ehub is a new potential market they want to tap into. Therefore, these experts recognise the potential and opportunities offered by ehubs.

It is notable that no interest groups are specifically engaged in developing the concept of ehubs. Interest groups play mainly a passive role in the development of the concept. One expert mentioned that in the Landelijk Actieprogramma Netcongestie (LAN), the organisations themselves are not part of the working group for ehubs but are periodically presented with the concept. Thus, the working group only receives periodic advice. As a result, the interest organisations do not play an active role in developing the concept, only in an advisory role. This can be seen as a challenge, as interest groups often play an essential role in promoting and driving innovation. The social group, the user group, and the media bring the link to the cultural and symbolic value of the innovation in the system (Geels, 2002).

Recently, the research network around the development of ehubs is slowly getting off the ground. The Rijksdienst voor Ondernemend Nederland (RVO) and TKI Urban Energy commissioned studies to gather more knowledge on ehubs (RVO, 2023a). The aim is to better understand ehubs and share this information. However, it is notable that there is currently little academic literature on the subject besides research on the technical implications, especially in balancing multiple ehubs. This indicates that there is still room for further research and knowledge development.

Generally, several stakeholders are part of ehub development. The innovation development is supported by parties different in format. The smaller parties, such as business site organisations and the new energy service providers, work closely with organisations from the old regime. The DSOs, banks, and provincial government are part of the network, bringing more resources to develop the innovation. It can be said that innovation is currently still developing, mainly from the bottom-up. It is slowly getting through to the larger parties in the regime.

Alignment

The second component of network formation is alignment, which is crucial in creating a successful collaboration. Alignment refers to the extent to which the participating parties share a common vision about the direction of innovation and the desired outcomes.

As described earlier in the section on expectations and robustness, it is essential that the different parties have a shared understanding of the intended direction of development. While there is agreement on the general direction, there are slight variations in the developments of the business case. Looking at the variations described in section 5.3.1, two distinctive ones can be identified: the financial and social business case. All experts in the interviews agree that ehubs can contribute to solving grid congestion and promoting a more sustainable energy infrastructure. Although specific expectations and priorities may differ, all experts recognise the importance of a well-developed financial business case related to ehubs. This financial case is a compelling argument for companies to invest in such innovations.

However, there is no shared common vision between the different actors in the system. When asking the different experts if they see a shared vision in the system, almost all of them do not think that there is a shared vision regarding ehubs. Despite the common vision concerning the expectations and future vision, described in subsection 5.3.1 and section 6.1, respectively, there is no alignment between the actors in the system.

5.3.3. Learning

A good learning process is essential for the successful development of an innovation. A good learning process consists of two aspects (Van der Laak et al., 2007). (1) The learning process should cover a broad spectrum. This means that learning should focus on techno-economic efficiency, user preferences, cultural significance and policy aspects. (2) The process should be reflexive. Meaning that there is a social value placed on innovation and a willingness to change direction when certain expectations are invalidated. When examining the impact of these indicators on ehubs, it is important to consider the st aspects of the innovation. Here the st aspects must remain balanced in the innovation development. For example, it is important to consider user development when developing a technical case. This could be done by repeatedly soliciting feedback from the user group. Moreover, social acceptance of innovation is crucial for any experiment.

When considering the situation around ehubs, it becomes clear that the technical aspect is already more developed. Interviews with experts reveal that the technical aspect of an ehub is not perceived as difficult. According to the experts, the technical aspect is feasible. However, they mainly stress the need for development in terms of organization, legislation and governance related to ehubs.

The LAN looks at the implication of an ehub. The LAN has three lines of action over which a program is being developed (EZK, 2022d). Ehub development falls under increasing flexible capacity. Although the LAN indicates that interest groups are also connected here, the experts mentioned that the working group of ehubs mainly includes grid operators (EZK, 2022d). One expert said the proposals were written for ehubs but periodically submitted to interest groups. The interest groups do not play an active role in shaping the concept. However, several grid operators mentioned cooperating with companies and regularly seeking advice from interest groups. In addition to business advocacy groups, it is also good to sit down with individual companies. A single grid operator during the interview indicated that discussions are being held with individual companies. Continuous contact with the user group is very important.

Learning is done mainly from a theoretical perspective within the system. Although some ideas are being tested with the user group, only one experiment is implemented. Many projects are still in the reconnaissance phase, investigating whether an ehub is a viable option in a particular location. More experiments must be conducted to learn. As Fleck (1994) states, learning by doing is essential. Conducting experiments (pilots) helps improve the quality and specificity of expectations. For example, business case expectations currently vary widely among stakeholders. Currently, ehubs are only implemented in locations where grid congestion is experienced. Establishing an ehub where grid congestion is not a problem, would be valuable. It would be possible to more realistically test what a business case without grid congestion would look like, as it is not the main driver. However, it is essential to note that initial investment costs for exploration will be challenging. Indeed, the current motivation source for implementing an ehub comes primarily from grid congestion. Financial support from the government or banks could be considered.

Looking at first-order and second-order learning, both aspects are not apparent in the system. Because there are hardly any experiments in progress where ehubs are active, it is impossible to learn about the effectiveness of an ehub. This is also reflected in some of the interviews with the experts, and it is mentioned that there are doubts about the effectiveness of an ehub in being attractive to companies and contributing to the congestion problem. The small number of active pilots explains this unfamiliarity. In addition, increasing efficiency and margins on ehubs is problematic in only a theoretical situation. Since there is no first-order learning in the system, second-order learning does not appear in the learning process. Therefore, it can be concluded that both orders of learning are missing in the development of ehubs.

5.4. Governance of Change

This section will look at the governance of change around ehubs using the framework of the same name. The governance of change framework consists of three aspects: (1) Capable agents and Opportunity structures; (2) Instrumentation; (3) Legitimacy. The first subsection will examine the legitimacy of the concept of ehubs itself. Before striving for change, it is crucial to see whether the innovation is legitimate to implement. After discussing the legitimacy of ehubs, the following subsection looks at the instruments. These are instruments that contribute to the governance of change. The instruments' capable agents and legitimacy will be examined.

5.4.1. Legitimacy Energy hub

Borrás and Edler (2014a) describe legitimacy as the change being socially widely accepted and supported. The development of ehubs is mainly driven from the bottom-up. Multiple experts indicate that the companies as users or the local government initiate an ehub. The motivation for this often comes from problems with grid congestion or a desire for sustainability. Getting started with an ehub is then accompanied by the expectation that an ehub will enable grid access or sustainability. This expectation is based on theory and a few practical cases. The experts did not mention the legitimacy of the concept ehub itself.

Because there is little knowledge about implementing an ehub in the Netherlands, legitimacy is essential. Borrás and Edler (2014a) see that legitimacy exists when users are included in decisions. User input becomes socially accepted when multiple perspectives are part of the decision-making process. In addition, legitimacy can be achieved when seen as effective (Borrás & Edler, 2014a). In this case, effective means successful in driving change.

The concept of ehubs currently enjoys legitimacy from the expectation that it is seen as a successful tool to solve grid congestion. Media coverage shows that an ehub is presented as an effective way to solve grid congestion (De Bree, 2022; Dijk, 2022; Jager, 2023; Laconi, 2023). In addition, experts expressed the potential of ehubs by which they support the adoption.

5.4.2. Instruments for implementation

This section will discuss instruments that can help reduce barriers and exploit opportunities. The legitimacy, relevant opportunities and barriers, and capable actors will be discussed for the different instruments. Table 5.1 on the following page summarises the instruments discussed.

Table 5.1: Overview of instruments that can exploit opportunities and reduce barriers - The numbers in the last two columns correspond to the interactions shown in Figure 5.5 on page 52.

Instrument	Capable agent(s)	Opportunities	Barrier
Subsidisation exploration phase	EZK; Province; Municipality		10; 14
Public Private Partnership	EZK; Province; Municipality		10; 14
Knowledge platform	EZK; Knowledge institutes	8	14
Lobby ACM Code changes	Netbeheer Nederland (individual grid operators); Business parks; Province: Municipalities	6; 8	13; 14
Simplifying data exchange	EZK; ACM		11
Ehub map	Grid operators; Province	7	14
Initiator rol	Province; Municipality		14

Subsidisation of exploration phase

Experts mentioned that starting up an ehub is often difficult. One of the obstacles is the initial exploration phase. This phase studies whether an ehub can be implemented in a business park. Subsidising the exploration phase helps reduce the costs incurred in this phase. It can be considered legitimate because all the experts say this phase is necessary but challenging to start. Therefore, explicitly subsidising this initial phase will be a supported method to support the development of ehubs. However, the experts point out that it should be considered that the subsidies for the investment costs are spent wisely. The experts say that investments should mainly be made in the societal business case of an ehub. The societal business case could be solving a congestion problem. Thus, companies are expected to invest in the financial business model of ehubs. Naming this can be related to the efficiency of an instrument. Using government money for a societal purpose can thus be seen as more efficient than using the same money for financial purposes.

The instrument reduces two identified barriers in the niche ehub. The first obstacle that subsidising the exploration phase reduces is the barrier to investing money in a concept whose added value is unknown, which makes investment slow. Extending subsidies then helps reduce this initial barrier to an exploration phase. The second barrier is the sharing of data by the companies. According to some experts, companies that do not plan to establish an ehub and do not encounter grid congestion tend to use data sharing as an argument not to participate. Although reducing the initial exploration phase directly removes privacy considerations, it is a way to reduce initial hesitation.

The application of subsidisation will be the responsibility of the government. The right conditions must be set to ensure better use of ehubs for societal purposes. One condition could be that there must be congestion to access the subsidy. Moving the subsidy to the lower tiers of government could contribute to better customisation. However, sufficient funds must be made available.

Public-Private Partnership

Setting up a Public-Private Partnership is similar to issuing subsidies for the exploration phase. Some experts indicated that setting up a public-private partnership is a way to use money more effectively than subsidizing the exploration phase. In such a partnership, the government will co-own the entity set up for an energy hub with the companies. In doing so, the government can steer towards societal goals, and in case of a successful financial business case, it allows the government to recoup the investment. It is assumed that the level of legitimacy will be higher than when using subsidies. It offers the possibility to use societal resources to stimulate energy hubs efficiently. However, some experts appoint that it requires more capacity from the government.

Public-private partnerships reduce the same barriers as subsidies. Therefore, reducing the barrier is done similarly. In addition, experts mention that companies may be more willing to invest if the government shows ”skin in the game”. By this, the experts mean reassuring the companies that an ehub is a valid option for releasing capacity on the grid.

