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Master's Thesis – Master Innovation Sciences

Organisation and Governance of Energy Hubs on Dutch business parks:

A multiple case study

By Jesse Aalders

Supervisor: **Dr. Elena Fumagalli**
Second reader: **Dr. Peter Mulder**

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j.j.aalders@students.uu.nl
6173748

Abstract

Energy hubs on business parks are expected to be a part of the solution for grid congestion in the Netherlands. This study aims to gain an understanding of the complex organisational and governance dynamics of energy hubs. This was explored by conducting a qualitative multiple case study approach. Data was collected through a combination of desk research and semi-structured interviews with 13 stakeholders. The study identified the key stakeholders and examined four most directly involved stakeholder groups regarding their roles, influence, interests, and challenges. Furthermore, the following barriers were identified: non-consideration of externalities, high initial investments, inadequate access to capital, liability issues, unclear stakeholder roles, lack of ownership, an underdeveloped legislative framework, difficulties in determining asset ownership, operational complexities, system constraints, and resistance to change. To address these issues, the study proposes several solutions: quantifying the societal benefits of energy hubs to support public investment, providing public support during the exploratory phase, offering government guarantees on loans, developing new insurance policies, standardizing the setup of energy hubs, adopting a top-down bottom-up approach, setting up a clear legislative framework, informing stakeholders about ownership options, involving technical expertise and building a measuring infrastructure, coordinating between DSOs and the TSO, and fostering a high degree of organization among stakeholders. Policymakers and industry stakeholders can use these insights to steer and stimulate energy hub development in the Netherlands. Future research could include economic feasibility studies and similar research aimed at stakeholders that are not yet part of an energy hub project.

Inhoud

1. Introduction

In 2015, the Dutch government signed the Paris agreement (United Nations, 2015). This international treaty has the goal to limit global warming by reducing greenhouse gas emissions. Subsequently, in 2019, industry and governmental bodies in the Netherlands reached the National Climate Agreement (Rijksoverheid, 201). The primary objective of this agreement is to reduce CO_2 emissions with 49% compared to 1990 levels by 2030, with a further reduction of 95% by 2050. Strategies to reach these goals involve increasing the amount of renewable energy and thereby reducing the reliance on fossil fuels.

Currently, at the end of 2023, almost half of the Dutch electricity production is generated from renewable sources (CBS, 2019). This increase of renewable energy influences the Dutch electricity grid in two ways. First of all, the electricity output of renewable sources fluctuates throughout the day due to their reliance on natural elements (Papaefthymiou & Dragoon, 2016). Secondly, it creates a transition towards a decentralized way of electricity generation. The Dutch electricity grid is built for a constant output with central points of production, as it used to be with fossil fuel fired power stations. A centralized grid makes it possible to adjust production and demand accordingly, making the grid robust and reliable (Netbeheer Nederland, n.d.).

Another factor that puts pressure on the Dutch grid is the rising demand for electricity. Both industrial and residential energy consumers are increasingly adopting electricity for heating, transportation, and various industrial processes, instead of using fossil fuels (Sijm et al., 2022).

Consequently, these shifts in the Dutch energy landscape lead to ‘grid congestion’. Grid congestion occurs when demand for electricity transport exceeds the transport capacity of the grid (RVO, 2021). Various regions in the Netherlands are currently affected by grid congestion. In a lot of areas it is creating difficulties, especially for businesses, as expanding the electricity connections in these places is not possible. This affects business growth and the electrification of industrial processes. Moreover, it hinders the integration of new renewable energy projects, as it creates complications for their connection to the grid (RVO, 2021). It can thus hamper the sustainable energy transition in the Netherlands. To deal with grid congestion, grid operators are expanding the electricity grid, but they simply cannot keep up with the increasing demand for transport capacity (Rijksoverheid, 2023). To relieve the electricity grid, a redesign of our energy system is necessary.

A part of this redesign could be the implementation of ‘Energy hubs’. Energy hubs are local systems where production, conversion, storage and consumption of energy takes place (Mohammadi et al., 2017). Through local energy generation and consumption, there is a reduced reliance on the central electricity grid. Moreover, it creates possibilities to harmonize supply and demand by trading energy between multiple carriers and actors in an efficient way (Eladl, 2023). It is important to note that the concept of energy hubs, as defined above, is broad and can entail diverse applications. To narrow the concept down, this research focuses on energy hubs in industrial or business park settings, while also including the potential integration of nearby residential areas or existing renewable energy plants.

According to a report by Royal HaskoningDHV (2023), out of 3411 business parks in the Netherlands, 355 are identified as having the potential to achieve significant CO_2 reduction by functioning as energy hubs. Currently, there are multiple pilots running in the Netherlands, often stimulated by grid operators (Royal HaskoningDHV, 2022). An example of such a pilot in is Energy Hub Hessenpoort, where a group transport agreement is being tested. Multiple business on this business park will virtually connect their grid connections to synchronise energy supply and demand locally. By a better distribution of the capacity, smart usage of renewable energy and a hydrogen plant to store energy, this hub is expected to create space on the grid (OostNL, n.d.-a).

The Dutch government recognizes the importance of energy hubs (RVO, 2023a). However, according to the Dutch Ministry of Economic Affairs (2022), the realisation rate of energy hubs is low, despite the existence of ongoing initiatives. They point out that complicated regulations hamper the realisation of energy hubs, including the fact that attractive contracts for sharing energy are still missing. Additionally, active mobilisation of actors is deemed necessary. In their research report on energy hub implementation in eastern Netherlands, Royal HaskoningDHV (2022) addresses the organisational and legal complexity of implementing energy hubs. Moreover, the report states that businesses do not always perceive the benefits to outweigh the related challenges.

The Dutch government recently announced that they will allocate €166 million to stimulate energy hub development (Rijksoverheid 2023). The National Action Programme for Grid Congestion (Het Landelijk Actieprogramma Netcongestie or LAN in Dutch) will develop a toolkit for energy hubs with the goal to facilitate collaboration and lower the development costs. Moreover, the LAN is developing legal contracts to enable the sharing of grid connections within an energy hub (RVO, 2023b).

Considering the above mentioned challenges and prospective changes for energy hub implementation, it is vital to better understand the governance and organisational aspect of the concept. Energy hubs consist of various types of stakeholders, including energy producers, energy consumers, grid operators, technology providers, (regional) government bodies and businesses (Mohammadi, 2017). Multi-stakeholder collaborations often lead to challenges caused by different visions, logics, interests and knowledge systems (Ayala-Orozco et al., 2018). To optimise the performance of energy hubs, it is essential for all these interconnected elements to collaborate efficiently.

In academic literature, multiple studies have researched the concept of energy hubs (Mohammadi, 2017), energy hub management (Parisio et al., 2012), and energy flows within hubs (Ma et al, 2017). These kind of papers primarily emphasize the technical aspects of energy hubs. Regarding the organisational dynamics, a variety of studies exist, exploring aspects such as stakeholder engagement in smart grid technologies (Vereshchagina et al, 2015), or the changing roles of actors in the transition towards a decentralised system (Rohde & Hielscher, 2021). Furthermore, Lammers & Hoppe (2019) stress the importance of collaboration and collective action between stakeholders when upgrading the energy system.

However, a common gap in these papers was the deeper focus on the stakeholders' roles, interests and potential challenges, especially in relation to current rules and regulations. Furthermore, unlike existing literature, this study narrows its focus to the context of the Netherlands. This geographical specificity is useful when considering the specific policies and regulations within a national context. Focusing on a national scale establishes relevancy and a more direct applicability.

To fill the earlier mentioned gap in research, this thesis aims to gain a better understanding of the governance and organisation of energy hubs in business park settings. Eventually, this will lead to the identification of challenges and solutions that must be addressed by industry and policy makers to stimulate the implementation of energy hubs. This will be established by exploring three energy hub projects in a multiple case study. The research goal will be accomplished by answering the following main question:

What challenges do energy hubs on business parks in the Netherlands face from both a governance and organisational perspective, and how can these challenges be addressed?

Having established the main research question, it is useful to split this into a set of targeted sub-questions. These questions address a specific element of the subject, offering a structured framework for the research.

1. *What stakeholders are involved and what are their roles, influences, interests and challenges?*

This parts gives an overview of the various stakeholders engaged in the implementation and exploitation energy hub projects. Describing what each stakeholder does, what they are accountable for, and what their interests are helps comprehend how the energy hub system is put together. Analysing the challenges that they face helps identifying the general challenges and barriers further on in this research.

2. *How can we map and analyse interactions among the stakeholders to understand collaboration dynamics and identify conflicts and misaligned interests?*

This sub-question investigates the current interactions and collaborations among the stakeholders in the three cases. Additionally, it points out potential complications that emerge from these interactions.

3. *What are the barriers and challenges hindering effective participation, collaboration and coordination among energy hub stakeholders?*

After having identified and characterised the various stakeholders and their interactional patterns, the next step is to explore the key barriers and challenges hindering energy hub development.

4. *What solutions can be proposed for the identified barriers and challenges?*

This sub-question proposes solutions for industry and policymakers to address the identified barriers and challenges.

2. Theory

This section describes relevant theory to the research. Firstly, it explains the theoretical background of stakeholder theory, which provides the foundation for the stakeholder analysis in this research. Secondly, a framework will be explained that provides structure for barrier identification and the proposition of solutions to those barriers. The theory section concludes with an overview of the state-of-the-art knowledge on the subject.

2.1. Stakeholder theory

Freeman (1984) argues that a firm or organisation should create value for all stakeholders, not just for shareholders. Stakeholders are described as groups or individuals who can affect or be affected by the action of an organisation. Over the years, many studies have explored stakeholder dynamics, producing multiple outcomes. For instance, Mitchell et al. (1997) argue that stakeholders with power, legitimacy and urgency of claims will more likely be responded to by managers or organisations.

Building on this foundation, Pahl-Wostl (2005) asserts that a stakeholder analysis should provide information about the social connections between all stakeholders, the rules governing their interactions and their roles, the characterization of individual stakeholders (interests, goals, power) and the decision making processes within the area of interest. Furthermore, Bakker et al. (1999) explains how stakeholders can be categorised along multiple variables: scale, tier, role and degree of aggregation. This research is carried out regarding water resource management, but is also referred to in more general literature on actor-based analysis (Pahl-Wostl, 2005).

These categorisation and characterisation frameworks have been adapted to the context of energy hubs, aligning with the scope and objectives of this research. The derived categories from existing literature that will be applied include:

Role
Refers to the functional role played by a stakeholder in the energy hub ecosystem. It aims to understand the specific contributions and responsibilities of each stakeholder group. Stakeholders in this category might include energy producers responsible for generating power, policymakers shaping regulatory frameworks, net operators managing the infrastructure, and others who play pivotal roles in the energy hub.

Interest
Explores the motivating factors driving stakeholders to participate or support energy hub development. Understanding these driving factors helps contextualize stakeholders' intentions and goals. Stakeholders may be motivated by financial considerations, practical benefits, or a commitment to sustainability and environmental goals.

Influence
Evaluates the extent of power a stakeholder holds within the energy hub context. It seeks to uncover the dynamics of decision-making and the ability of stakeholders to shape outcomes.

Challenge

This explains the main concerns and challenges that stakeholders have within energy hub projects. This can later on be used to derive general challenges and barriers from.

After describing the characteristics of stakeholders, the next step is to gain an understanding of the interactions between them. In a paper on multi-actor systems, Hermans et al. (2010) explain how mapping formal institutions and relations is an important step in an actor or stakeholder analysis. This offers a good starting point to understand how other, more informal, relations manifest. The authors' methodology advocates for the creation of a visual representation, typically a formal chart, where each stakeholder is strategically positioned. Within this chart, arrows are employed to illustrate regulations, responsibilities, and relations. This provides a tool to explain how the interactions between stakeholders take shape within the energy hub landscape and how this differs from the conventional centralised energy system.