Knowledge platform

A knowledge platform is a central place where different parties can gather information about ehubs in a low-threshold manner. The information helps companies, for example, to make informed decisions and it helps to create a realistic picture of the concept. It is also a way to share information about the results of pilots. Having more accessible access to these outcomes then stimulates the learning process. A knowledge platform will help to reduce the transaction costs of setting up and initiating an ehub. This lowers the threshold for companies to start an ehub. In addition, it contributes to having an equal conversation between the different parties. Gathering all information about ehubs in one place makes ehubs more attractive. This assumes that such a platform is a legitimate means of contributing to innovation development. Setting up and maintaining a knowledge platform will be a role for the central government or a knowledge institute. Here, the central government can provide the resources for setting up, and the knowledge institute can provide the platform with information about the concept from a neutral position.

Setting up a knowledge platform for ehubs helps to address an opportunity and reduce an obstacle. Such a platform will help reduce transition costs. Gathering information about ehubs will take less time and money. This will make it easier for (potential) participants to understand the value of implementing an ehub. Furthermore, a knowledge platform benefits by contributing to a more realistic and precise picture of the innovation. This allows users to express desired social values more easily.

Lobby Code changes

Currently, the grid codes are based on the old situation of the Dutch energy system. In the new situation, there is a call for better grid utilisation. For better utilisation, different types of transmission agreements are needed. Better grid utilisation is essential for the future of the energy system (Van Cappellen et al., 2022; Giesbertz, 2022; Wiebes, 2020). With that, lobbying to authorise alternative transmission rights is an effective way to contribute. As such, it is seen as a legitimate instrument. However, adapting the codes must be done correctly to ensure its acceptance. Therefore, gathering knowledge about the use and implications of ehubs is essential. The role of lobbying will mainly be the responsibility of Netbeheer Nederland. It is also up to the business parks, municipalities, and provinces to clarify the essence of alternative transmission rights. This includes the importance of including ehubs in the grid code.

Lobbying for adapting codes applicable to the electricity system affects various interactions between the landscape or regime and niche innovation. Allowing and setting up alternative transmission rights, mainly group transmission rights, shapes the contract needed at an ehub. Therefore, setting the necessary boundaries for such transportation rights is essential. This allows the reliability of the energy system to be guaranteed. Establishing an ehub is receiving positive media coverage (De Bree, 2022; Dijk, 2022; Jager, 2023; Laconi, 2023). This positive media can contribute to the importance of alternative transportation rights. Besides taking advantage of the opportunities at an ehub, some obstacles are being reduced. Lobbying to legalise an ehub through a code change will reduce the current grid code's barrier on ehubs. In addition, the possibility of a contract will remove some of the uncertainty from the market to invest in developing ehubs. When a pilot is started for an ehub, there is uncertainty about the future of an ehub once the pilot has been completed. One expert mentioned that this is a barrier to implementing an ehub. Clarity about the future of ehubs in the grid code provides perspective for pilots and implementation of ehubs.

Simplifying data exchange

Exchanging data is essential to efficiently balance capacity in an ehub. Several experts mention that much time is spent collecting data from different companies in an ehub. It takes a lot of effort to gain permission to access the needed data. At the moment, experts mention this is a time-consuming process. Establishing a way to exchange data more efficiently is essential to reduce the barrier to initiating an ehub. Energy data should be more available to relevant parties, but the direction of the data should remain with the owner (mffbas, n.d.-b). Because the data remains in the control of the data owner, the process is seen as legitimate. In addition, simplification must adhere to the GDPR regulations which helps with the legitimacy. Simplifying data exchange is the responsibility of the legislative parties, EZK and ACM (mffbas, n.d.-a).

Simplifying data exchange will help reduce the reluctance of parties to share data. The simplification will make the conditions of data exchange clear. In addition, if data access from a third party can be quickly withdrawn and the control lies with the data owners, granting access to exchange data will be more comfortable.

Energy hub map

Several experts mentioned that clarity in the objective for the future energy system would help reduce uncertainty. A single expert named a map showing where an ehub will be beneficial according to the province and grid operators reduces the uncertainty about the future. Such a map is similar to one presented by Tennet (2023). This map shows how much battery capacity is desirable for each province of the Netherlands. The experts mentioned that a clear picture would make it easier to persuade both companies in a business park, banks, and insurance companies to participate in an ehub. It contributes to a vision for the companies to stick to. In doing so, however, it must be appropriately implemented. If many areas are designated but ultimately do not turn out to be ideal locations, this will reduce the measure's success and, thus, its legitimacy. It can also contribute to the legitimacy of other measures. Granting subsidies for areas designated by the grid operators and provinces ensures that social money is more likely to be well spent.

Creating a map exploits the potential of ehubs to solve grid congestion. The effort put into encouraging ehubs can be focused on locations with more potential to contribute to solving grid congestion. In addition, such a map, as mentioned above, reduces some of the uncertainty. As a result, companies will be more willing to invest in developing an ehub. Experts mention that the lack of clarity makes companies less willing to cooperate.

Initiator

Most experts say initiating an ehub now comes primarily from the companies. These are often companies that experience obstacles from grid congestion. However, some experts expect an ehub can also prevent grid congestion. In addition, setting up an ehub is a lengthy process, which makes it too late when grid congestion occurs. Appointing a party to act as an initiator can ensure that establishing an ehub can be started preventively. Several experts mention that this role is reserved for a province or municipality. The experts mention that municipalities are often closer to local companies. However, some experts mention that municipalities may not have enough capacity. Therefore, acting as an initiator in cooperation with the province is advised. There is legitimacy for initiating ehubs because they can be seen as legitimate, as described in subsection 5.4.1. The connections of an initiator are crucial to connect all parties. This will help to improve cooperation in the network between the parties.

Establishing an initiator role will reduce corporate hesitance. It does not reduce the extent to which the opportunity for investment return is possible but ensures earlier awareness of the barriers from grid congestion. Besides this, easier connections between different parties will help to reduce the initial transaction costs. Therefore, this instrument does reduce the barrier to investment in development.

5.5. Conclusion

Concluding the chapter, the different sections will be summarised. After this, a summary of the chapter will be given.

In the first section, the definition given by the experts was compared to the theoretical definition between the experts. The definition in chapter 2 matches the definition given by experts in the interviews. In addition, contrary to the experts' belief, the definition is indeed monotonous.

Secondly, the opportunities and barriers resulting from niche interactions are analysed. The analyses set out the st system of the Dutch energy system affecting niche innovation ehubs. Generally speaking, the system is still based on a time when there was a fossil-based energy system. Due to recent changes in the landscape, that energy system has become unstable and finds itself in a system striving for sustainability. In addition, the desire for autonomy and reliable energy supply from the European Union contributes to the move towards renewable energy. Renewable energy sources are preferred in the new system, resulting in energy not exclusively flowing to users from central points but increasingly based on decentralised generation. The current electricity grid is not designed for this, resulting in grid congestion.

Because grid congestion hinders business parks from becoming more sustainable or expanding, or both, a new solution is sought. The ehub concept offers a possible way out of grid congestion at business parks. For the innovation ehub, several opportunities offer potential.

It offers an opportunity for companies to show prestige. For example, an ehub offers the opportunity to create a positive image for a business park. It can also provide a business model for energy-intensive companies.

Besides the expected opportunities an ehub offers, there are also obstacles. For instance, there are doubts about whether ehubs can offer the same high reliability of energy supply as the national grid. Furthermore, parties must be prepared to surrender part of their autonomy to become more autonomous from national energy sources. Ehubs are also hampered in how data-intensive it is to initiate and operate. Companies may be reluctant to release data. Although under pressure from grid congestion or higher mutual trust, releasing data may be perceived as less of a problem. A further obstacle is that it is uncertain when an ehub has a business model. Therefore, companies are less likely to make the initial investment to determine whether an ehub is a reasonable solution. Investing in ehubs is further complicated by the uncertainty about the future of ehubs. In the current grid codes, an ehub is only allowed in pilot situations. This uncertainty makes getting companies on board in initiating an ehub difficult.

The third analysis looks at the niche management of ehubs. The expectations in the social network of ehubs can be seen as robust. Stakeholders generally have similar views on the role of ehubs. The expectations vary most regarding the business case of ehubs. The experts have different expectations about the business case after this period of grid congestion. Some experts expect there to be a business case only when there is grid congestion. Others hope there is still a role for ehubs besides congestion areas. The quality and specificity of expectations are on the low side. The expectations are currently theoretical and cannot yet be supported by niche experiments. The expectations are thus not confirmed from examples. It is, therefore, difficult for the experts to properly formulate what is needed to do justice to the expectations.

The ehub social network encompasses a wide range of stakeholders, both established and newcomers to the energy system. Established parties include government agencies, grid operators, banks and energy suppliers. With new entrants such as business parks and energy service providers. This division presents an exciting opportunity for knowledgeable parties to develop the concept further and for newcomers to bring innovative and radical ideas.

The learning process can be improved by conducting more experiments with ehubs. The network currently learns mainly in a theoretical context. While this is a positive initial move, it does not comprehensively understand the ehub's capabilities. To introduce more learning into the system, it is crucial to gain practical experience. There is only one active pilot in the Netherlands; therefore, increasing the number of pilots would benefit effective learning.

As last, the legitimacy of pursuing change through an ehub is examined. Generally, an ehub is expected to be an effective way to reduce congestion. In addition, ehubs appears positively in the media. Both contribute to the legitimacy of seeking change by promoting ehubs. According to Borrás and Edler (2014a), this legitimises using tools to encourage change.

Several measures can be taken to the barriers of influence on niche innovation development. Some instruments exploit the opportunities at an ehub. Table 5.1 on page 60 summarises the instruments that can be used.

In conclusion, the niche innovation is still early for ehubs. Much is expected from ehubs to solve the current congestion problem, and some additional benefits, like financial gain, autonomy, security, and more, are expected. However, there is still a lot of uncertainty around ehubs. Removing the uncertainty and maximising the benefits is important for adapting the innovation. From the niche management of ehubs, it is essential to undertake a hands-on approach through learning by doing. During this process, it is crucial to prioritise the user group and focus on elaborating the norms and values of the system. To further develop ehubs, multiple legitimate instruments can focus on the development.

CHAPTER 6

Ways to the future

This chapter applies the backcasting framework to the case study of energy hubs. The first step of the backcasting analysis according to Quist (2013) is Strategic problem orientation. In this first step, expectations and goals are considered. The following aspects are essential for this step: stakeholders, opportunities, and solutions. In the previous chapter, these aspects have been dealt with using the frameworks in the appropriate order: SNM in section 5.3, MLP in section 5.2, and GoC in section 5.4. Within this chapter, using the backcasting method, a future vision and the possible paths towards this future vision will be presented. Then, the possible paths towards the future will be validated by discussing them with an expert.