2.2. Identifying barriers and challenges

Painuly (2001) describes how renewable energy technologies often have difficulties in reaching acquiring widespread adoption. Although they are generally economically viable and sustainable, these technologies face barriers and challenges that limit their penetration into the energy system. The paper provides a framework for identifying these barriers and proposes measures to overcome them (Painuly, 2001).

The author explains how barriers can be identified through a combination of literature review, site visits and stakeholder interactions, such as interviews or questionnaires. According to the author, barriers or challenges can be categorised in several area's. These areas include: Market Failure/imperfection, Market Distortions, Economic and Financial, Institutional, Technical, and Social, Cultural and Behavioural. Categories such as 'Technical' might not initially appear relevant to organizational and governance dynamics. However, addressing barriers in these areas often requires organisational and governance solutions. Therefore, all categories will be included in this research. The paper proposes several barriers per category, which may be hampering the diffusion of renewable energy technologies. A short overview of the barrier categories including examples of the major barriers proposed by Painuly (2001) is provided below:

Table 1: Barriers to RET's Penetration (Painuly, 2001)

Barrier category	Barriers
Market Failure/imperfection	Lack of information and awareness, Lack of competition, High transaction costs, High investment requirements
Market Distortions	Non-consideration of externalities, Non-consideration of externalities, Taxes on RETs
Economic and Financial	Economically not viable, High payback period, Lack of access to capital, Lack of financial institutions to support RETs, lack of instruments
Institutional	Lack of institutions/mechanisms to disseminate information, Lack of a legal/regulatory framework, Lack of involvement of stakeholders
Technical	Lack of standard and codes and certification, Lack of skilled personnel/training
Social, Cultural and Behavioural	Lack of consumer acceptance of the product, Lack of social acceptance for some RETs
Other Barriers	Uncertain governmental policies, High risk perception for RETs

Furthermore, the paper addresses how measures to overcome the barriers should be obtained. This can be done through including interview or questionnaire questions related to potential measures or solutions. The last step is described as designing policy actions in order to operationalise the measures. The paper ends by discussing several policy actions taken by governments to overcome barriers related to renewable energy technologies (Painuly, 2001).

While the concept of energy hubs cannot be classified as a renewable energy technology, it is related to the subject due to its integration in the same broader energy system. This causes an overlap in relevant stakeholders, and could result in similar challenges and barriers. Painuly's framework is relevant to this research as it provides a comprehensive methodology for identifying and analysing barriers that can hamper the adoption and development of energy hubs. For clarity reasons, the seven categories have been brought back to five, by combining the two 'market' categories and by no longer including 'other barriers'.

2.3. Prior research and background

The concept 'energy hub' was initially introduced in a project called "a vision of future energy networks (VOFEN)" (Mohamaddi et al., 2017). Within this project, an energy hub was defined as follows: "An energy hub is considered as a unit where multiple energy carriers can be converted, conditioned, and stored. It represents an interface between different energy infrastructures and/or loads. Energy hubs consume power at their input ports connected to e.g. electricity and natural gas infrastructures, and provide certain required energy services such as electricity, heating, cooling, compressed air, etc. at the output ports" (Geidl et al., 2007). Main conclusions from the VOFEN project include that an energy hub can reduce energy costs and emissions, increase security, reduce congestion and improve overall energy efficiency (Geidl et al., 2007). The definition posed in the VOFEN project is mainly on the technical nature of an energy hub. As this research focuses on organisational and governmental dynamics, the following definition by RVO (2024) better fits the scope of the study: "a local collaboration, based on agreements, between multiple parties in the field of energy. These parties coordinate energy production, transport, storage, conversion and consumption".

Energy hubs use various types of energy *inputs* and carriers. This includes renewable energy sources such as wind or solar power, natural gas, electricity, heat, hydrogen, etc. According to Eladl et al. (2023), the most mentioned energy inputs in previous academic studies are the electrical grid and natural gas, followed by solar and wind power (figure 1).

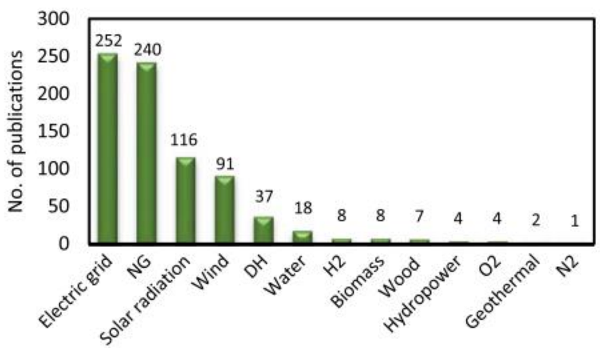

Figure 1: Most common energy inputs in previous studies (Eladl et al., 2023)

These various energy sources may require different forms of *conversion* before being used. Converters play a key role in this process and encompass a range of technologies such as transformers, gas boilers, heat exchangers, electrolysers, fuel cells, and compressors (Mohammadi et al., 2017). While certain converters facilitate the conversion of one energy type, others can generate multiple outputs from a single energy source. One prominent example is combined heat and power (CHP), which can produce heat and electricity from a single fuel source. Given the importance of diversifying energy carriers to meet varied demands within energy hubs, cogenerative converters like CHP systems contribute significantly to overall efficiency. Academic literature on energy hubs frequently highlights CHP as an important converter, as noted by Eladl et al. (2023) and Mohammadi et al. (2017). In addition to converters, energy hubs incorporate various types of *storage* facilities to manage energy supply and demand dynamics effectively. Storage plays a crucial role in balancing fluctuating energy inputs and outputs, ensuring stability and reliability within the system. Options for energy storage within energy hubs contain thermal storage, battery storage, ice, natural gas, hydrogen, etc. (Eladl et al., 2023). The *outputs* in an Energy hub depend on the type of user needs. Most common types of output are electricity and heating, followed by less used types such as cooling, natural gas or hydrogen (Eladl et al., 2023). Energy hubs can manifest in various forms, such as being implemented at transportation hubs like airports or ports, within residential areas, or on industrial estates (Geidl et al., 2017).

According to multiple academic papers, energy hubs can be categorised in four sectors or categories: Residential, commercial, agricultural and industrial (Azar et al., 2020; Eladl et al., 2023; Mohammadi et al., 2017). This study specifically focuses on energy hubs situated within business park settings, making the industrial sector the relevant category in this context. The industrial sector, being the largest consumer of energy worldwide, plays a crucial role in improving overall energy efficiency and reducing Greenhouse Gas (GHG) emissions (Azar et al., 2020). Therefore, energy hubs within industries hold significant value. One advantage is that the energy load in industry is more predictable compared to commercial or residential sectors, which might make it easier to implement an energy hub or energy management systems. However, switching to renewable energy in industrial settings require large investments, thus resulting in less tendency to transit into renewable and smart energy systems (Azar et al., 2020).

In addition to the previously described physical aspects of energy hubs, the organisational dimension is an important factor. The integration of all physical assets within a hub requires effective collaboration among stakeholders. Within this research, the focus is on the organisational and governance aspects of energy hubs on business parks. While there is a relatively limited base of academic research on this precise subject, an overview of the available papers in similar contexts will be provided.

According to Vereshchagina et al. (2015), smart grid technologies and the deployment of renewables need active engagement of all stakeholders. They state that reluctance of certain stakeholders could be one of the reasons for slowing down development of these technologies in the European Union. In this paper, the authors propose a framework for the interplay of energy stakeholders. Furthermore, they conclude that governments should take an active role in creating awareness for the benefits (Vereshchagina et al., 2015). These insights on stakeholder engagement in smart grid technologies and renewables are relevant, because both are important aspects of energy hubs. However, the study by Vereshchagina et al. (2015) primarily focuses on the broad system-level promotion of these technologies and does not delve deeply into the dynamics and interactions of stakeholders at the project level. Additionally, their research covers the entire European Union, which means it does not account for national rules and regulations that can impact the development and implementation of energy hubs in specific countries, such as the Netherlands.

Rodin & Moser (2021) identified barriers to industrial energy cooperation, clustered along the following categories: Economic barriers, Social/Managerial barriers, Framework barriers , Technical/Engineering barriers , Information provision barriers. The study identified a total of 100 barriers divided over these categories and associated with different implementation phases. Examples of barriers concerning governance and organisation include issues like a lack of trust between companies and park managers or service companies, incentive structures in companies influencing decision-makers' objectives negatively impacting acceptance, counterproductive regulations for certain technologies or measures, and frameworks hindering technically and economically sound cooperation in gas and electricity, among others. The authors' goal to identify barriers for energy cooperation aligns with the scope of this research. The empirical data collected in Rodin & Moser's (2021) research consists of interviews with companies. This research extends their work by also interviewing other stakeholders, such as DSOs and municipalities. Furthermore, this study delves deeper into stakeholder characteristics, dynamics and interactions, in addition to the identification of barriers.

Rodhouse et al. (2023) explore societal value co-creation in energy hub projects, focusing on how different stakeholder expectations evolve and are operationalized in the GZI Next project in Emmen, the Netherlands. The study highlights the importance of managing diverse and sometimes conflicting stakeholder expectations in renewable energy projects. The authors researched this by carrying out a longitudinal single case study, where they gathered data through interviews, documents and observations. It underscores the need for active stakeholder engagement and it demonstrates the complexities of aligning stakeholder interests. It thus provides a similar scope when it comes to stakeholder and organisational dynamics. In addition, its geographical scope is somewhat similar, as the case is also based in the Netherlands. However, the findings are mostly of a descriptive character, without actionable solutions or recommendations. Moreover, the authors recommend a multi-case study for future research, which is something this study provides.

Heunincks et al. (2022) conducted a study examining the objectives of stakeholders considering joining an energy community (EC). By examining multiple Flemish cases, the authors first provide an overview of the relevant stakeholders involved. Subsequently, the stakeholders are divided into four groups: EC members, DSO, (local) government and other stakeholders. For each group, the authors address the most important objectives for joining an EC. The main findings indicate that the financial aspect is a significant consideration for EC members, although it is not the only objective. Offering a future-proof and reliable energy system are also regarded as important. For DSOs, main objective for joining an EC is that the community is beneficial for the grid. The government's primary focus is on the environmental and social benefits of an EC. For the other stakeholders, the objective is dependent on the role of the specific stakeholder. By delving in the stakeholder dynamics and objectives for stakeholders in the related field of energy communities, there are some clear links to this research. However, it does lack the next step of providing the challenges and barriers that these stakeholders face. Furthermore, the geographical context being Flanders makes it difficult to generalise these conclusions to a Dutch context regarding policy, laws and regulations.

To conclude, existing studies provide valuable insights into the organisational and governance aspects of renewable energy technologies, smart grid technologies, energy cooperation, and energy hubs. However, they do not address the specific scope of this research, which focuses on business parks in the Netherlands. Additionally, these studies lack the combined analysis of stakeholder dynamics and the identification of barriers that this research provides. Moreover, this research offers actionable solutions, making it a more practical guide for stimulating the development of energy hubs within the regulatory conditions of the Netherlands.

To understand these regulatory conditions, an overview of the current laws and regulations regarding energy hubs is provided. In 1998, the Dutch electricity law was accepted. This law was designed to govern the production, transport and supply of electricity in the Netherlands. In a letter to the Dutch House of Representative, the minister of Economic Affairs and Climate argues that this law is currently hindering the energy transition. An important aspect is the sharing of energy. Currently, any surplus electricity must be fed back into the grid before it can be redistributed to another user. Considering grid congestion, the Ministry of Economic Affairs and Climate aims to renew the electricity law to enable sharing of electricity and power capacity in multiple ways (Jetten, 2023). The National Action Programme for Grid Congestion (Het Landelijk Actieprogramma Netcongestie or LAN in Dutch) is currently working on new laws to enable the formation of energy hubs. Various contractual forms are discussed below. While some are new or still in development, others are already being used in practice.