6.1. Future vision

To envision what the future holds, the experts' answers are examined. According to ten experts, local ehubs will be preferred, with four predicting that they will be used in business parks and residential areas. Three experts believe that a local ehub should ideally help balance the national grid. The experts also expect the exchange capacity and energy exchange to be used in an ehub, with eight and seven mentions, respectively. According to seven experts, energy exchange will involve electricity and other energy carriers. Heat exchange is specifically mentioned as one of the possible alternative carriers. Experts indicate heat exchange will be the most realistic alternative energy carrier by 2030. While ehubs are currently being implemented to address grid congestion issues, five experts see a future role for these ehubs even when congestion is not a problem. Moreover, some experts to see standard ehub forms developed in the future. One expert also suggested that ehubs can be created using standard components, allowing for customisation while still adhering to standardisation. Overall, experts interviewed mentioned the importance of ehubs in contributing locally to solving the problems experienced due to grid congestion. The experts expect the ehub to play a social role at the local level. Despite the above, several experts mention that by 2030, ehubs will be primarily active in low quantities. According to the experts, an ehub will be used in congestion areas.

After gathering responses from the experts, their collective insights will be used to form a cohesive vision of the future. This vision will not encompass all of the individual aspects mentioned by each expert, but will instead highlight the generally agreed-upon expectations. Based on these insights, a possible future scenario emerges: By 2030, local ehubs will be established to facilitate the exchange of energy flows and transport capacity. And thus fulfils a social role in reducing grid congestion issues. This includes not just electricity but also heat and potentially other energy sources. Additionally, the role of ehubs outside of congestion will be better understood.

6.2. Pathways

This section will examine the changes needed to achieve at the future vision presented in section 6.1. Quist (2013) states that four questions can be asked to arrive at the steps needed to achieve the future vision.

The first question is what technical changes are needed. In the interviews, experts repeatedly mention that setting up an ehub is technically possible. Instead, according to the experts, change is needed in the other areas surrounding the ehub concept to ensure that it can be implemented. The technical changes will mainly come from optimising the ehub itself. However, first-order learning is limited because few pilots are active, as described in subsection 5.3.3. Therefore, which technical changes are needed is unclear.

The second question is about which cultural and behavioural changes are needed. Four experts mention that awareness-raising among companies is needed to get more attention for ehubs. It is common for companies to overlook the importance of ehubs in preventing congestion until they experience the problem firsthand. Unfortunately, it may be too late to implement effective solutions by that point. In addition, not all business parks are organised. Experts expect that an organised business park will be conducive to the speed with which an ehub can be set up. This is because it is quite a cultural change to go from being unorganised to being organised as a group. As the experts say, this should happen before an ehub is initiated. In addition, several experts mentioned reluctance from grid operators to initiate ehubs. One grid operator indicated that there is a lot of work to be done before a pilot project can be launched. Thereby, section 5.3 shows an interest in more hands-on learning. So behavioural change is needed to move from figuring everything out theoretically to more hands-on learning.

The third question is what structural-institutional change is needed to achieve the vision outlined. According to experts, the main obstacle is the fact that aspects of an ehub are not legally allowed in the electricity code of that ACM and the Electriciteitswet 1998. Under current legislation, entering into a transport agreement as a group is impossible, as discussed in section 2.4. Therefore, sharing transport capacity within an ehub is impossible. In addition, mutual energy trading as a small consumer is not allowed under the current Electriciteitswet 1998. Mutual energy trading will be allowed in the current draft version of the new Energy Act (Tweede kamer der Staten-Generaal, 2023). However, group ATO will require revising the ACM's electricity codes. Section 5.4.2 therefore, suggests lobbying for change to the codes.

The fourth question relates to organisational change needed for the desired future vision. Organisational change is mainly needed when initiating an ehub. A stakeholder will have to raise awareness about ehubs earlier and thus act as an initiator, as described in subsection 5.4.2. In addition, companies should be relieved as much as possible when setting up an ehub. Experts mention that companies often lack time besides their business operations to delve into the concept. However, getting companies involved in the process is precisely what is important. Both for gaining insights into the norms and values of the concept and for participating in pilots to develop ehubs. The threshold to get involved in setting up the concept must be as low as possible. For instance, companies should be able to gather information in a low-threshold manner. Section 5.4.2 mentioned that setting up a knowledge platform can contribute to reducing the threshold. Another way to reduce the threshold for companies is to make it easier to exchange data as described in subsection 5.4.2. Apart from simplifying the process, certainty about the future of ehubs is also needed. Experts say that companies may be reluctant to participate because of the uncertainty surrounding legislation and, therefore, the future of ehubs. In addition, certainty also ensures that larger established companies participate in developing ehubs, such as investment and insurance companies. One way to achieve certainty is to adapt legislation and electricity codes. Furthermore, clarity in shared vision about ehubs and socially desirable locations can increase certainty. In subsection 5.4.2, an ehub map is proposed with suggestions for locations where ehubs bring added value both in congestion areas and preventively.

6.3. Follow-up agenda

This section set out the follow-up agenda arising from the shared future vision and required changes. First, the broad outlines will be set out using backcasting frameworks. Then the instruments from subsection 5.4.2 will be used in the phases resulting from the backcasting approach.

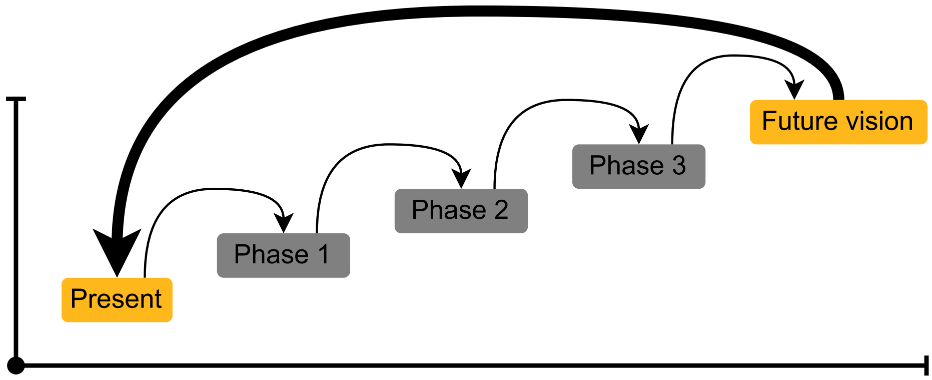


Figure 6.1: Simplistic representation of phases towards a future vision for energy hubs - The arrow from the future vision to the present presents the changes identified in the previous section. The phases between the current state and future vision present the intermediate steps needed to reach the future vision.

The previous section identifies three phases for the future vision, as presented in figure 6.1. The first part is to validate or disprove the expectations around ehubs among the stakeholders, as discussed in section 5.3. Utilising the SNM framework, this can only be done through learning by doing. Therefore, the first phase will be learning by doing. In this phase, the foundations are laid out to move from theory to practical knowledge. By strengthening expectations, it will be possible to provide more certainty about the future of ehubs. The second phase is to establish certainty around ehubs. Legally enabling important functions in an ehub will increase certainty. In addition, laying a good foundation on data exchange and a revenue model for ehubs will ensure that potential participants are more likely to see the potential. More ehubs will emerge by removing or reducing several barriers. An incentive must be created to ensure that ehubs arise in the right places. The incentive should thus aim to establish ehubs in socially desirable locations. This will be done in the third phase, the societal focus. The way different phases work through the shared future vision is detailed below.

Although this is a follow-up agenda, no dates are linked to the different phases. Instead, the actions are relative to each other. Both the different phases and the agenda items are relative to each other. This was chosen because of the uncertainty about the duration of essential actions on the agenda. When the new energy law goes into force is not yet certain, nor is its exact form. This makes it difficult to attach timeframes to certain elements on the agenda. The agenda is therefore based on the following actions being carried out. Figure 6.2 on the next page visually represents the different phases and how each phase leads to the future vision.

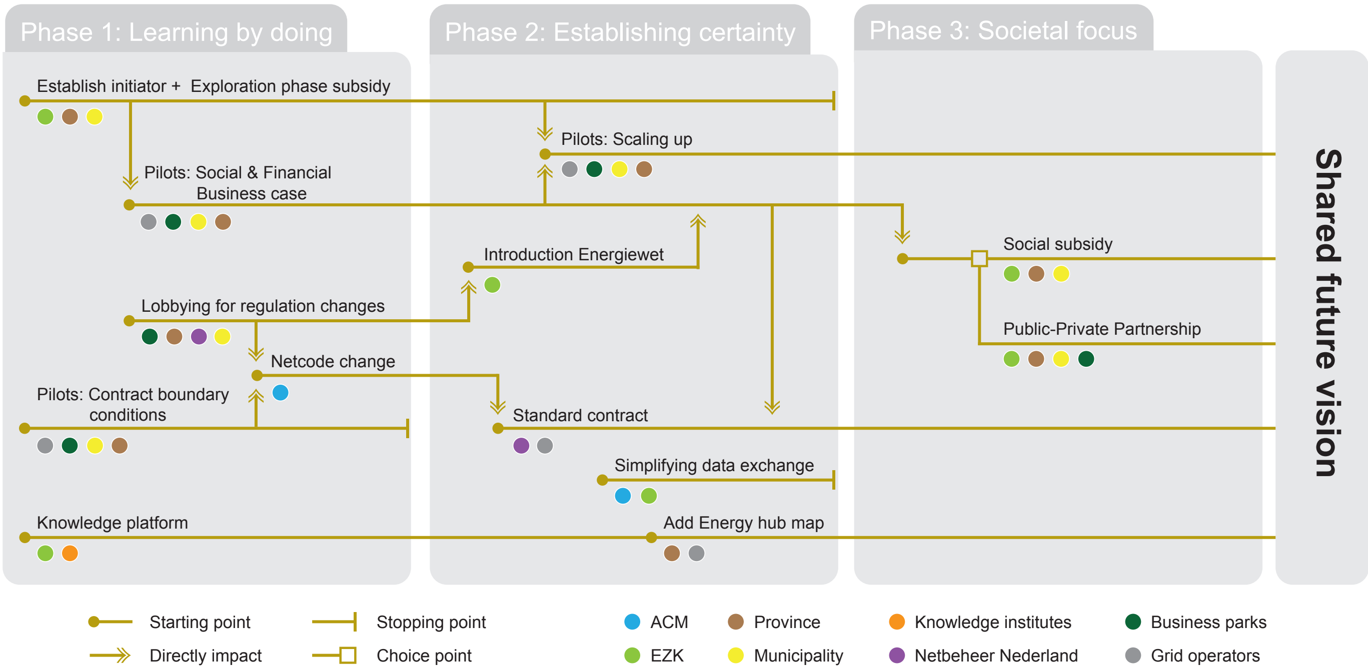


Figure 6.2: Follow-up agenda

Phase 1: Learning by doing

The primary goal of the first phase is to establish a strong foundation for the future development of ehubs. Experts have specified that legal barriers are one of the most significant challenges to the success of ehubs. It is, therefore, crucial to remove the legal obstacles in the netcode as soon as possible The insights from the current pilot projects can be a starting point for netcode adaptation. The current pilots are an excellent opportunity to experiment with different contract types and setups relevant to needed changes in the netcode. The knowledge gained from these pilots can form the basis for the necessary adjustments to the netcode. To make the importance of adjusting the netcodes known to the ACM, lobbying can be done by the different parties. During this phase, it is essential to focus on learning by doing, which requires new pilot sites. Raising awareness about the potential of ehubs can be achieved using an initiator. Informing companies about the benefits of ehubs can help to generate awareness. The role of the initiator is mainly to start up pilot sites, both within and outside congested areas, to learn about their social and financial business cases. As the current business case of ehubs is still uncertain, it is clear from the interviews that getting companies on board is a challenge. Therefore, a subsidy is needed to finance the exploration phase into the potential of ehubs. As described in subsection 5.4.2, an initiator role will stimulate cooperation in the network and reduce transaction costs.

So, in addition to the initiator role, a subsidy is needed to start more pilots, as described in subsection 5.4.2. Experts have different expectations of the business case, so it is essential to determine the business case for ehubs. The knowledge obtained from conducting pilots can be shared on a knowledge platform to improve knowledge dissemination and promote learning across the network. Establishing a platform early on is crucial to maximise its usefulness. Additionally, creating awareness around the concept is essential. An informational website with a low threshold should be established to aid in understanding the system. After the first phase, learning from the already active pilots will continue to be necessary. While learning from these pilots, it is essential to consider first- and second-order learning. As described section 3.2, a balance between both learning orders is essential to get a complete picture of the niche innovation.

Phase 2: Establishing certainty

The second phase focuses on removing uncertainties. The first step is to change the ACM netcodes. Enabling ehubs in the netcodes removes uncertainty about the possibility of going onwards with ehubs. After changing the netcodes, it is desirable to form a standard contract. A standard contract will clarify the participants in an ehub. Aspects like allocated capacity and the financial scheme will help to provide insight into the business case for an ehub. For example, one expert mentions the need for a detailed business model to get a loan from the bank. If there is uncertainty in the business model, it is more challenging to get a loan. Besides, the netcode and standard contract will also contribute to the certainty of the financial business case for ehubs if the new energy law is adopted. Certainty about the financial business case will help with upscaling of the innovation. The current draft version of the energy law allows peer-to-peer energy trading (Tweede kamer der Staten-Generaal, 2023). The chances of a profitable financial business model are higher with peer-to-peer energy trading, which provides an additional way to recover the required investment. However, the uncertainty persists longer if it takes more time for the new energy law to be passed. As mentioned by multiple experts, this might result in relying on alternative incentives to enable ehubs. The need for financial compensation in an ehub contract has been discussed during the interview with experts working for the DSO. This means that the pilots' outcome will influence the contract's form. Besides certainty from legislation, it can also be created by identifying locations where locating an ehub is socially desirable. In subsection 5.4.2, using an ehub map is suggested. Knowing socially desirable locations shows ehub participants where implementing will be most beneficial. In the second phase, simplifying data exchange is also important. Simplifying data exchange is part of the new energy law (EZK, 2022c). This should make it easy to understand and share data with parties.

Phase 3: Societal focus

In the third phase, the implementation of ehubs must be driven by social added value. Ensuring social value will help the legitimacy of promoting ehubs. Keeping the increase in social value from the implementation will increase the legitimacy of spending social capital. If the pilots show that ehubs can contribute socially to preventing and resolving grid congestion, it must also be done correctly. If the financial business case is not profitable enough to be taken up on business sites, it is important to subsidise the unprofitable top to make it more attractive. The subsidy must be granted only in socially desirable locations. Several experts also stress that focusing on social contribution regarding government support is essential. When there is a social and financial business case, some experts mention that a public-private partnership is an excellent option to ensure the social purpose is not lost. In addition, public money can be spent efficiently because part of the investment can be recovered.

6.4. Validation

During a validation session, one expert was consulted to assess the frameworks. The expert's opinion was sought on the findings and whether anything was missing from the analysis. The expert agreed with the findings throughout the session and noted that they provided a clear picture. The only point of discussion was the elaboration of the public-private partnership. The expert was curious about how it would work in practice but acknowledged its usefulness.

Summarising, the validation with an expert shows that the findings do not contain any peculiarities that do not correspond to the expert's view of the system.

6.5. Conclusion

In conclusion, this chapter merges the findings from the previous chapter to form a follow-up agenda. First, it formulates a future vision to work towards. The future vision is formulated as follows: By 2030, local ehubs will be established to facilitate the exchange of energy flows and transport capacity. And thus fulfils a social role in reducing grid congestion issues. This includes not just electricity but also heat and potentially other energy sources. Additionally, the role of ehubs outside of congestion will be better understood.

With the future vision in mind, four questions were asked to gain insight into the required changes towards such a future vision. The questions examine technical, cultural and behavioural, structural-institutional and organisational changes. The need to learn more in practice, have higher certainty, and maintain a social focus regarding ehubs comes from these questions. Three phases were then established 1) Learning by doing; 2) Establishing certainty: 3) Societal focus.

The first phase of learning by doing revolves around launching pilots. To encourage learning, an initiator and knowledge platform will be established. At the same time, the first steps will be taken towards reducing uncertainty through lobbying for netcode change. With the netcode change, the follow-up agenda moves into the second phase. The second phase focuses on reducing uncertainty. This mainly concerns institutional and financial security regarding ehubs. In the last phase, financial incentives ensure implementation focuses on social added value. The follow-up agenda is presented in Figure 6.2 on page 70.

The follow-up agenda was validated in a session with an expert. The expert agreed with the follow-up agenda that was drawn up. It knew the issues outlined in the follow-up agenda and saw the importance of the agenda items that have been proposed.

CHAPTER 7

Conclusion, Discussion, and Recommendations

This chapter will address the sub-questions, presented in section 1.3, to answer the main question. Once the main question has been answered, the discussion will be presented. On this basis, recommendations for future research and policy advice will be given.

7.1. Conclusion

This study aims to provide insights into implementing ehubs in the Dutch energy system. To gain these insights, four theoretical frameworks have been used. First, the MLP framework is used to gain insights into the Dutch energy system. See section 5.2. these findings examined the opportunities and barriers to implementing an ehub in the system. The SNM framework was then used to gain insights into the development of niche innovation concerning the ehub concept. See section 5.3. Next, the GoC framework looked at the legitimacy of pursuing change by implementing an ehub. See subsection 5.4.1. Different tools are proposed to support the development of ehubs based on the expectations formulated with the SNM framework. In addition, legitimacy and capable stakeholders are considered for implementing the instrument using the GoC framework. See subsection 5.4.2.

The frameworks have been used to answer the sub-questions in subsection 7.1.1. The main research question can be answered in subsection 7.1.2 by answering the sub-questions.

7.1.1. Sub-questions

Section 1.3 presents the sub-questions and the frameworks used in to answer the sub-questions.

Sub-question 1

The first sub-question is *How to define and characterize energy hubs?*. A literature review was first conducted to determine the definition and characteristics of an ehub. This identified the following characteristics of an ehub:

- Must be spatially demarcated locally;
- Is a single legal entity representing multiple stakeholders;
- Has flexibility options for scaling up or down demand and supply of energy;
- Applies smart energy management system for optimal matching of supply and demand

The characteristics formulated above combine the academic, grey and policy literature. Although the academic literature also requires different energy carriers, this is not part of the characteristics. This was chosen because the scope of the study is the Netherlands. In the Dutch literature, an ehub is also referred to when it only involves the application of electricity. This was also reflected in the interviews with experts. The experts mentioned that applying several energy carriers is possible in the future, but at the moment mainly concerns electricity. In the interviews, the latter characteristic did not emerge. However, based on the literature, it is essential for balancing the energy flows in an ehub.

The following definition has been formulated from the characteristics: *An energy hub is a cooperation of actors at a local geographic scale. This cooperation results from smartly matching supply and demand with flexibility for optimal energy usage. The flexibility options concern one or more different energy carriers.*

Sub-question 2

The second sub-question is *How is the innovation energy hub currently positioned as a niche in the socio-technical system?*. The ehub innovation has only just started to develop and is, therefore, in the early stages. Those involved in the development see ehubs as a promising concept to support the energy transition by making better use of the electricity grid. Several parties are involved in the innovation development of ehubs. This includes new players who want to introduce ehubs as innovation and established parties in the current regime, such as energy companies, grid operators, and public authorities. This variation of parties is conducive to innovation. For instance, the established parties bring more capacity and network into the niche innovation, whereas the new players bring more radical change to the innovation.

The parties involved have mainly theoretical expectations about the potential of ehubs. For example, they expect that ehubs can contribute to more efficient electricity grid use, reduce dependence on fossil fuels and create a resilient energy system. Stakeholders' expectations have similarities, which means they can be considered robust. However, these expectations have not yet been fully confirmed due to the relatively recent emergence of ehubs as a concept. As a result, the quality of expectation is lower. Moreover, it is unclear how exactly these expectations can be met. The mechanisms and technologies required for ehubs to function effectively still need further research and development. The lack of clarity on the realisation of expectations contributes to the low specificity.

Van Eijck and Romijn (2008), Raven (2005) and Schot and Geels (2008) describe that quality and specificity can be improved by learning through experimentation in the form of pilots. According to Hoogma (2000) cited in Raven (2005), there are two ways of learning, first- and second-order learning. First-order learning concerns learning about the effectiveness of an innovation, e.g. improving the business case. Second-order learning is about the norms and values of the users of an innovation, e.g. what aspects are essential for the users to start using the innovation. By applying both orders of learning through pilots, knowledge can be accumulated and exchanged between stakeholders. Resulting in a better understanding of the concept making the expectations from better quality and specificity.

All in all, the concept of ehubs is still in the early stages of niche innovation. Although there is already a lot of interest and commitment, many lessons remain to be learned from practice. Through experiments, pilots and cooperation between different stakeholders, knowledge about ehubs can be increased, and the current theoretical expectations can be tested and improved. This will further strenghten the position of ehubs as a niche innovation in the st system.

Sub-question 3

The third sub-question is *How does the current socio-technical system of electricity infrastructure influence the introduction of energy hubs?*. An initial positive influence comes from the desire for energy supply sustainability and security. It is expected that an ehub can ensure that a new connection to the grid can access unused transmission capacity. Grid congestion currently hinders the traditional procurement of capacity. As a result, companies are hindered from becoming more sustainable through electrification, and new renewable energy installations cannot be connected. The introduction of ehubs is then encouraged out of a desire for sustainability and to solve the current grid congestion problem. There has been positive coverage of ehubs due to the expectation that they can help relieve network congestion. The positive exposure contributes to the acceptance of ehubs and thus helps their introduction. The introduction of ehubs is also positively influenced by the push for autonomy from EU legislation. The EU seeks more energy autonomy for local communities. An ehub is such a local community. Ehubs therefore experience positive influence for their introduction. In addition, the increased cost of fossil energy sources makes introducing an ehub more attractive. Because an ehub may enable electrification, it helps reduce dependence on fossil fuels such as natural gas. For example, an ehub can provide a way out if a business park is prevented from switching.