Group transport agreement (GTO)

A Group Transport Agreement (GTO in Dutch), as shown in figure 2, is a contract where individuals make contractual agreements with the DSO as a group entity. This type of contract can only be concluded in pilots, requiring a tailor made solution and the cooperation of the grid operator (Van Rhee, 2023). A GTO replaces the individual contracts (ATO) of the participants, providing the group with a shared grid capacity. This means that the group collectively agrees on the maximum amount of power they can import from the grid. In addition to this contract with the DSO, participants within the group must also establish agreements among themselves regarding power usage, determining who can use electrical power at what moment. A necessary condition for a GTO to work is that the group needs one representative as the contractual counterparty (Netbeheer Nederland, 2023).

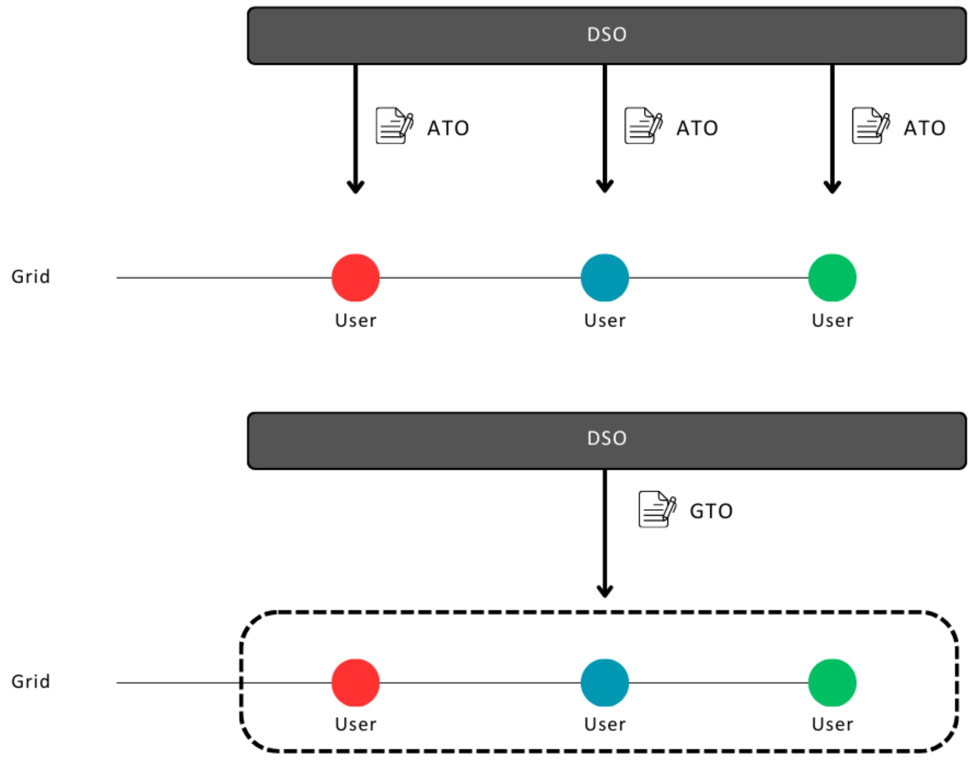

Figure 2: Schematic overview of a Group Transport Agreement

Group capacity agreement (GCO)

In a group capacity agreement, individual entities have a collective power capacity. In contrast to the GTO, the individual entities keep their own transport agreement (Van Rhee, 2023). Through smart coordination, businesses have the opportunity to electrify or expand their operations (under certain conditions), can collectively invest in energy and flexible assets like batteries, and collaborate on energy management initiatives (Stedin, 2023). The collective capacity is lower than all the individual capacities combined, which is beneficial for the DSO and the grid. Just as the GTO, this agreement can only be used in pilots (Van Rhee, 2023).

Collective Capacity Restriction Contract (C-CBC)

Another type of legislative contract is the Collective Capacity Restriction Contract (C-CBC). To facilitate this type of contract, a group of energy consumers requires a Congestion Service Provider (CSP). This CSP negotiates the contract with the DSO, where they agree that the energy hubs lowers its power consumption during moments of congestion. In return, they get a financial compensation (Liander, n.d.). Because this contract falls under the congestion code, there is already an existing legal framework for it (Van Rhee, 2023).

Closed Distribution System (GDS)

A Closed Distribution System (Gesloten Distributie Systeem or GDS in Dutch) is a small-scale electricity or gas network. This system or grid is owned by a private entity, such as a company, a housing association or a municipality. This owner is responsible for its management. A GDS can for example be used to distribute renewable energy production between users, without the need to feed it back into the regular grid. In contrast to the above mentioned agreements, a GDS can already be implemented in regular practice (Innax, n.d.).

Direct line

For this application, an electricity consumer is directly connected to a nearby electricity producer. A direct line can then be used to directly supply electricity to a consumer, without using the public grid. A direct line is, in contrast to a GDS, is not geographically bounded (Van de Kant, 2018). The Authority for Consumers and Markets (ACM) needs to be informed about the installation of a direct line. Just as the GDS, a direct line is allowed to be implemented in general practice (ACM, n.d.).

The first part of this theory section outlines the theoretical framework that guides and structures the analysis in the results section. The second part offers an overview of existing knowledge from previous research, highlighting the gaps that this study aims to fill. Finally, the section provides essential background on rules and regulations in the Dutch energy hub landscape.

3. Methods

This section describes how data was collected and analysed to answer the research question. Furthermore, it explains how reliability, validity, and ethics were incorporated into the research process.

3.1. Research design

The research objective was to enhance the understanding of organizational and governance dynamics within energy hubs in business park settings and propose solutions to identified challenges. Given the limited existing academic knowledge on the subject, the research was exploratory in nature. This type of research was used to gain insights, identify relationships, and establish a foundation for further practical applications and research activities. Furthermore, the research applied a qualitative approach using a multiple case study. The sources of data were interviews and desk research.

3.2. Data collection & sampling

The first stage of the study involved desk research. First, the literature review was used to refine the conceptual understanding of energy hubs and to provide an overview of the state-of-the-art knowledge on energy hubs in academic literature. This review enabled a thorough exploration of the energy hub concept and background on current laws and regulations. This literature review can be found in the theory section. Additionally, literature has been used in the results to draw parallels to findings from the interviews. Both academic and grey literature were consulted. Academic papers were found through search libraries such as Google Scholar and Worldcat by using and combining search keywords such as: “Energy hubs”, ”Energy cooperation”, “Business parks”, “Stakeholders”, “Smart Grid”, “Governance” and “Energy collaboration”. Non-academic research reports, policy documents, and other articles were found through public websites from stakeholders such as government or business websites.

Interviews formed the other source of data, allowing for an in-depth exploration of the organizational and governance dynamics. By engaging with stakeholders directly, the research aimed to uncover insights into their roles and interactions, contributing to a comprehensive understanding of the energy hub system. The semi-structured nature of the interviews allowed for flexibility, enabling the researcher to adapt and delve deeper into relevant subjects. Rather than following a formalized list of questions, the interviews were guided by a thematic framework, providing structure while allowing interviewees to introduce new insights or ask questions back (Bryman, 2016). The interview guide can be found in Appendix A. The interviews lasted between 30 and 60 minutes and were held in Dutch.

In this study, a multiple case study approach was employed to examine energy hub projects in business parks in the Netherlands. A list of energy hub projects in the Netherlands was generated through a Google search on “energy hub projecten Nederland” (in English: “energy hub projects

Netherlands"), identifying projects such as: Hessenpoort, XL Businesspark Almelo, A1 Bedrijvenpark Deventer, Broeklanden-Hardenberg, Innofase Duiven, De Mars Zutphen, Brick Valley, Lorentz Harderwijk, TPN West Nijmegen, Harselaar, Bedrijvenpark Pannenweg II, and REC Tholen (OostNL, n.d.-b; Samen Om, 2023; Solar Magazine, 2023). Additionally, the researchers' professional network was used to identify the energy hub project at the Oostervaart business park in Lelystad. Considering the time span of this study, three cases were chosen. The most important selection criterion was that each of the three cases was situated in different Distribution System Operator (DSO) areas, where the three largest DSOs in the Netherlands—Stedin, Enexis, and Liander—operate. This selection aimed to encompass a variety of perspectives from hubs being developed by different DSOs. Moreover, some of the earlier listed projects were rejected because the energy hub was not on a business park. Taking these criteria into account, while also considering the findability of data, the following three cases were chosen: Energy hub Hessenpoort, Business park Oostervaart, and REC Tholen. By examining energy hub projects across various DSO areas and provinces, this multiple case study design enabled an exploration of commonalities and differences, facilitating a broad analysis of the factors influencing the implementation and outcomes of energy hub initiatives in diverse settings.

The selection of interviewees was mainly done through purposeful sampling. This allowed the researcher to select interviewees that had relevant insights regarding the research topic. The criterion of selection was the role that a potential interviewee had within one of the three selected cases. This purposeful sampling method was sometimes overtaken by convenience sampling, because not every approached stakeholder was willing to cooperate. For instance, this has led to the fact that only one of the three DSOs has been interviewed. This resulted in the following list of interviewed stakeholders (table 2).

Table 2: Overview of interviewed stakeholders

Stakeholder type	Organisation	Position	Abbreviation
Muncipality	Zwolle	Councillor	MUN1a
		Process manager energy transition	MUN1b
	Tholen	Projectmanager and policyadvisor sustainability	MUN2
	Lelystad	Program manager heat transition	MUN3
Business	Tiem	Managing director	BUS1
	Deltaglass	Managing director	BUS2
Energy director / Hub manager	Hired by municipality of Lelystad	Energy director	EC/HM1
	On e Target	Hub manager / initiator	EC/HM2
	Hired by province of Overijssel	Energy director	EC/HM3
DSO	Stedin	Advisor energy transition	DSO2
Engineer/advisor	Equans	Consultant energy systems	ENG3
Province / ministry of economic affairs and climate	Overijssel	Project manager Smart Energy Hubs	EZK
	EZK	Sr. Policy advisor energy systems	
Netherlands Enterprise Agency	RVO	Senior Energy Innovation Advisor	RVO

All stakeholders were approached through LinkedIn or E-mail. The stakeholders in the table above were interviewed about their experiences regarding the specific energy hub projects. Additionally, some of the stakeholders shared their broader perspectives on energy hubs. For instance, the DSO and municipalities were also interviewed about their organisational strategies and initiatives concerning energy hubs. Besides the stakeholders that were directly linked to one of the three cases, interviews were also conducted with a policymaker at the national level from the Ministry of Economic Affairs and Climate (EZK) and an innovation advisor from the Netherlands Enterprise Agency (RVO). These interviews were relevant for gaining more insight into policy strategies concerning energy hubs in the Netherlands.

Interview questions were formed to characterise the stakeholder along the categories mentioned in the theory section. Furthermore, questions were posed regarding their interactions with other stakeholders and their perspectives on regulation, governance, and the organisation of energy hubs. Finally, questions were asked concerning barriers and their insights on how to solve these. An interview guide can be found in Appendix A.

3.3. Data analysis and operationalisation

The acquired literature from desk research was used to find theory that helped set a foundation for answering the sub-questions. When additional data were needed to substantiate the findings, the search for additional articles and documents continued. This made the data collection and analysis of the literature an iterative process.

The interviews were recorded and transcribed with the permission of the interviewees. The analysis of these transcripts was carried out through the grounded theory approach. First, the transcripts were read superficially to understand the roles and perspectives of the interviewed stakeholders. Second, the coding process started with open coding, where first-level codes were ascribed closely to the original words of the respondent. Third, second-order codes were generated by categorising the earlier described first-order codes into more interpretive second-order categories. Fourth, these second-level codes were grouped further through top-level coding. These top-level codes served as thematic umbrellas, aligning with the research sub-questions, to help organize the data (Bryman, 2016). Examples of top-level codes include 'Stakeholder profile', 'Interactions', and 'Challenges'. The coding also assisted in finding relevant quotes by respondents. As the interviews were in Dutch, the quotes that are used are translated literally, to keep as close as possible to the original statement.