Although fossil fuel costs contribute to the uptake, the cost of initiating an ehub is hindering the implementation. It requires an initial investment before setting up an ehub. Companies are reluctant to make this initial investment because of the novelty and unfamiliarity surrounding ehubs. This is a barrier to the introduction of ehubs. Besides an investment of money, it also requires a reduction in autonomy for the companies. They depend on the local community for energy supply when participating in an ehub. As a result, participants surrender a small part of control over their energy supply. The group also needs to share data with external parties for proper functioning. As a result, participants must also give up some of their privacy. Being dependent on the local community and opening up data may deter the introduction of ehubs. Because ehubs are still mainly theoretical, experts are uncertain how much an ehub can alleviate the congestion problem. It is still unclear in which situation an ehub can ensure that the network could provide a reliable energy supply for the participants. The uncertainty about this is hampering the uptake of ehubs. Not being legally allowed to conclude the necessary transport contract to set up an ehub with a grid operator is a major obstacle to introducing ehubs. As a result, an ehub can only be set up as a pilot.

From the above text, it is clear that according to the experts are three main influences from the current st system. The experts mentioned that the possibility of being an answer for companies in grid congestion areas is an essential source of motivation. In addition, the fact that it is not legally allowed results in ehubs only being possible in pilots. However, according to experts, initiating such pilots is difficult because the initial investment of time and money makes companies reluctant to set up an ehub pilot.

Sub-question 4

The fourth sub-question is *What does the governance of change entail regarding introducing energy hubs?*. The governance of change looks at the legitimacy of the change towards introducing ehubs with instruments used by capable agents. First, the legitimacy of the innovation itself is examined. According to Borrás and Edler (2014a), the pursuit of change is legitimate if the change enjoys support or is perceived to be effective in initiating change. With this, it can be concluded that ehubs are legitimate. Experts and media support introducing ehubs, despite uncertainty about their impact on congestion. According to Borrás and Edler (2014a), applying instruments that contribute to the introduction of ehubs is legitimate since it enjoys support.

To effectively change the system for the introduction of ehubs, several instruments can reduce barriers and exploit opportunities. Table 7.1 shows the instruments that can contribute positively to the introduction of ehubs.

Table 7.1: Overview of instruments that can exploit opportunities and reduce barriers. The numbers in the last two columns correspond to the interactions shown in Figure 5.5 on page 52.

Instrument	Capable agent(s)	Opportunities	Barrier
Subsidisation exploration phase	EZK; Province; Municipality		10; 14
Public Private Partnership	EZK; Province; Municipality		10; 14
Knowledge platform	EZK; Knowledge institutes	8	14
Lobby ACM Code changes	Netbeheer Nederland (individual grid operators); Business parks; Province: Municipalities	6; 8	13; 14
Simplifying data exchange	EZK; ACM		11
Ehub map	Grid operators; Province	7	14
Initiator rol	Province; Municipality		14

Sub-question 5

The fifth sub-question is *What is a possible pathway to encourage energy hub niche development towards the future vision in the Netherlands until 2030?*.

The first step in creating a possible pathway to encourage ehubs is to define the future vision for the year 2030. The future vision is formulated based on expert interviews. From these interviews, the following combined future vision is formulated: By 2030, local ehubs will be established to facilitate the exchange of energy flows and transport capacity. And thus fulfils a social role in reducing grid congestion issues. This includes not just electricity but also heat and potentially other energy sources. Additionally, the role of ehubs outside of congestion will be better understood.

The path towards the future vision is presented in Figure 7.1 on the following page. The road towards the future vision is divided into three different phases. The different phases aim to develop further ehubs.

The first phase aims to lay a foundation for gathering knowledge. The theme is learning by doing. With this, instruments are proposed that will facilitate the setting up of pilots. It will also start lobbying for change in the netcode and the new energy law. Changing the netcode by the ACM thus indicates the next phase.

The second phase creates certainty for the future of ehubs. This mainly concerns certainty about the role of ehubs in legislation and regulation. This phase also looks at certainty about the financial and social business case. This is done through pilots and vision as an ehub map. The next phase starts when there is more clarity on the social and financial business case.

The third phase focuses on steering ehub implementation in socially desirable places. Depending on the financial business case, a different approach is proposed. In the absence of a financial business model, it is proposed to set up subsidies to develop ehubs in locations where it is socially desirable. But a public-private partnership is proposed when there is a financial business case. With this, the government can invest in control to keep a social focus within ehubs while recovering that investment.

The different steps within the phases are shown in 7.1, thus presenting the way to the future vision for 2030.

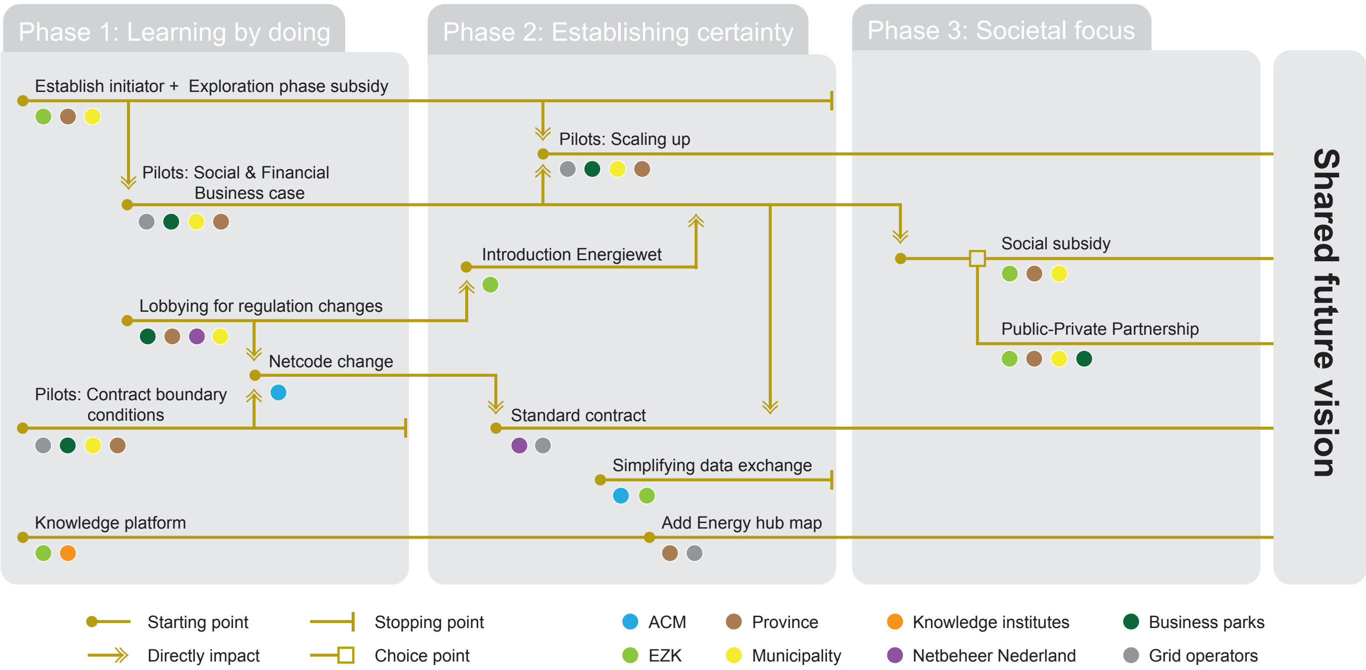


Figure 7.1: Follow-up Agenda

7.1.2. Main research question

The sub-questions from subsection 7.1.1 all serve to answer the main question. The main question is as follows *What is needed to stimulate the implementation of energy hubs from a governance and innovation perspective?*.

This study found that the development of ehubs is just getting started from a governance and innovation perspective. In both areas, little is in place to further develop ehubs into a concept that can move on from the niche environment.

Regarding governance it will help development if a party takes ownership of ehub development. The follow-up agenda presented in sub-question five can be implemented from this role. The party with ownership is additionally tasked with involving critical stakeholders in the development. Therefore, it must be a stakeholder established in the current regime. For the other parties, it is important that the need for ehub development is experienced but also made known to other parties unaware of the necessity. Parties familiar with the importance of ehubs can share the potential with other parties. For example, through the knowledge platform proposed in figure 7.1 or by lobbying towards parties who can steer to adapt legislation and regulation. From the governance role, the legitimacy of ehubs should not be compromised. Therefore, it will be relevant not to lose sight of the social focus of the concept. Although the concept can still fulfil a role when it does not actively contribute to solving or preventing grid congestion, it must not work against social values. Therefore, during development, the social role of ehubs needs to be taken into account in the governance of development.

Besides the governance aspect, there are also adjustments favourable from an innovation perspective. Currently, niche innovation mainly takes place in a theoretical context. This is a consequence of the small number of currently active pilots engaged in implementation. A good development from an innovation perspective is robustness in the expectations regarding ehubs. However, the quality and specificity of expectations are on the low side. To promote innovation, it is important to raise these two aspects. Raising these two aspects can be done by conducting more pilots. It is then essential for the pilots to confirm or disconfirm the expectations to adjust the overall expectation to eventually adjust. In the learning that reinforces expectations, learning about the more efficient and better application of the ehubs, while also learning about the users' wishes, is essential. If a pilot solves the congestion problem but is not workable for the users, it will not contribute to adapting and blossoming in the regime.

In summary, from a governance perspective, it is necessary for a party already established in the current regime to take responsibility for pulling the development forwards. In addition, from an innovation perspective, it is important to reinforce expectations. This reinforcement will mainly come when more learning is done through the implementation of ehubs in pilot situations.

7.2. Discussion

In this section, the presented conclusion and analysis will be discussed. First, the innovation will be compared to similar innovations. After which, an academic discussion will be presented. The combination of the used frameworks will be presented within the academic discussion, and a reflection will be given about the combined use. After the academic discussion, the limitations and recommendations will be given.

7.2.1. Ehub compared to similar innovations

Looking at the characteristics of an energy hub described in the answer to the first subquestion, see subsection 7.1.1, there is overlap with other smart grid developments. In this subsection, the concept of ehubs will be compared with the concepts of virtual power plants, citizen energy communities, and renewable energy communities. Comparing these developments shows why it is important for ehubs to have a role under smart grids and why the knowledge gathered on the other developments is separate from the development of ehubs.