To answer sub-question 1, the relevant stakeholders for each of the three cases were identified. The four most directly involved stakeholders were examined regarding their role, influence, interests and challenges. These categories were used to structure the interview questions, ensuring that all elements were covered. The data from the interviews was analysed using the previously described coding process. Statements from respondents were categorised into the four predefined areas. This allowed for a detailed narrative description of each stakeholder group, which was further substantiated by interview quotes from the respondents. Statements followed from questions regarding interaction and communication were used to answer sub-question 2. The identified relationships and transactions between stakeholders were then visually mapped in a chart. The findings from sub-questions 1 and 2, combined with additional insights from interview questions about difficulties and potential problems, facilitated the identification of challenges hindering the functioning or development of energy hubs, thus addressing sub-question 3. The analysis was structured using the barrier identification framework discussed in the theory section. Challenges and barriers proposed by stakeholders were categorised into one of the five defined barrier categories. Subsequently, additional barriers were identified that were not directly mentioned by respondents but could be deduced from combining multiple respondent perspectives. In the last step of the research, sub-question 4, the identified barriers and challenges were addressed by proposing solutions. These suggestions were based on insights gathered from the stakeholders involved in the three cases. Moreover, the interview with the representatives of EZK and RVO played a significant role. Furthermore, relevant literature was consulted to draw parallels with solutions proposed in similar contexts.

3.4. Validity, reliability and ethics

There is a distinction between internal and external validity. Internal validity concerns the extent to which observations lead to justified conclusions (Bryman, 2016). The usage of a variety of reputable scientific publications by different authors, in combination with insights from multiple interviews, led to an internally valid study. External validity refers to the extent to which the research is generalizable in different social settings (Bryman, 2016). This research concentrated on three cases of energy hubs in Dutch business park settings, but the findings may have broader applicability. Although the insights are case-specific, the organizational dynamics and the forthcoming challenges in energy hub development are likely to be similar in other energy hub projects.

The same distinction can be made between internal and external reliability. Internal reliability refers to the consistency of measurement (Bryman, 2016). This consistency was increased by using an interview guide that provided the same kind of structure for all interviews. Additionally, since this study was carried out by an individual, the coding and analysis of the data were consistent. External reliability refers to the replicability of the study (Bryman, 2016). Precisely writing down every step that was taken in this research enables other researchers to perform the same study in a similar fashion. This ensures transparency of the research process.

To ensure the ethics of this research, all interviewees were asked to sign an informed consent form. Additionally, all personal information was anonymized. The recordings of the interviews were deleted after the transcripts were made.

4. Case description

This section provides a description of the three cases that have been researched. The aim of this description is to provide background information on the specific environments in which the energy hubs operate. As described in the method section, these three cases have provided the stakeholders that have been interviewed for this study. The section starts with a short introduction to the state of energy hub development on business parks in the Netherlands.

In the Netherlands, just as elsewhere in the world, industrial business parks are significant users of energy. The approximately 3800 business parks account for half of the gas consumption in the country and for a third of its electricity usage (TNO, 2023). According to research by Royal HaskoningDHV (2023), energy hubs on business parks can cause a 4 to 6 megaton CO_2 reduction in the Netherlands by 2030. This estimate is based on the implementation of energy hubs on 355 business parks, a subset of the total 3411 regular business parks in the Netherlands. A regular business park is a mixed business park with three or more businesses (RLI, 2023). In addition to reducing CO_2 emissions, this approach also creates opportunities for growth, electrification and the implementation of more sustainable energy projects on business parks (Royal HaskoningDHV, 2023). These kind of initiatives are currently hindered by grid congestion. While this potential appears to be promising, practical implementation remains limited. Currently, there is only a handful of pilot projects in the Netherlands, as earlier mentioned in the method section. Three of those projects have been selected for this case study.

4.1. Hessenpoort

Business park Hessenpoort is a business park located in Zwolle. It is home to various companies within sectors such as transport, food and manufacturing industry. Examples are Wehkamp, DHL, Picnic and Euroma (Zwolle, n.d.). The Hessenpoort business association aims to be 100% self-sufficient in terms of energy in the future. To achieve this goal, the project Energy hub Hessenpoort was launched. In 2019, a solar park was established, providing approximately 25% of the business park's annual electricity needs. However, due to grid congestion in the area, further expansion of renewable energy generation is hindered. Businesses that want to install solar panels on their roofs are currently unable to feed the excess electricity back into the grid, as they are unable to get feed-in capacity contracted. One business on Hessenpoort even already has a PV installation on their roof, without being able to feed in. Consequently, they need to shut down the whenever their generation exceeds their usage (BUS1). To solve this, the business is part of the pilot project in cooperation with the DSO, Enexis. This project is known as Smart Energy Hub Zwolle Noord, where they are conducting an experiment with a precursor of a group transport agreement (GTO). In fact, the contract that the project uses is a group capacity agreement (GCO), where the participants keep their own contracted transport capacity (GTV). The first three companies signed the GCO by the end of 2023 (OostNL, n.d.-c). Through this group contract, the aforementioned business can use the feed-in capacity of the other two businesses when they are not using it. The same principle applies to supply capacity (EC/HM1). On top of this group contract, the business park is exploring the production of hydrogen as a way of energy storage (Ondernemersvereniging Hessenpoort, n.d.).

4.2. Tholen

The business park Slabbecoornpolder en Welgelegen, located in the municipality Tholen, is a regionally oriented business area that is home to various companies. Most businesses are in the manufacturing sector (glass, service machinery, plastic manufacturing, etc.). In total, there are 140 businesses established on the business park. Over the past few years, there has been a lack of grid capacity for feeding in electricity. Additionally, since July 2023, there has been no available capacity for (new) large consumers of electricity (Van Rhee, 2023). In 2019, Renewable Energy Cooperation (REC) Tholen was initiated (Slabbecoornpolder, n.d.). In September 2023, REC Tholen and DSO Stedin signed a Group Capacity Agreement (GCO). It is the first time that Stedin enters such an agreement. Initially, the contract has started with four businesses, but the goal is to expand this step by step. In 2024, a 2MW battery has been added to the energy hub, to help achieve a better balance. Businesses within the energy hub will now be able to expand or electrify their operations, as the group capacity is higher than their maximum individual capacity. Moreover, they will be able to expand PV installations on the business park, as they are able to share feed-in capacity and store surplus electricity in the battery. Thus, the business park can improve its sustainability, without the need of extra capacity of the public grid (Stedin, 2023).

4.3. Oostervaart

Business park Oostervaart is located in the northeastern part of Lelystad. It has a total area of almost 130 hectares. With its location near the highway A6 and various waterways makes the area easily accessible. The business Park primarily focuses on heavy industrial activities (Lelystad, n.d.). As part of the heat transition vision (transitievisie warmte in Dutch), the municipality is exploring options to make the industrial park natural gas free. This begins with a handful of companies that account for the majority of the natural gas consumption. However, due to grid congestion, there will not be enough capacity to electrify their industrial processes. Therefore, they are currently investigating the possibility of directly connecting these companies to Smart Grid Flevoland. This is a GDS managed by Equans. Smart Grid Flevoland is a generative GDS, with wind parks, solar parks and batteries connected to it (Smart Grid Flevoland, n.d.). Connecting users, such as the businesses on Oostervaart, to the GDS would the first time. Consequently, it is currently under investigation to determine whether it can secure approval from the ACM and the grid operators (ENG3). Another step that will be taken in the nearby future is the signing of a declaration of intent between the municipality, the businesses and the GDS operator (EC/HM3).

5. Stakeholder analysis

This section presents a stakeholder analysis for energy hubs in business parks in the Netherlands. Section 5.1 begins with a general overview of the key stakeholder groups involved in these energy hubs. Section 5.2 aims to answer sub-question 1, by providing an in-depth analysis of the four stakeholder groups that were most directly engaged in the three case studies. This analysis examines their roles, influences, interests, and challenges. The section concludes with an examination of the interactions between stakeholders, supported by a visual chart that maps these relationships. This aims to answer sub-question 2.

5.1 Energy hub stakeholders in the Netherlands

As mentioned in the introduction, energy hubs consist of various types of stakeholders. In their study on business concepts for energy hubs, Sepponen & Heimonen (2016) sketched an overview of all stakeholder involved in a district energy system. Other studies on stakeholders regarding the energy system, energy hubs and energy cooperation in business parks mention the same stakeholders, while also introducing new insights (Heuninckx et al., 2022; Hwang et al., 2017; Rodin & Moser, 2021). As this study focuses on energy hubs in business park settings in the Netherlands, the stakeholders identified in these studies have been adapted and specified accordingly: *End users* include businesses. *Authorities* involve the Dutch government (especially the ministry of economic affairs and climate), provinces, municipalities and the ACM (an independent regulator). *Service providers* consist of transmission system operators (e.g. Tennet) and distribution system operators (e.g. Stedin, Liander, Enexis). *Intermediaries* include energy coordinators or hub managers. *Financial* stakeholders include banks or other investors The stakeholders are displayed in the figure below.

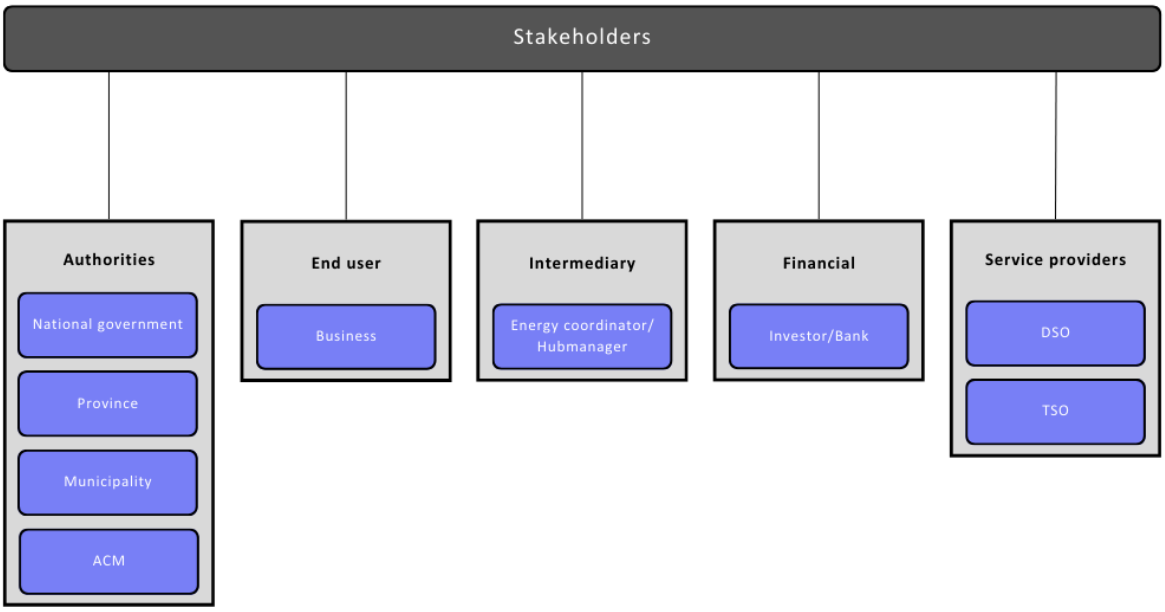

Figure 3: Energy hub stakeholders

5.2. Stakeholder analysis of the three cases

The stakeholder analysis in this section will focus on the four stakeholder groups that are most directly involved in the energy hub projects. These groups are the DSOs, municipalities, businesses, and energy coordinators or hub managers. These stakeholders will be analysed regarding their roles, influence, interests, and challenges.

While the broader system includes additional stakeholders such as TenneT, ACM, the national government, provinces, financial institutions, and more, the focus of this in-depth analysis is on those with the most direct impact on the three energy hub projects. This decision has been made because the focus of this research is on three specific cases of energy hub projects. Consequently, interviews were conducted with stakeholders directly tied to these projects, which is less feasible for other stakeholders who are merely involved in the bigger system. Therefore, the collected data primarily focuses on the insights of the four mentioned stakeholder groups.

In the interactional analysis (section 5.3), other stakeholders will be incorporated, and their broader role in the system will be displayed. This approach provides a detailed understanding of the dynamics and interactions within the energy hub projects, while still considering the wider context in which these projects and stakeholders operate.

Table 3: Stakeholders per case

	Hessenpoort	**Tholen**	**Oostervaart**
DSO	Enexis	Stedin	Liander
Municipality	Zwolle	Tholen	Lelystad
Businesses	Tiem, Zehnder, Axxor	Jansen, Deltaglas, U-Tube, Nestaan	McCain, Marfo
Energy coordinator/ Hub Manager	Coordinator deployed by province of Overijssel	Hub manager from executing party	Coordinator deployed by municipality of Overijssel

5.2.1. DSO

5.2.1.1. Role

Historically, Distribution System Operators (DSOs) in the Netherlands have been responsible for managing and operating the electricity distribution network. This encompasses maintaining the physical infrastructure, including cables, transformers, and substations, as well as connecting new customers to the grid. Since the increasing issue of grid congestion, the DSOs are focusing heavily on the expansion of the Dutch electrical grid. Simultaneously, they are developing ways to utilise the existing grid more efficiently. The latter is the reason why they are actively participating in energy hub projects. One of the crucial roles of DSOs in energy hub projects is to inform potential hub participants about the available capacity on the regional grid. According to a DSO representative, "It began with identifying what space there is on the grid and what they want to do with it. How can they use it smarter without causing higher peaks?" (DSO2). Another aspect of the DSOs' role is ensuring grid security. This involves continuous monitoring and management of the grid to prevent any disruptions. The DSOs' operations centres keep a close watch on grid activities to ensure stability and security: "Our operational centre monitors the grid 24/7; they need to know what's happening" (DSO2). DSOs also play a vital role in navigating and complying with regulations. They need to ensure that all activities within the energy hub align with current energy laws and network codes. This involves close coordination with regulatory bodies like the Authority for Consumers and Markets (ACM) to ensure compliance and avoid any regulatory breaches (DSO2). Negotiating and finalising contracts is another activity of DSOs in energy hub projects. This process includes collaborating with various departments within the DSO and external stakeholders to ensure all legal and operational aspects are covered. DSO2 described the process as involving multiple internal departments and extensive discussions with representatives from the businesses involved: "I went through all these departments, and everyone had their say. If it all works out, you put it all in a contract and sign it" (DSO2).

5.2.1.2. Influence

The interviewed DSO at REC Tholen decribes that their influence in setting up energy hub projects could be significantly larger than it is now. However, they have chosen to take a more modest role: "If we wanted, our influence could be significant. But I think one of the strengths of these group contracts is that you leave a lot to the market" (DSO2). Other stakeholders describe the influence of the DSO as extremely important, as they are such an important partner in energy hub projects (EZK). This is confirmed by representatives from the municipality and hub management at REC Tholen, who state that the project's success relied heavily on the DSO's proactive involvement (MUN2; HM2). At Oostervaart, the process cannot proceed without permission and cooperation of the DSO: "The biggest obstacle now is that we are not receiving cooperation from the grid operator, both the regional and the national grid operator" (HM3). The involvement of a DSO is thus crucial. So even though the interviewed DSO states that they try to take on a modest role, it should be seen as a highly influential stakeholder in determining the locations and projects where they choose to provide support or participate in energy hub initiatives.

5.2.1.3. Interest

The primary interest of DSOs in participating in energy hub projects is to reduce grid congestion. However, the immediate impact on the available grid space is minimal. A DSO representative explains that instead of considering the contracted capacities of their users, they assess the total load for each substation, where electricity is transformed from high to low voltage. Therefore, the DSO already accounts for the fact that users often do not use their entire contracted capacity. For determining the capacity that an energy hub is allowed to use, they consider the historical peak usage of the individual participants. This means that energy hubs are permitted to have the same net impact as they historically had. Although the space created on the grid is limited, it does take away some risk for the DSO, as it ensures that the businesses in the hub cannot fully use their contracted capacity anymore (DSO2). Furthermore, the approach taken by DSOs is more of a long-term strategy aimed at improving grid efficiency and promoting grid-conscious behaviours for electricity users. By participating in energy hub projects, DSOs aim to foster a more sustainable and adaptable energy usage pattern among businesses. "We hope that despite congestion, we can help and facilitate companies in their sustainability and expansion efforts," stated DSO2. The energy hubs encourage businesses to manage their energy consumption more efficiently, by using technologies like solar panels, EV charging stations, and battery storage for congestion management services. In the long term, this results in a grid-conscious business park that requires fewer grid reinforcements to facilitate its expansion and sustainable development.

5.2.1.4. Challenges

While energy hub projects offer numerous benefits, they also pose several challenges for DSOs. One concern has to do with simultaneity. Normally, different businesses have peak energy demands at different times of the day. However, when businesses within an energy hub coordinate to maximise their usage of available grid capacity, they tend to fill their connections as broadly and as flatly as possible. This means that rather than having peaks, the combined demand of these businesses is likely to be flatter. The profiles of other local energy users outside of the hub will be put on top of this straighter line, instead of alternating its peaks. So although the energy hub stays below its contracted capacity, its behaviour can cause higher loads on local substations at certain moments (DSO2). It has to be noted that businesses inherently have the right to utilise their individual connections to the fullest extent. This always poses a risk for DSOs. But within an energy hub, this becomes easier and is actively encouraged. Liability is another significant challenge. If an energy hub causes damage to the grid, it can be challenging to determine who is liable. One respondent explained that their legal department considers it a risk if a group contract is signed with a shell company that has no assets to cover potential damages: "Our legal department saw this as a risk and said it can't be that we sign a contract with an empty company and the liability lapses" (DSO2). This issue is compounded by the fact that individual companies within an energy hub might resist being held jointly liable for damages caused by others (DSO2). The challenge of assigning liability remains an ongoing discussion. "While the chance that an EHUB causes such a significant fault that it results in high damages is minimal, the biggest discussion is about liability" (DSO2).

5.2.2. Municipality

5.2.2.1. Role

Municipalities play a crucial role in energy hub projects, particularly in the areas of permits, subsidies, and coordination among stakeholders. Their involvement ensures that regulatory requirements are met and that projects are supported through necessary administrative, financial and logistical assistance. Municipalities are responsible for managing permits required for the development and operation of energy hubs. They facilitate the process by ensuring that all necessary documentation is prepared and submitted correctly (MUN2). Municipalities also play a role in securing and managing subsidies for energy hub projects. They help organize and gather funds to support these initiatives: “Where I will help you is in securing financing from other parties. From the national government, from the province. From Horizon, from Brussels. Wherever we can haul money from" (MUN3). In the cases of Hessenpoort and Oostervaart, municipalities take on an active role by financing process costs, especially in the initial phases of the project. This involvement is essential to get the project off the ground and ensure its viability. This financial support can for example include funding for project management (MUN1; MUN3). At REC Tholen, the municipality did not contribute financially. Moreover, municipalities often act as contact points for various stakeholders involved in the project. They facilitate communication and coordination between different parties, ensuring that everyone is informed and aligned with the project's goals. At Hessenpoort, the municipality of Zwolle has set up a coordination team: “We have an administrative steering committee, an administrative consultation. And beneath that is the coordination team where we try to, well, guide the development of smart energy” (MUN1b). Another activity that municipalities engage in is lobbying the national government for changes in policy or law. This involves coordinating with other municipalities and organizations, making their collective voice more powerful. A representative from the municipality of Lelystad explains how they coordinate with other municipalities, such as the G40, to be able to send a united message to the national government when necessary (MUN3). For example, this can concern changes in law regarding energy sharing. On a municipal level, it might involve lobbying to obtain a pilot status for a project.

5.2.2.2. Influence

Municipalities have varying degrees of influence in energy hub projects, depending on their level of involvement and the resources they bring to the table. First of all, municipalities can influence where energy hub projects are located and where assets such as batteries are placed. While the specific influence may depend on the municipality’s level of engagement, they can certainly steer decisions related to spatial aspects. A municipality representative of Tholen explains: "You can certainly influence or steer as a municipality if you want to, particularly in spatial aspects. For example, if a battery needed to be placed, the municipality could have had a say in that if we had wanted to" (MUN2). Furthermore, he describes that is important for municipalities to not use their influence for favouring one project of solution over another. They focus on informing stakeholders about all available initiatives without directing them towards a specific option. "I can't push people towards one initiative, but I can inform them about everything that is available" (MUN2). The level of financial contribution a municipality makes can also determine its influence on the project. A representative of the municipality of Zwolle argues: "Depending on what you bring, knowledge or knowledge and money, your influence can be significant. But it's more about ensuring that you achieve what the businesses want to achieve, and representing the public interest as effectively as possible" (MUN1b). This emphasizes the need for municipalities to balance their involvement to support both the business objectives and the broader community interests.

5.2.2.3. Interest

Municipalities have several interests in supporting energy hub projects, including helping local businesses, reducing grid congestion, and meeting sustainability goals. One of the primary interests for municipalities is to create and maintain a good business climate. This ensures that businesses can get new electricity connections and expand their capacities, which is important for their operations and growth. "As a municipality, you want to ensure a good business climate, so companies can do what they want to do" (MUN1b). By supporting energy hub projects, municipalities can help businesses overcome the challenges of grid congestion and electric capacity shortages, making the area more attractive for existing and potential businesses. Managing grid congestion is another important interest for municipalities. Reducing the need for extensive grid reinforcements can help lower societal costs, which ultimately benefits the residents. "You want to ensure that there is not an unlimited expansion of the electricity grid, as these are societal costs that we all eventually pay" (MUN1b). By participating in energy hub projects, municipalities can implement smarter energy management solutions that reduce congestion and improve grid efficiency. Municipalities also have a responsibility to ensure the future of local businesses and their employees, who are often residents of the municipality. Supporting energy hubs helps businesses become more energy autonomous and sustainable. "We have a big responsibility to ensure the future of these companies. In this case, we want to show that" (MUN1a). The municipality representative of Tholen confirms: "The main reason is indeed grid congestion related, but it also benefits the business climate on the business park" (MUN2). By fostering these projects, municipalities can enhance the attractiveness of the area for businesses and ensure a stable and reliable energy supply (MUN2). Finally, municipalities are driven by sustainability objectives, such as making business parks free from natural gas to meet the 2050 sustainability targets. This involves working closely with local businesses to understand their energy needs and implementing tailored solutions (MUN3).

5.2.2.4. Challenges

A significant challenge for municipalities is deciding how active they want to be in the project and determining the right moment to withdraw their support. "That's the beauty of it. You never step out at the right time because you either leave too early or too late. So timing is very important" (MUN3). Municipalities need to balance their involvement, ensuring that they provide enough support without overstepping, and recognizing when businesses are ready to operate independently. Additionally, municipalities face the challenge of choosing their role in the project. They need to consider questions like: Do we want to finance the project? Do we have the expertise in-house to help? Should we hire external experts? (MUN1). Another challenge is the increasing control of energy supply by private entities, which may prioritize their own interests over the public good. This raises questions about whether such developments serve the best public interest: "The smart energy hub at Hessenpoort is partly public but mainly private. Eventually, it will be fully private. The concern is, who controls the energy and determines the price, especially during shortages?" (MUN1a). Municipalities must consider how to protect public interests and ensure fair access to energy, particularly in times of scarcity.