Ehub VS Virtual power plant

A virtual power plant aggregates multiple smaller-scale energy sources acting as one, thus coordinating with grid operators as a virtual unit (Martin & Brehm, 2023; Saboori et al., 2011). These energy sources can produce, store and consume. Using this definition, a virtual power plant has similarities with an ehub. However, the main difference is the closeness of the energy sources. In a virtual power plant, the individual energy sources may be distributed across the entire power grid, while an ehub looks specifically at energy sources on a local scale (Pourghaderi et al., 2022; Sympower, 2022). As a result, an ehub operates mainly through joint use of transmission capacity by multiple customers under the same substation. While at a virtual power plant, the aim is to jointly participate in the wholesale electricity market (*Informatie- en Consultatiedocument VPP*, 2005). In doing so, they both fulfil a different purpose.

As a result, they are two different concepts. An ehub could, however, use a virtual power plant within the local area and start trading on the wholesale electricity market with it. This could be a potential source of income for an ehub.

eHub VS Citizen energy community & Renewable energy community

According to Algarvio (2021), a citizen energy community is a legal entity composed of consumers, generation and system operators. In the European internal electricity market directive, the participants of a citizen energy community are natural persons, local authorities and companies (EP, 2018b). A citizen energy community is a way for citizens to work together in the energy sector. The purpose of a citizen energy community is to contribute to environmental, economic or social community delivery (EP, 2018b; Rescoop.eu, n.d.). A renewable energy community is part of the definition of a citizen energy community (Rescoop.eu, n.d.). In addition, participants in a renewable energy community must be localised near the project (EP, 2022b; Rescoop.eu, n.d.). Autonomy in a renewable energy community is also required. Autonomy means that the governance of a renewable energy community is democratic in nature, and each participant has an equal say in the decision-making process.

The development of ehubs does not yet meet the above-mentioned energy community criteria. Depending on future developments in the concept, an ehub could fall under the definition of an energy community. It, therefore, depends on the interpretation given to an ehub in practice whether it meets the criteria set for citizen or renewable energy community. Because the interpretation of an ehub in the Dutch context is still mainly in its early stages, it is impossible to make a final comparison between an ehub and the two definitions of an energy community. It is, therefore, unclear to what extent an ehub can learn from energy communities in both practice and theory.

Experts mentioned that setting up ehub pilots is currently perceived as difficult. In addition, only a few ehubs are active in the Netherlands. It could be valuable to look at the lessons learned from energy community pilots to advance the development of ehubs. In addition, renewable or citizen energy community boundary conditions could serve as a starting point for ehubs. However, the question is whether this is desirable.

7.2.2. Academic discussion

This study looks at a niche innovation in the Dutch energy system. This innovation is still in the early stages of niche innovation. In addition, the study looks at what is needed to promote niche innovation from a governance perspective. To study the current status of niche innovation, the MLP framework of Geels (2002) and SNM of Kemp et al. (1998) were used. Genus and Coles (2008) states that the MLP framework is mainly used ex post. With that, the MLP framework in this study serves as a method to find out the current opportunities and barriers of interest for ehubs. Giganti and Falcone (2022) appointed that SNM complements the MLP framework by analysing more specifically the niche level in this framework. Giganti and Falcone (2022) conclude that the SNM framework is worthy in analyzing transitions toward a sustainability in st systems. Markard et al. (2012) appoints that the SNM framework is insufficient in assessing whether a transition is legitimate. The choice was made to use the GoC framework. The legitimacy of change is a component of the GoC framework. It thus complements the SNM framework. Furthermore, a critical issue is that the SNM and MLP frameworks are mainly looking at transitions from a bottom-up perspective (Geels, 2011). The GoC framework helps to assess stirring change through governmental and social instruments. According to Borrás and Edler (2014a), this makes it possible to view change from both bottom-up and top-down. Along with legitimacy, the GoC framework of Borrás and Edler (2014a) makes valuable contributions to the SNM and MLP frameworks. The GoC framework thus provides a valuable addition from a policy perspective to the innovation perspective outlined in the other two frameworks.

In addition to the frameworks mentioned above, this research uses the backcasting framework. This framework creates a shared vision and establishes a follow-up agenda to move the innovation towards the desired future vision. Vergragt and Quist (2011) argue that backcasting is similar to frameworks such as MLP and SNM in the principle that it assumes that with a clear enough picture, steps can be taken towards a desired vision of the future. However, Vergragt and Quist (2011) stress to doubt the assumptions made in the SNM framework on how transitions come about. In addition, Vergragt and Quist (2011) mention that backcasting can be used to evaluate the future picture against the system's current situation to see what changes are needed to work towards a robust future vision. In this study, contrary to the scepticism of Vergragt and Quist (2011), it was found that the MLP and SNM framework along with the GoC framework is a valuable complement to the backcasting approach. The MLP and SNM frameworks provide clear insight into the current state of innovation development. Then the GoC framework can provide insight into the legitimacy of the change and the instruments needed to drive this change. The backcasting approach can then be used to create a follow-up agenda to deploy the follow-up agenda can be made to deploy the instruments needed in the current situation to steer towards change effectively.

In figure 7.2 on the following page, the used frameworks are combined in a single image. The figure presents the main elements of the frameworks to show how the different elements of the frameworks align. In the figure, the SNM, GoC, and backcasting framework are combined into the MLP framework. The main elements of the MLP framework are present in the combined figure. However, some changes are made to represent the different frameworks.

The SNM framework is represented on the niche-innovation level. The three key internal processes of SNM are added. The external pressures from the regime and landscape influence the Voicing and shaping of expectations and network formation. The three key internal processes shape the change within the niche-innovation level until the innovation leaves the

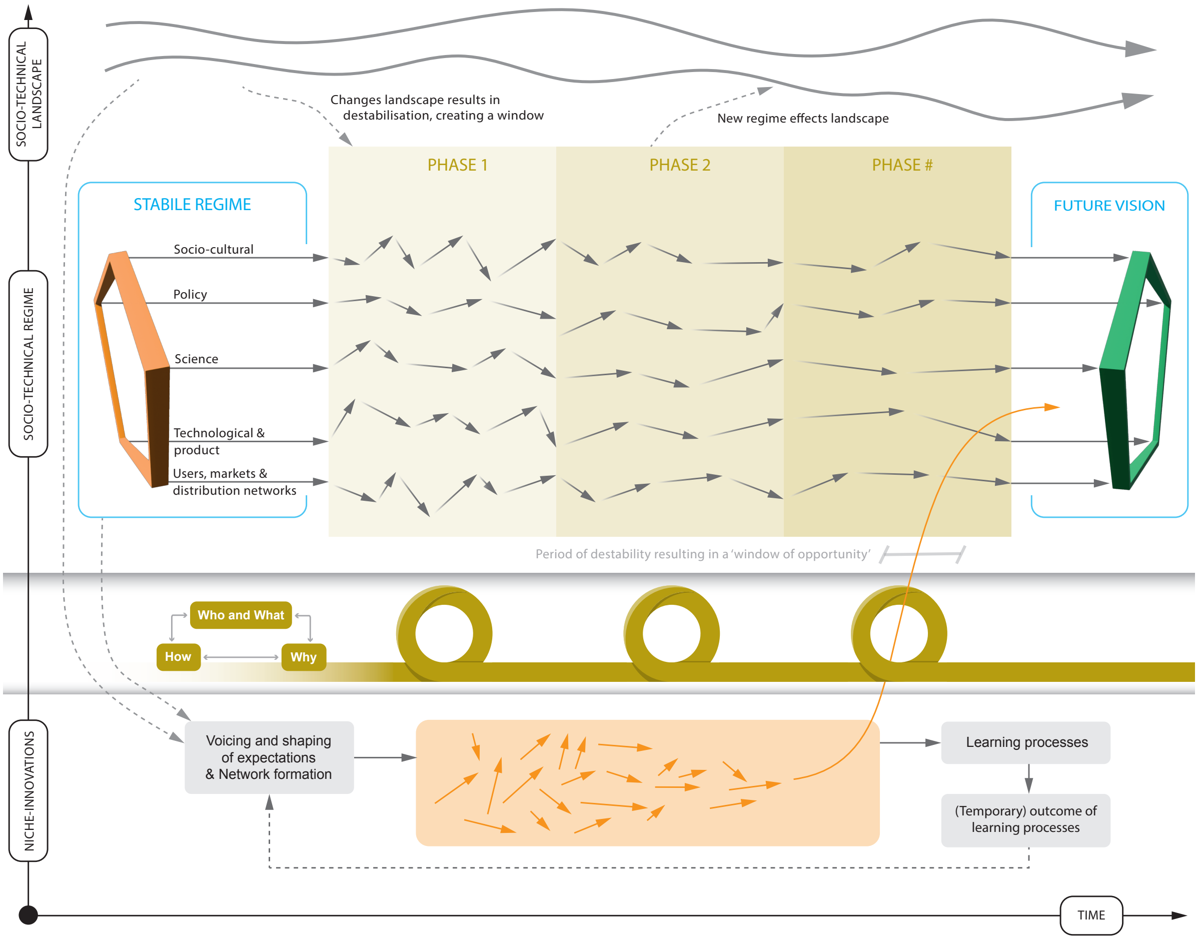


Figure 7.2: Representation of a combined framework.

niche. The external pressures on the niche-innovation level must go 'through' an additional layer. This layer is based on the GoC framework. The external factors of niche-innovation and innovation breakthroughs towards the regime can be examined using the GoC framework. As described in section 4.5, the GoC primarily adds legitimacy to the instruments and actors in contrast to the other frameworks. The GoC framework stands between the niche-innovation and the upper layers to represent the importance of legitimacy when interacting with the niche innovation. The backcasting framework is represented in the figure through the different phases in the regime. In every new phase, the arrows are slightly less chaotic. The reduction in chaos presents the change in the regime through the action of backcasting. The arrows point towards the future vision, symbolising the idea of working towards the future vision.

In figure 7.2, the original frameworks, seen in chapter 3, can be clearly recognised. Consequently, the visual representation of the separate frameworks was straightforward to combine. The ease of combining was also experienced during the analyses with the frameworks together. Each framework serves a specific role in ultimately arriving at a desired policy agenda. The MLP framework creates a clear picture of the current situation in the entire system. Additionally, the SNM framework specifically highlights the niche innovation and the role of the current system within the niche. Both frameworks provide a holistic view of the current system. This provided crucial information for the two remaining frameworks. The remaining frameworks work towards a policy agenda which governs change towards a future vision. Backcasting helps in this by providing a clear picture of the future vision and what is needed to achieve it. Whereas the GoC framework helps by analysing the necessary policy instruments needed to bring about the necessary changes.

Despite providing a holistic view of the system, applying four frameworks requires a higher investment of time when seeking the same amount of specificity when using the frameworks individually. This study uses an interview to gather knowledge for all frameworks. Due to the limited time of experts within the field, not all aspects of the different frameworks could be asked. However, applying a combination of the frameworks provided a holistic view of the system and was detailed enough to get the essence of the innovation.