5.2.3. Businesses

5.2.3.1. Role

Businesses are involved in an early stage of the process. However, they often lack the knowledge and resources to set up an energy hub project. A businessowner in Tholen mentions, “But yes, who is going to manage that? Look, from my company, I am not going to manage that. It is not my core business. I mean, I need energy and that’s it” (BUS2). A business representative at Hessenpoort confirms: Because who deals with energy technology on a daily basis? Not many business owners”(BUS1). So despite their early involvement, participating businesses do not often have the main initiating role within the project. At Hessenpoort for example, it was the parkmanager who took the first steps and approached the businesses to get them to participate (BUS1). Once involved, an important part of the businesses' role is to share information. They need to provide their energy profiles, supply historical data, and improve monitoring capabilities if necessary (MUN1; MUN2). Furthermore, a business representative at Hessenpoort explains that the role of a business mainly involves deciding whether to participate and whether to invest in certain assets, such as generation or storage facilities (BUS1).

5.2.3.2. Influence

The influence of businesses in energy hub projects can vary significantly depending on their level of involvement and the decisions they choose to engage in. Businesses have the option to join the board or other governing structures of the energy hub, which allows them to have a more direct influence on decisions. As one respondent observed, "As an individual company, you don't have that much influence unless you join the board and participate in the decision-making, provided you have the skills, time, and knowledge for it" (BUS1). Additionally, businesses naturally have full control over their own investment decisions. Consequently, their choice to participate and invest in assets can directly influence the development of an energy hub project (BUS1). Multiple respondents emphasised the importance of proactive and collaborative businessowners for the successful development of an energy hub (MUN1; MUN2; BUS1). This illustrates the influence businesses exert over the process.

5.2.3.3. Interest

Businesses have several key interests when participating in energy hub projects. These include becoming more sustainable through electrification and the use of renewable energy sources, obtaining additional electrical capacity from the grid, and expanding their operations. One of the primary interests for businesses is to become more sustainable by integrating renewable energy sources such as PV panels. Businesses recognize the importance of reducing their carbon footprint and achieving sustainability goals. However, due to grid congestion, businesses are often not able to get a feed-in connection to the grid. A respondent explains how their business had a PV installation that had no connection to the grid. Consequently, whenever the generated energy was not required for personal use, the panels had to be curtailed. In that context, a collective contract provides a solution (BUS1). Another respondent confirms this interest, "We have always been looking for sustainability steps and from the beginning, I was involved because we also wanted to purchase solar panels. That ultimately didn't work out due to grid congestion. But the whole idea appealed to me, and that's how I got involved in the whole project" (BUS2). Another interest is obtaining more electrical capacity from the grid. Many businesses are looking to expand their operations, which requires additional power. However, they often face challenges due to grid congestion and limited capacity. As noted by a respondent, "It offers perspective for those entrepreneurs, as I know some of them want to expand. They want an extruder, but they won't get that capacity from the grid operator" (MUN2). This limitation drives businesses to seek innovative solutions through energy hubs. Beside expansion, additional electrical capacity is required for phasing out fossil fuels, such as natural gas. This is the case for the Oostervaart business park, where businesses need to electrify their processes in to meet the sustainability targets of 2050. As grid congestion makes expansion of their individual electrical capacity impossible, they have an interest in exploring other solutions (HM3). Economic benefits were not explicitly mentioned as a primary interest by respondents, which is noteworthy. However, it can be concluded that economic interests are implicitly embedded in the mentioned interests. The desire to expand their business is inherently driven by economic motives. Additionally, by electrifying their processes, businesses are preparing for the anticipated rise in fossil fuel prices. This suggests that while immediate economic gains were not highlighted, the long-term economic interests of businesses are present.

5.2.3.4. Challenge

Businesses may face several challenges when participating in energy hub projects. One of the most important challenges for businesses is the financial uncertainty in the early stages of energy hub projects. The costs often precede the benefits, making it challenging for businesses to justify the initial investment. These investments can for example include feasibility studies, measuring infrastructure or assets such as a battery. As highlighted by a hub manager, "Funding is a very big problem. For many things, the societal business case is evident, but at the business level, it is not there. There has to be money added because what are the costs of having grid congestion?" (HM3). This financial burden can deter businesses from participating, especially when the economic returns are not immediately apparent. Moreover, a respondent highlights the risk involved in obtaining bank loans when financial returns are uncertain (BUS2). Another challenge is the difficulty of sharing information and data among businesses that may be competitors. While energy hub projects require a high level of cooperation and transparency, businesses can be hesitant to share sensitive information. As one interviewee noted, "Businesses find it challenging to be completely open about everything. They sometimes have competing interests. For example, if you applied for additional grid capacity just before your neighbour, it works on a first-come, first-served principle" (HM1). However, in the three cases that have been researched, this has not yet been an issue, as multiple respondent highlighted the cooperative spirit between businesses (HM1; BUS2). A final challenge for businesses is the lack of expertise in energy technology. Many businesses do not possess the in-depth technical knowledge required to explore the opportunities in energy management. A businessowner pointed out that their board consisted of laymen. In hindsight, he believes it would have been beneficial to involve individuals with the right expertise from the beginning of such a project (BUS2).

5.2.4. Energy Coordinators and Hub Managers

5.2.4.1. Role

Energy coordinators and hub managers often act as the central figures who facilitate collaboration among different stakeholders. They ensure that all parties are aligned and working towards the shared objectives of the project. As one energy coordinator described, "It is a multistakeholder collaboration where many parties make their own decisions. There is no hierarchical connection, but you do have influence by working together on a common focus, ensuring that you are all in the same film, and initiating and connecting certain things from a collective interest" (EC/HM1). This role requires an understanding of various stakeholders' perspectives and the ability to bring them together. Energy coordinators or hub managers are often deployed by governmental bodies such as municipalities or provinces. These coordinators and managers need to have expertise across multiple domains to effectively connect different parties involved in the project. They must understand technical details, business processes, and regulatory requirements. As one respondent highlighted, "You need to know what you are talking about. As a hub coordinator, you need to be somewhat familiar with the installation industry, understand the costs and revenues, and know how business processes work" (MUN3). This broad knowledge helps in the communication between all stakeholders. The managers and coordinators ensure that all stakeholders are informed and engaged, while helping them with the complexities of energy management. As one respondent explained, "We are the connecting factor in it. We arranged the subsidies and also had discussions with the technical people. We communicate very differently with the municipality than with the people who need to do the technical part" (EC/HM2).

5.2.4.2. Influence

Formally, energy coordinators and hub managers often do not possess decision-making authority. As one energy coordinator noted, "Formally, I have no influence. I can't make decisions. I can only make choices within the mandate I have as a hired force of the Province of Overijssel, within the allocated budgets" (EC/HM1). Despite this lack of formal authority, their practical influence is significant. They play an important role in multistakeholder collaborations, where they can exert influence in aligning multiple views into a common objective (EC/HM1). Energy coordinators and hub managers have a unique position as the stakeholder that all other stakeholders can communicate with. Their influence lies in their ability to provide practical solutions that align with the broader policies of large organisations. One energy director highlighted this aspect, saying, "You have no influence on the policy [of large corporations], but you can influence . . . the solutions they choose" (EC/HM3). Energy coordinators or hub managers are often deployed by governmental bodies such as municipalities or provinces. This allows them to operate in a dual role, representing public entities while also being perceived as external consultants. This gives them access to various levels of government, while they stay acceptable to businesses because they are not seen as purely governmental figures (EC/HM3). This enhances their ability to be influential on multiple levels.

5.2.4.3. Interest

The main interest of energy coordinators and hub managers is advancing the energy transition, particularly from a sustainability perspective. They provide the necessary expertise and coordination to help businesses adopt new energy solutions that they might not be able to implement on their own. "In this way, you can actually help the energy transition and also help these companies in solutions that they alone would not be able to achieve" (EC/HM3). Another respondent explains his intrinsic motivation to ensure that plans executed, "I hate making plans and not executing them because in the Netherlands we tend to make a lot of plans and then just say, oh yes, this is the plan. And here is the report, and then you don't see what you do with it" (EC/HM2). This interest drives their effort to bring various stakeholders together, to ensure effective execution of the plans within a project.

5.2.4.4. Challenge

Energy coordinators and hub managers face several challenges in their roles, primarily due to their responsibility to connect and coordinate among various stakeholders. One of the primary challenges for energy coordinators and hub managers is obtaining the necessary cooperation from stakeholders. This includes DSOs, regulatory authorities, and financial institutions. As one respondent states, "The biggest obstacles now are that we are not yet receiving cooperation from the grid operator, both the regional and the national grid operator" (EC/HM3). Another hub manager also highlights the difficulties that may arise regarding cooperation by the DSO (EC/HM2). Moreover, getting cooperation by financial institutions is a challenge, as banks are hesitant to invest in projects with uncertain outcomes (EC/HM2). Finally, the novel nature of energy hub projects means that coordinators and managers often deal with new territory, requiring extensive research, experimentation, and problem-solving. "Those are the main hurdles in such a project, where you are essentially doing things that have not been done before. You have to figure out all these things, and that sometimes costs much more money than you had ever budgeted" (EC/HM1). This process can lead to unexpected challenges and delays.

5.2.5. Overview of the findings

The table below provides a comprehensive overview of the most important findings from the stakeholder analysis above. It displays the roles, influences, interests, and challenges of each stakeholder group involved in the energy hub projects, written in key points. The table shows that stakeholders in the projects fulfil multiple roles. This indicated the multifaceted nature of energy hubs. Regarding influence, no single stakeholder appears to have significantly more influence than the others. Each stakeholder exerts influence in its specific area, impacting the development of the energy hub project in their own way. When examining interests, it is noteworthy that there are no significant conflicts of interest. Although each stakeholder's interests vary slightly, they generally steer the project in a similar direction. Furthermore, a common goal of all stakeholders is to contribute to the sustainable energy transition. Finally, the challenges faced by the stakeholders provide a solid foundation for section 6, where barriers and challenges will be addressed in further detail.

Table 4: An overview of the most important findings of the stakeholder analysis

Stakeholder	Role	Influence	Interest	Challenge
DSOs	• Inform users about available capacity and network infrastructure • Ensure network security • Regulatory compliance • Negotiate contracts	• Modest position • Essential partner • Consent and cooperation required	• Reduce grid congestion • Improve efficiency • Promote grid awareness • Gain flexibility	• Higher grid load • Liability
Municipalities	• Permits • Subsidies • Coordinate stakeholders • Lobby for policy changes	• Influence on spatial matters • Determine where to contribute and invest	• Good business climate • Reduce grid congestion • Sustainability goals	• Role decision • Timing of involvement • Fear of private party dominance
Businesses	• Share information and data • Decide on participation • Participate in boards	• Varying influence depending on role • Investment decisions	• Sustainability through renewable energy • Obtain more grid capacity • Expand operations	• Financial uncertainty • Data sharing • Lack of expertise
Energy Coordinators/Hub Managers	• Facilitate collaboration • Ensure alignment among stakeholders • Use broad knowledge to connect stakeholders	• No formal authority • Practical influence • Represent public and business interests	• Promote energy transition • Effectively executing plans	• Securing cooperation • New project challenges

5.3 Stakeholder interactions

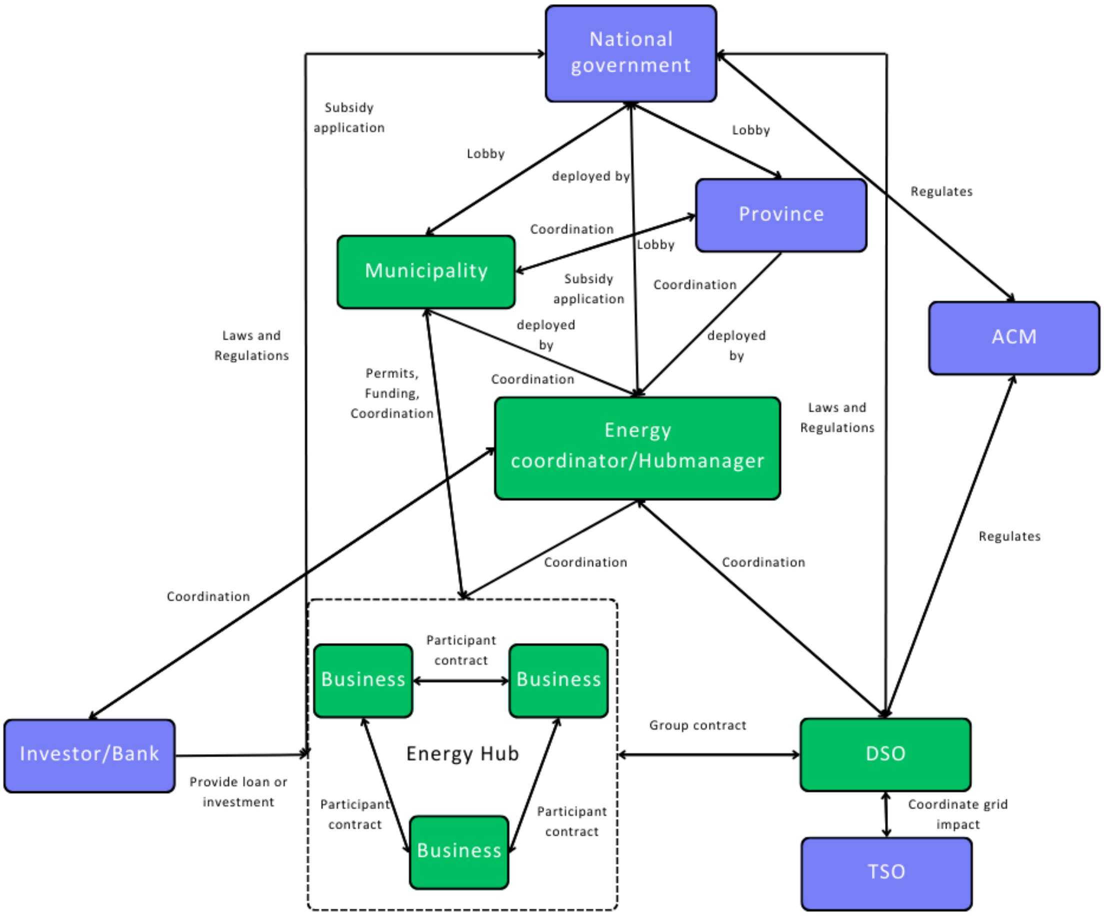

Figure 4: Stakeholder interaction chart

Figure 4 illustrates the key relationships between stakeholders in the energy hub ecosystem. The green-coloured stakeholders represent the most directly involved stakeholders, which have been analysed in detail in the previous section. The blue-coloured stakeholders, while less directly involved, still play significant roles within the broader energy hub landscape. A description of the chart is provided below.

The energy hub is displayed as multiple businesses that are connected through a participant contract, which forms the formal foundation of the energy hub. As a collective, they sign a contract with the DSO. The TSO and DSO coordinate the grid impact that an energy hub has on the high voltage grid. The set up of an energy hub requires a lot of coordination between different stakeholders. This is the main task for the energy coordinator or hub manager, which functions as a connector. An energy director is often deployed by a municipality, a province or the national government. Furthermore, the government bodies provide policy, regulation, coordination and support. Out of the three government bodies, the municipality is the most directly involved. This is mainly through providing permits, funding and coordination. Besides funding by municipalities, energy hubs can acquire funding through applying for subsidies. This can be done directly by the energy hub, but is often supported or facilitated by municipalities or an energy coordinator or hub manager. Furthermore, banks or investors can invest in or provide loans for energy hubs. The national government formulates laws and regulations for the energy hub and the DSO. At the same time, energy coordinators, municipalities and provinces may lobby for changes in this legislative framework. The ACM acts from their role as regulator, where they decide whether certain solutions or contract proposals fit within the regulations and the grid code. Moreover, their lobbying can concern getting approval for certain projects or acquiring a pilot status. Businesses, municipalities and energy coordinators or hub managers often form the core governing body of an energy hub. A board, committee or team, consisting of representatives of these stakeholder groups communicate and coordinate the process by holding regular meetings. Stakeholders describe these relationships as informal (MUN2). The interviewed stakeholders are in general satisfied about the collaboration with other stakeholders. Multiple respondents highlighted that it helps that most stakeholders are on the same page, as they mainly want to achieve the same goals (EC/HM1; DSO2). The interaction between the governing body of an energy hub and the DSO differs between the three cases. In the cases of Tholen and Hessenpoort, there is strong communication and collaboration between the DSO and the other stakeholders in the hub (EC/HM1; EC/HM2; MUN1; MUN2). This can be explained by the fact that the DSOs were involved from an early phase and saw potential in using the project as a way to learn (DSO2; EC/HM1). At Oostervaart, there is no cooperation yet from the DSO. A respondent explains that the DSO has indicated they are too busy to review their case (EC/HM3). Communication and coordination with governmental bodies is mostly characterised regarding the pace of decision making processes. Stakeholders describe how governmental bodies move slowly in general, but that it gets worse on a higher governmental level (MUN1a; MUN3).

This chart displays the stakeholder relations of one energy hub. However, it is important to note that there also are a lot of relations and interactions between stakeholders from different hub projects. For instance, the energy coordinator at Hessenpoort describes that he is part of a steering group that consists of multiple energy directors, where they share knowledge based on experiences from their energy hub projects (EC/HM1). The municipality representative for Oostervaart highlights the sharing of knowledge and the coordination between municipalities (MUN3).

To conclude, the development and operation of energy hubs involve extensive coordination among various stakeholders, with the energy coordinator or hub manager playing a crucial role in connecting businesses, DSOs, and government bodies. This coordination is generally viewed positively by the respondents, who find the collaboration and communication to be effective. Beyond individual hubs, there is also substantial coordination and knowledge exchange across different hubs.

6. Barriers and Challenges

This section identifies and categorizes the barriers and challenges faced by energy hubs based on the insights gained from the stakeholder analysis and interviews. It covers market, economic and financial, institutional, technical, and social, cultural, and behavioural challenges. Thereby, it aims to answer sub-question 3.

6.1. Market

Non consideration of externalities
An important barrier for the implementation of energy hubs is the often non-existent business case. This is caused by a market failure where externalities are not adequately accounted for. Externalities, in economic terms, refer to the costs or benefits that affect third parties that are not directly related to the activity (Painuly, 2001). In the context of energy hubs, the externalities are the societal benefits of reducing grid congestion and contributing to a decentralised energy system. As a result, it is likely that fewer investments in grid expansion will be necessary. Moreover, it stimulates the renewable energy transition. These effects benefit society as a whole, but are not directly captured by the businesses involved in energy hubs. This results in the fact that there is often no business case on firm or hub level without public support, which was highlighted by multiple respondents (EC/HM1;EC/HM3;MUN1b).

6.2. Economic and financial

Economically not viable
As a novel approach, energy hubs require initial investments in assessing the feasibility of an energy hub project. These costs are high due to the lack of established approaches on how to set up a hub and the necessity for solutions tailored to specific local contexts. The high costs associated with the development phase are further raised by the need for investments in monitoring infrastructure, software, and assets such as batteries. Moreover, the financial returns from these investments are not immediately apparent. In the initial stages, the direct financial benefits of establishing an energy hub are often minimal (EC/HM1). The gap between investments and returns for energy hubs is partly due to the significant time required to become operational. At Hessenpoort and Tholen, this process took over three years (EC/HM1; EC/HM2). Although this timeframe is expected to decrease as the energy hub landscape matures, there will always be a considerable period where costs are made without immediate returns. Once operational, energy hubs can generate direct financial benefits through revenues from trading on energy markets, access to cheaper electricity, and improved energy efficiency. However, a study on barriers to energy cooperation highlights that savings are often minimal due to the cost-effective nature of existing systems, which frequently rely on relatively cheap fossil fuels (de Bruyn et al., 2019).

Inadequate access to capital
Another economic barrier for the development of energy hubs is the challenge of securing capital. The substantial investments required for infrastructure, research, and development often need external funding. Businesses must seek bank loans or other forms of financial support to proceed with the development of energy hubs. Securing these loans can be difficult. Financial institutions can be hesitant to provide loans or investments for energy hub projects due to the high level of uncertainty associated with their outcomes. The innovative nature of energy hubs means that there is a lack of historical data to demonstrate their financial viability and success. This uncertainty increases the perceived risk for banks and investors, making them unwilling to invest in these projects (EC/HM2; EC/HM3).

Liability issues
Liability is another financial barrier in the landscape of energy hubs. When multiple stakeholders are involved, determining who is liable if something goes wrong becomes a complex issue. For instance, if an energy hub causes grid instability or damage to the grid, it is challenging for the Distribution System Operator (DSO) to determine who they can hold accountable (DSO2). The complexity increases with shared assets, such as batteries, where determining responsibility for damage or malfunction can be difficult. For example, in the case of a shared battery, questions arise about how the damage is insured and who bears the financial responsibility for repairs or replacements. Similarly, when a business has a PV system on its roof that delivers energy to the hub, there must be clear agreements on liability in the event of incidents like fires (RVO).

6.3. Institutional

Unclear stakeholder roles
The lack of a robust institutional framework poses a barrier to the implementation and development of energy hubs. An institutional framework refers to the system of laws, regulations, procedures, as, norms, and practices that shape social, political, and economic interactions (Polski & Ostrom, 1999). In the context of energy hubs, the institutional framework is still evolving, which leads to several challenges. Due to the novel character of energy hubs, the roles and functions of stakeholders are often unclear. This ambiguity can lead to confusion and inefficiencies in project implementation. Stakeholders such as municipalities, grid operators, and businesses are still determining their responsibilities and contributions within these projects . As the institutional framework develops, clear delineations of roles and functions are necessary to streamline processes and enhance cooperation.

Lack of ownership
A second important institutional challenge is the lack of ownership. Historically, grid operators were responsible for addressing electricity issues. However, with the increasing decentralization of the energy system, it has become more challenging for them to manage these issues alone. The shift towards decentralized energy systems requires a rethinking of ownership and responsibility. Therefore, public parties, such as municipalities, often take the initiative during the exploratory phase of energy hub projects. Over time, this ownership needs to

transition to other entities, such as the business park itself (EZK). This shift in ownership also poses a challenge for governmental bodies like municipalities in deciding their role and the timing of their withdrawal from projects (MUN1b; MUN3; RVO). Municipalities must balance their involvement to ensure the project's success without becoming indefinitely responsible for its operation.

Lack of legislative framework
Another barrier is the legislative framework governing energy hubs. Many of the innovative solutions proposed within energy hubs, such as energy sharing, are not yet legal under existing laws. Consequently, many projects remain in a pilot phase while new regulations are being developed. This legal uncertainty slows down the progress of energy hub projects and imposes additional burdens on stakeholders. The process of navigating the current legal landscape can be time-consuming and complex. Stakeholders must invest a lot of effort in drafting and negotiating contracts, coordinating with grid operators, and ensuring compliance with existing regulations. This legal ambiguity not only delays project timelines but also increases the administrative burden and costs for all parties involved (MUN2; EC/HM2; BUS1; EC/HM3).

Determining ownership of assets
A fourth institutional challenge in the development of energy hubs is determining the ownership of assets such as batteries, electrolysers, and PV systems. The ownership structure impacts not only the financial dynamics but also the operational and maintenance responsibilities of these assets. Respondents described three primary approaches to asset ownership within energy hubs. In the first option, all stakeholders collectively invest in the necessary assets. They can do so through establishing a cooperation (EC/HM1). A second option is investment by individual entities. In this case, entities, such as companies within the hub, invest in assets. These assets are then made available for use by the rest of the hub in exchange for financial compensation (EC/HM1). In a third scenario, an external company invests in assets and leases them to the hub or to its users (EC/HM2). Choosing the optimal ownership structure for these assets is a complex organizational challenge.