7.2.3. Limitations of the research

One of the main findings of this study is that the system will benefit from more learning from practice and learning by doing. This finding is based on predominantly theoretical knowledge gathered by experts in the system. Inherently, the findings from this research are mainly based on theoretical knowledge since the source of knowledge for this study is from the experts and based on literature. This limits the research to the same shortcoming experienced in niche development. This could lead to missing or overestimating opportunities and barriers for ehubs. However, it still presents the current situation of niche innovation and is therefore expected to have minimal impact on the final findings of this study.

A second limitation is the number of expert interviews per type of organisation. Although 20 experts were interviewed, the experts were mainly employed by grid operators. As a result, there may be some bias in the findings. However, this impact is considered minimal because there was also saturation between the responses from the different organisations. Therefore, it can be assumed that interviewing more experts in other organisations will not change the overall findings. On the other hand, it is impossible to draw conclusions based on the interviews about possible differences in expectations among the different types of organisations, which might be beneficial.

A third limitation is uncertainty about the social and financial business case of ehubs among experts. This may cause the desirability of ehubs to change. The fact that experts expect a social business model but do not know how effective it will be, may increase or decrease the desire from public parties for ehubs. The final phase of the follow-up agenda assumes that an ehub will continue to be socially desirable. However, time will tell whether this is really the case. Therefore, this research needs to be more iterative in nature. As the research is limited in duration, it is impossible to conduct iteratively.

7.2.4. Suggestions future research

Currently, setting up pilots is perceived as difficult by experts. Although the follow-up agenda aims, among other things, to contribute to overcoming the obstacles to setting up pilots, the knowledge gathered about energy communities may help. However, this raises the question of whether applying the requirements for a citizen or renewable energy community is desirable for an ehub. The first proposal for future research is to see how the requirements for an energy community can be applied to the concept of ehubs. The design chosen for such an energy community could possibly be beneficial if applied to ehubs. Thereby, the concept of energy communities is further developed than that of ehubs, and it is possible to learn from already running energy communities to implement ehubs.

A second proposal for future research relates to further exploring the applicability of the GoC and backcasting frameworks with renewable transition frameworks. This study mainly applies the combination of frameworks to a case whose innovation development is still early. Because the MLP and SNM frameworks are mainly applied retrospectively, it is also interesting to see how the GoC and backcasting framework can be applied when the innovation has already entered the regime. It is particularly interesting to see how the latter two frameworks can be used when looking at the past and whether they add value to retrospective analysis.

A third suggestion for future research is replicating the study after several years. As described under the limitations in subsection 7.2.3, it is desirable to conduct this study iteratively. This is because the expectations have low specificity and quality, as described in subsection 5.3.1. As more pilots are conducted, expectations may change. Consequently, a change in expectations may also change the effectiveness of the instruments or require different instruments. Therefore, it is beneficial for the development of ehubs to re-evaluate the current state after a few years.

7.3. Recommendations for stakeholders

This section offers recommendations for the various stakeholders in the social network around ehubs. The recommendations are intended to provide these stakeholders with a guide to help the development of ehubs to move forward from the current situation. The recommendations are based on the conclusions drawn for the main and sub-questions.

The recommendations are mainly based on the three main changes presented in the follow-up agenda from section 6.3. The first change needed is to learn by doing. This includes starting more pilots to learn from practice rather than theory. Next, creating certainty about the future of ehubs is essential. This mainly involves making ehubs and their components legally viable. After creating certainty, it is essential to ensure that ehubs deliver socially added value. The third phase of the follow-up agenda presents measures that can be used to give ehubs a societal focus. Although the follow-up agenda deliberately did not opt for time-bound targets, this is ideally done. Because of the time pressure behind resolving grid congestion, ensuring that the points in the follow-up agenda are carried through into practice is crucial.

With the follow-up agenda in mind, a series of recommendations specific to the different stakeholders in the social network are given below.

- For all stakeholders, it is essential to lobby for a change in the ACM's netcode and the introduction of the new energiewet. This will result in more prospects for ehubs.
- The government can contribute by financially supporting the concept. Initially, this funding will mainly be for setting up pilots. After that, to stimulate social interest.
- For the provinces expressly, it is advised to take an initiating role. It is essential to involve the municipalities. The municipalities are closer to the various industrial estates, making it easier to contact them. In the initiating role, it is imperative to set up more pilots. Creating awareness and a subsidy for exploring the possibility of setting up an ehub is necessary.

- As grid operators, learning about the preconditions needed in an ehub through pilots is essential. This involves experimenting with different aspects of a potential standard contract in the pilots. Not all preconditions lend themselves to experimentation. Aspects such as grid safety must be guaranteed, but experimenting with the minimum and maximum physical size of an ehub on the grid might be interesting.
- The grid operators are advised to use the knowledge from the pilots and the adjustments in the netcode to formulate a standard contract form for ehubs. Such a contract will contribute to certainty about the future of ehubs and their correct implementation.
- Knowledge institutions are advised to collect knowledge in an accessible way to facilitate and publicly disseminate knowledge about pilots through social networks. The EZK is advised to provide the resources to maintain such a platform.
- A valuable part of such a knowledge platform will be an ehub map. As grid operators, preparing such a map is relevant to ensure that ehubs emerges where it can contribute most to remedy or prevent grid congestion. The provinces can contribute by using knowledge from the initiating role and about the energy transition vision in the region to support the grid operators.
- For companies and park managers in a business park, it is advisable to get organised around energy facilities. Organisation is essential for simplifying the initiation of an ehub. It can also be valuable for the sustainability task ahead.

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CHAPTER A

Dutch electricity grid

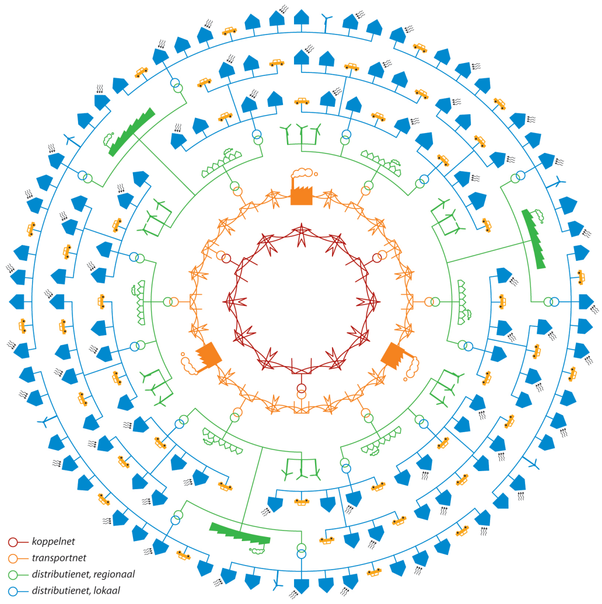

Figure A.1: Schematic representation of the Dutch electricity grid from (Phase to Phase, 2023)

The information regarding the Dutch electricity grid was obtained from ACM (1999) and Phase to Phase (2023).

Within the Dutch electricity network, a distinction is made between three types of network, each with its function: interconnection, transmission and distribution. The first grid's function is international interconnections with neighbouring countries and, at the national level, the transmission of electricity from large power plants (>500 MW). Shown in Figure A.1 with the red colour. From the national level, electricity travels to the provincial level, the transmission grid. The function of The transmission grid is to serve as a link between the interconnection and distribution grid. At this level are power plants and industrial connections above 10 MW. The transmission grid is marked in yellow in Figure A.1. Below the transmission grid is the distribution grid. The distribution grid can be seen as a kind of 'capillaries' of the electricity grid and contains all branches. Within the distribution network, there are then two further divisions. The regional level's function is to connect large decentralised generators and industrial customers with a capacity larger than 0.3 MW. The regional distribution grid is green in Figure A.1. Then at the bottom is the local distribution network connecting users with a capacity smaller than 0.3 MW.

In addition to the subdivision based on function, the grid can be further divided into the following high, medium and low voltage levels. The high-voltage level covers the voltage from 50 kV to 380 kV and concerns the coupling and transmission grid. Management of the 110 to 380 kV cable is the responsibility of the TSO. The medium-voltage level concerns 3 to 25 kV. The medium-voltage cables collectively form the regional distribution network. At the lowest level is the local distribution network with a low voltage of 0.4 kV with a phase voltage of 0.23 kV. The medium and low voltage network responsibility is divided among several DSOs. The different DSOs have a geographical area over which they are responsible.

A summary table of the text above can be found in Table A.1 on the following page.

Table A.1: Summary of electricity grid function and the respective voltage levels.

Function	Voltage level
Interconnection grid	High voltage (220/380 kV)
Transmission grid	High voltage (50/110/150 kV)
Distribution grid (regional)	Medium voltage (3 up to 25 kV)
Distribution grid (local)	Low voltage (0,4 kV or lower)

CHAPTER B

Interview protocol

The study involves the geographical area of the Netherlands. The interviewees are all Dutch-speaking. Therefore, the questions drafted in the interview protocol are in Dutch.

Part I: Introduction

- Thank the interviewee for their time.
- Explain the thesis project and the goal of the interview.
  - Transition of the innovation energy hub from a niche to mainstream use.
  - Gain insight into aspects around the transition like governance and experimentation.
- Explain the structure of the interview and expected duration.
- **Start recording**
- Informed consent signed? If yes, proceed otherwise ask if they have read the informed consent and if they agree with the conditions explained in the document.
  - Inform about recording the interview.
  - Explain what will be publicly available.
  - Mention that if the interviewee does not wanna answer a question that it is accepted.

Part II: General questions

1. Aan welke organisatie(s) bent u verbonden en welke positie vervult u daar?
2. Bent u bekend met het concept Energie hub?

   Ja Kunt u een energie hub voor mij definiëren?
   Nee *Korte uitleg geven. (Vanuit energie delen)*

3. In welke mate bent u bezig met het concept energie hub?

Part III: Innovation development

4. Welke voordelen biedt een energie hub volgens u?
   - Technische, Culturele, Organisatorische voordelen.
   - Ten opzichte van traditionele aanpak.
5. Zou u kunnen benoemen welke stimulans u ervaart voor het implementeren van een energie hub?
   - Regime destabilisatie factoren MLP.
   - Door wel en niet overheidsinstaties instrumenten.
   - Op persoonlijk vlak.
6. Zou u kunnen benoemen hoe de implementatie van energie hubs belemmerd wordt volgens u?
   - Regime lock-in factoren MLP.
   - Door wel en niet overheidsinstaties instrumenten.

7. Hoe wordt volgens u het succes van een energie hub momenteel gemeten?
    - Welke processen zijn hiervoor belangrijk?
    - Zou je het willen formuleren als KPI?

Part IV: Governance

8. Welke rol spelen overheidsinstanties en beleidsmakers bij de ontwikkeling van energie hubs en hoe zijn ze betrokken bij het proces?
9. Welke rol spelen bedrijven bij de ontwikkeling van energie hubs en hoe zijn ze betrokken bij het proces?
10. Welke partijen zijn er volgens u nog meer betrokken bij energie hubs?
    - Hoe spelen ze een rol?
11. Is er volgens u momenteel sprake van een visie over het introduceren van energie hubs?
    - Waaraan merk je dit?

Part V: Future vision & pathways

12. Hoe zou een ideaal toekomstbeeld eruitzien voor energie hubs in 2030?
13. Wat is er nodig om deze visie te realiseren?
    - Technische verandering
    - Culturele verandering
    - Institutionele verandering
    - Organisatorische verandering

Part VI: Concluding

14. Benoemen dat dit alle inhoudelijke vragen waren en dan vragen of ze mij nog iets willen meegeven wat niet aanbod kwam in het interview. → Schiet je nog iets te binnen wat niet aanbod kwam tijdens het interview?
15. Heeft u suggestie voor mensen die nog meer waardevol zijn om te interviewen?
16. Heeft u relevanten bronnen die ik kan gebruiken?

Part VII: Finishing the interview

- Bedankten voor de deelname.
- Waar kan het uiteindelijke verslag gevonden worden?
- Delen van informatie over het interview.

CHAPTER C

Informed consent template

Informed consent interview

Master thesis project at the Delft University of Technology

You are being invited to participate in a research study titled *Energy hubs as the solution to net congestion: a governance and innovation perspective on implementing energy hubs*. This study is being done by Twan Kramer from the TU Delft and Stedin.

The purpose of this research study is to investigate how the implementation of energy hubs can be stimulated from a governance and innovation perspective and will take you approximately 60 minutes to complete.

The data will be used for master thesis research which will be published in the repository of the TU Delft. In addition, an academic publication can be done based on the master thesis. We will be asking you to participate in a one-on-one semi-structured interview which help to gain insight into the implementation of energy hubs.

The interview will be recorded. This recording will be used to summarize the interview. The summary of the interview will be shared with you, and you will have the opportunity to omit any information in the summary. The summary will be used for analysis. Anonymity will be maintained by displaying only an overview of the types of companies the interviewees are related to and the general analysis of the information gathered. There will be no direct information related to the interviewee in the final product. This work may lead to an academic article. The audio recording and transcript will be preserved for up to two years under the responsibility of Thomas Hoppe to support such potential article, only accessible to the research team. Should such publication take place, you will remain anonymous, and all privacy measures presented in this document will be enforced.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions.

As with any online activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain anonymous. Anonymity is preserved by not including any personal information in the interview summary. We will minimize any risks by keeping the data in a TU Delft approved storage, and the data will only be accessible to the research team (Principal investigator (Me); First supervisor (Thomas Hoppe); Second supervisor (Linda Kamp)).

By signing this form, you confirm that you have read and understood the information provided and agree to participate in the study voluntarily.

Corresponding researcher:
Name: Twan Kramer
E-mail: T.kramer-1@student.tudelft.nl

Responsible researcher (First supervisor):
Name: Dr. Thomas Hoppe
E-mail: T.hoppe@tudelft.nl

Second supervisor:
Name: Dr. Linda M. Kamp
E-mail: L.M.kamp@tudelft.nl

TU Delft

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICIPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information dated 04/05/2023, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.		
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.		
3. I understand that taking part in the study involves: • An audio-recorded interview which will either be conducted in person or through Microsoft Teams. In the case of Microsoft Teams, the recording also includes video. However, only the audio recording will be used in the study. • The interview will be a semi-structured interview with open-ended questions. • The audio-recording will be summarized as text based on the recording; The summary will be sent afterwards, and you will be able to suggest changes, remove parts of the summary. • The audio-recording will be stored on TU Delft SurfDrive owned by Dr. Thomas Hoppe (First supervisor, TU Delft). The recording will be kept for a maximum of two years after the completion of the research.		
4. I understand that I will not be financially compensated for my participation.		
5. I understand that the research is expected to end by August 2023 and that an additional academic publication might be done.		
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
6. I understand that taking part in the study involves the following risks: • Risk for leaked information. • Risk for reputation damage as result of leaked information. I understand that the risks above will be mitigated by the researcher. Information gathered will be anonymized by excluding the summary and personally identifiable information in the final product. In addition, the interviewee is free to not answer a question and is able to omit information in the summary. Personal data will only be accessible by people involved in the research *(Corresponding researcher, Twan Kramer; Responsible researcher, Thomas Hoppe; Second supervisor, Linda M. Kamp)*.		
7. I understand that taking part in the study also involves collecting specific personally identifiable information (PII) [name, interview data, occupation] and associated personally identifiable research data (PIRD) with the potential risk of my identity being revealed.		
8. I understand that some of this PIRD is considered as sensitive data within GDPR legislation, specifically political views.		
9. I understand that the following steps will be taken to minimise the threat of a data breach and protect my identity in the event of such a breach. • The interview will be anonymized as explained at point 6. • The data collected will be preserved up to two years after the completion of the master thesis.		
10. I understand that personal information collected about me that can identify me (such as my name, contact details, and occupation) will not be shared beyond the study team.		
11. I understand that the (identifiable) personal data I provide will be preserved up to two years after the graduation of the research, expected in August 2023		

TU Delft

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
12. I understand that after the research study the de-identified information I provide will be used for a master thesis and the results from the analyses done by the researcher will be publicly available at the TU Delft Repository (https://repository.tudelft.nl/).		
13. I agree that my responses, views, or other input can be quoted anonymously in research outputs.		
D: (LONGTERM) DATA STORAGE, ACCESS, AND REUSE		
16. I understand that the de-identified data will be used in the master thesis project of the researcher and might be used in an academic publication.		

If you do not wish to sign this form, we will go through the informed consent at the start of the interview verbally, and you can agree to these terms verbally before the interview.

Name participant:

Signature:

Date of signing:

In the case of verbal consent:

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Name researcher:

Signature:

Date of signing:

TU Delft

CHAPTER D

Invitation mail

Van: T.kramer-1@student.tudelft.nl; Twan.kramer@stedin.net
Aan: ⟨*Interviewee*⟩
Onderwerp: Uitnodiging voor interview TU Delft master thesis
Bijlage: informedConsent_interview.pdf

Geachte ⟨*name*⟩,

Ik ben momenteel bezig met mijn master thesis bij de netbeheerder Stedin voor mijn opleiding aan de technische universiteit Delft. ⟨Korte zin om aan te geven hoe ik bij hun kom⟩. Ik ben geïnteresseerd in uw algemene kijk op het gebied van energie hubs voor mijn master thesis. Ik zou u graag willen uitnodigen voor een interview om meer inzicht te krijgen in uw perspectief en ervaringen met betrekking tot energie hubs. Onderaan de mail staat meer informatie over mijn opleiding en doel van het onderzoek.

Het zal ongeveer *60 minuten* duren en kan fysiek of online plaatsvinden afhankelijk van uw voorkeur. Het interview zal opgenomen worden om achteraf te gebruiken als persoonlijk naslagwerk.

Ik verzeker u dat er zorgvuldig om gegaan zal worden met uw privacy. Naast mijn master thesis zal de informatie, vergaard tijdens het interview, potentieel gebruikt worden voor een academische publicatie. Mocht er een publicatie plaatsvinden dan zal uw anonimiteit gewaarborgd blijven. Uw privacy zal op dezelfde manier gewaarborgd worden als in de master thesis. In de master thesis zal alleen een samenvatting worden gepresenteerd van de verschillende soort organisaties en de analyse van die uit de verschillende interviews komt. Voorafgaande aan het interview zal ik u vragen een informed consent-formulier te ondertekenen, hierin wordt meer uitgelegd met betrekken tot privacy en omgang met de vergaarde data. Het formulier is in de bijlage toegevoegd. Het formulier kan digitaal ondertekend worden of we nemen het formulier door aan het begin van het interview.

Als u geïnteresseerd bent om deel te nemen, kunt u uw beschikbaarheid aangeven en een voorkeursdatum en -tijd opgeven voor het interview. Als u nog vragen heeft, aarzel dan niet om contact met mij op te nemen.

Met vriendelijke groet,
Twan Kramer
Telefoonnummer: 06 41886892
Mail adres: T.kramer-1@student.tudelft.nl | Twan.kramer@stedin.net

Doel van onderzoek: Het doel is om te onderzoeken hoe energie hubs als nieuw concept kunnen door ontwikkelen zodat het toepasbaar is in het Nederlandse energie systeem. Het onderzoek bekijkt energie hubs vanuit een socio-technische perspectief. Als eindresultaat wordt er een beleidsagenda opgesteld die bijdraagt aan de doorontwikkeling van energie hubs.

Mijn Opleiding: Mijn master programma is Complex Systems Engineering and Management aan de TU Delft. De opleiding is gericht op het ontwerpen van oplossingen in een complex socio-technisch probleem. Bij het ontwerpen van oplossingen wordt er rekening gehouden met de technische, institutionele, economische en sociale aspecten. Een voorbeeld van een complex socio-technische probleem is netcongestie omdat het een technische probleem is in een complexe omgeving waar er sprake is van meerdere belanghebbende zowel private als publiek met allemaal een andere perspectief.

CHAPTER E

Interview codes

E.1. Codes frameworks

Table E.1: Codes interviews - Codes checked for each question in the interviewees' responses.

Framework	Code	1	2	3	4	5	6	7	8	9	10	11	12	13	14
MLP	Regime influence			x		x	x		x	x	x				x
	Landscape influence			x		x	x								x
	Destabilized regime			x	x	x			x	x	x		x		x
	Window of Opportunity		x	x		x			x	x	x		x		x
SNM	Expectations		x	x	x			x	x	x	x	x	x	x	x
	Network formation	x				x			x	x	x	x			x
	Learning process							x	x	x	x	x			x
GoC	Instrumentation								x				x	x	x
	Legitimacy				x		x		x				x	x	x
	Capable agents			x					x	x	x	x	x	x	x
Backcasting	Future vision											x	x	x	x
	Pathways						x		x				x	x	x

E.2. Codes definition and future vision

- Definition
  - Balancing supply and demand
  - Energy trading
  - Flexibility options
  - Focus on electricity
  - Grid Capacity
  - Inclusion citizens
  - Multiple energy carriers
  - Optimal use of energy
  - Regional area
  - Self-regulation in group
  - Smart functioning
- Future vision
  - Capacity exchange
  - Energy exchange
  - External impact
  - Local
  - Mandatory
  - Multiple energy carriers
  - Outside of grid congestion
  - Residential areas
  - Self sufficient