6.4. Technical

Operational difficulties
A technical barrier to the implementation of energy hubs is the operational difficulties they can cause. Energy hubs require equipment to have more advanced functions than before, leading to increased complexity in their operation and maintenance. For instance, making a PV system controllable and integrating it into a smart energy hub requires sophisticated technology and advanced control systems. This process can be time-consuming and requires technical human labour, which is currently in short supply (EC/HM1). Moreover, there is often insufficient data on energy usage available because real-time monitoring is not standard practice. Multiple stakeholders describe having access to real-time data is the first step in the setup of an energy hub project (EC/HM1; EC/HM2; EZK).

System constraints
Another technical barrier for energy hubs is their integration into the broader grid system. While the primary goal of energy hubs is to distribute the load more evenly and reduce grid congestion, a respondent from a DSO explained how it can also have negative effects on the grid. As explained earlier, an energy hub can cause a higher overall grid load due to the more intensive usage of their capacity. Locally, this could increase congestion at certain moments, when no adequate measures are taken (DSO2). Moreover, concerns arise from the TSO, TenneT, regarding the impact on the high-voltage grid. TenneT has pointed out that they encounter different electricity profiles than the DSOs. When the profiles of the low and medium voltage grids display troughs, the high voltage grid does not always experience the same troughs. The peaks on the high-voltage grids are challenging to predict due to weather impacts on winds and solar power generation and the international exchange of electricity. Consequently, TenneT states that there is little room for extra electricity usage by large consumers by shifting the moments of peak usage (TenneT, 2024). Thus the flexibility offered by energy hubs may be less than initially anticipated (EZK). TenneT indicates that energy hubs in the provinces Utrecht, Gelderland, and Flevoland will require tailored solutions for the foreseeable future. This means that each potential energy hub needs individual assessment to determine whether flexible grid usage through a hub is possible and desirable for the grid (TenneT, 2024).

6.5. Social, cultural & behavioural

Resistance to change
Resistance to change is a behavioural barrier in the implementation of energy hubs. Although this has not been identified as a major barrier in the currently researched cases, it is anticipated to become more prominent as the energy hub landscape evolves. Stakeholders are often reluctant to change due to various reasons, including satisfaction with the status quo and a lack of perceived urgency. For instance, stakeholders who currently have sufficient electrical capacity might not see the immediate benefits of participating in energy hub projects. This can hinder the adoption and success of energy hub solutions, as these stakeholders may not feel the need to invest in new technologies or adapt their operations to fit within a more decentralised energy system (MUN1a; EC/HM1). One could pose the question on why stakeholders should join energy hubs when they perceive no urgence. It could be argued that businesses that currently have enough electrical capacity can anticipate for future uncertainties, as the entire energy system might shift towards a more and more decentralised system.

The objective of this section was to answer sub-question 1: *What are the barriers and challenges hindering effective participation, collaboration and coordination among energy hub stakeholders?*

Eleven barriers and challenges have been identified across all five categories. So although the development and collaboration was generally perceived as good in the three researched cases, as described in section 5.3, there were still challenges to be identified in various categories. This indicates that difficulties are widespread across the energy hub landscape rather than limited to one or a few areas. The next section will provide directions on how to address these barriers and challenges.

7. Solutions

This section aims to answer sub-question 4, by proposing solutions to the barriers and challenges identified in the previous section.

7.1. Solutions to market challenges

Non consideration of externalities
Energy hubs come with certain externalities that need to be considered for their effective implementation. As previously discussed, an external effect of energy hubs is their potential to stimulate the overall energy transition. However, the size of this effect is unclear. To address this challenge and directly account for these externalities, the societal benefits of energy hubs must be quantified. This involves several steps. The first step is to quantify the societal costs caused by grid congestion. A recent study conducted by Ecorys for the Dutch Ministry of Economic Affairs and Climate, has estimated the costs of grid congestion (Benthem et al., 2024). This study provides a first step in understanding the financial impact of grid congestion. After identifying these costs, it is essential to determine the specific impact that energy hubs can have on mitigating these issues. This includes evaluating to what extent energy hubs can reduce grid congestion, facilitate the integration of renewable energy sources, and support the sustainability and growth of businesses. Once the societal benefits and impacts of energy hubs are quantified, this data can be used to inform policy and investment decisions (RVO). For instance, the Dutch government has currently allocated 166 million euros to stimulate energy hubs. With a clearer understanding of the societal benefits, policymakers can make better informed decisions about whether this amount is sufficient or if adjustments are needed. Moreover, grid operators will be better informed in deciding whether to invest more in grid expansion or in hub stimulation. This approach ensures that investments are based on concrete data, maximizing the efficiency and effectiveness of public spending.

7.2. Solutions to economic and financial challenges

Besides the fact that subsidy applications can be a timely process,

Economically not viable
The economic viability of energy hubs at the company level is perceived as a barrier. While there are high initial research costs and investments needed in monitoring infrastructure, software, and assets like batteries, the financial benefits are often not immediately apparent. Consequently, public support is perceived as essential, especially during the initial phase of energy hub projects. Respondents highlighted four types of public support. Firstly, public organisations, such as municipalities and provinces can support energy hub projects by directly financing process costs in the exploratory phase. Secondly, energy hubs can apply for subsidies. However, there is uncertainty in securing these subsidies. A respondent highlighted how they navigate from one subsidy to another (EC/HM3). It was evident that the kind of subsidies mentioned by the respondents varied widely, as there were no subsidies specifically designed for energy hubs. Dedicated subsidies, specifically made for energy hub projects, might provide

a more effective solution for both applicants and providers. For applicants, the application process will likely be less time-consuming, and for providers, it may be easier to target their resources. A third option is for municipalities or provinces to contribute by deploying project managers to oversee energy hub projects. Their involvement can also facilitate communication and collaboration between different stakeholders, which is vital for the success of energy hubs (MUN1b). Hiring external energy coordinators is the last type of support. In cases where municipalities may lack the internal resources or expertise, hiring external energy coordinators can be an effective strategy. These coordinators bring specialized knowledge and experience, helping to navigate the technical and regulatory complexities of energy hub projects. By implementing one or more of these measures, public organisations can significantly reduce the financial barriers that businesses face when participating in energy hub projects.

Inadequate access to capital

To secure investors or bank loans, it is crucial to demonstrate the value of energy hubs and their financial viability. Facilitating the initial phase with public support, as described earlier, can help show that a project is economically viable through feasibility studies. However, banks and investors might still be hesitant. In such cases, government guarantees can provide a solution. By providing guarantees, the government can reduce the financial risk for banks and investors, making them more likely to fund energy hub projects. These guarantees act as a safety net, ensuring that lenders will recover their investments even if the project encounters difficulties. This assurance can significantly enhance the attractiveness of energy hub projects to potential investors and financial institutions. While it would be beneficial for hub stimulation, the question arises whether the government should be providing these guarantees. Previous academic research demonstrates that government loan guarantees can be effective in promoting the financing of renewable energy projects (Shi et al., 2016; De Jager et al., 2008). However, it is crucial that these guarantees are only issued once the viability and the effects of the energy hubs are thoroughly assessed. Moreover, it is essential to establish stringent conditions for these guarantees, as research indicates that not every business park is suitable for an energy hub (Royal HaskoningDHV, 2023). This approach ensures that public resources are allocated efficiently.

Liability issues

Addressing liability issues within energy hub projects requires the development of new types of insurance policies. Unlike traditional policies that fit individual entities, these new policies must reflect the collaborative nature of energy hubs. Since these projects involve shared responsibilities and risks among multiple stakeholders, insurance companies need to create frameworks that adequately cover collective contracts and insurance needs. A strategy to create these new insurance policies is to draw on the experiences of existing energy cooperatives, which often contain joint investments and shared risks in sustainable energy generation projects. These cooperatives provide valuable insights in understanding how to handle liability in a collective context. It has to be noted that insurance is also identified as one of the bottlenecks for energy cooperatives in a research issued by RVO (Graaff et al., 2023). It is stated that, for example, strict requirements are placed on solar energy projects regarding theft and fire prevention. Consequently, insurance gets increasingly expensive. Additionally, it is not always possible to cover joint installations under one collective policy, resulting in the need for multiple policies. Developments in this area are therefore important for energy hubs. At REC Tholen, a step has been taken by involving Achmea, a major insurance company, to play a role in the insurance of the energy hub. This collaboration shows how large insurers can contribute to the development of appropriate insurance products for energy hubs (RVO).

7.3. Solutions to institutional challenges

Unclear stakeholder roles

One of the significant challenges in implementing energy hubs is the lack of a well-defined institutional framework. This encompasses unclear roles and responsibilities among stakeholders. To address this challenge, standardization in the setup of energy hub projects is essential. Standardization involves creating clear guidelines and frameworks that define the roles and responsibilities of all stakeholders involved. The Dutch government has already initiated efforts to promote standardization through the "Roadmap for Collaboration in Energy Hubs" developed by the Netherlands Enterprise Agency (RVO). This roadmap provides a structured approach to developing energy hubs, offering guidelines on stakeholder collaboration, project management, and legal considerations (RVO, 2024). Additionally, a recent report has been released to specifically provide insight into which roles are suitable for municipalities in the development of energy hubs. This document describes seven roles that municipalities can adopt: initiator, process coordinator, connector, participant, permit facilitator, knowledge sharer and financier (Pennings et al., 2024). These roles correspond with the roles identified from the stakeholder interviews. A respondent from RVO highlighted that it is natural and not problematic for municipalities to behave differently in their involvement in energy hubs. After all, each energy hub and municipality also differ in character. However, it was also noted that municipalities need to know how to manage under various circumstances, and this requires support from the national government (RVO).

Lack of ownership

The uncertainty surrounding ownership and the initiation of energy hub projects poses a challenge. Addressing this issue requires finding a balance between top-down and bottom-up approaches, as highlighted by one respondent (RVO). Energy hubs should ideally emerge from local initiatives, using the unique insights and creative solutions tailored to the specific needs and conditions of the area. Local stakeholders, such as businesses and municipalities, possess valuable knowledge about the local energy demands, infrastructure, and potential challenges. Their involvement ensures that the energy hub projects fit in the local context. Simultaneously, these local efforts must be supported and facilitated from above through public support mechanisms. One respondent from EZK explained that the goal is to define and create the right conditions on a national level, such as clear regulations, access to data, or an energy monitoring standard (EZK). These top-down approaches provide guidance, resources, and standardisation that can help streamline the development process and ensure alignment with broader energy transition goals. Academics argue that combining top-down and bottom-up approaches can be highly effective, as each approach brings unique strengths. Top-down approaches offer overarching guidance, standardised procedures, and access to significant resources, while bottom-up approaches leverage local knowledge and creativity, leading to more practical and adaptable solutions (Crescenzi & Rodríguez-Pose, 2011).

Lack of legislative framework

A major challenge for energy hubs is the lack of clear laws and regulations. To address this, it is essential to establish well-defined laws regarding group contracts and energy sharing. The European Union is encouraging member states to adapt their legislation to facilitate energy sharing, recognising its importance in the energy transition. This is part of the broader EU efforts to reform the energy market, aiming for a more integrated and sustainable energy system (Council of the European Union, 2023). In the Netherlands, group transport contracts are expected to be available in the first quarter of 2025 (RVO, 2023b). However, stakeholders indicated in interviews that all three DSOs in the Netherlands are developing their own contracts (DSO2). For national legislation, it might be more beneficial to streamline these efforts. Coordination among the DSOs and alignment with national policy would help create a consistent and clear framework for energy hubs. By standardising contracts and regulations, the energy hub projects can move forward with more certainty and efficiency. This will reduce administrative burdens, avoid conflicts, and ensure that all parties are working under the same legal guidelines. The pilot projects play an important role in this process. They provide insights and practical experiences on the feasibility of and potential issues with policies and regulations.

Determining ownership of assets

Determining asset ownership is a significant challenge in the setup of energy hubs. As previously described, there are three different options for asset ownership. It is important to note that there is no one-size-fits-all solution for every energy hub, as each option has its pros and cons. Collective investment with the cooperation of the hub ensures that every participant is equal and can both invest and benefit. However, this approach can slow down decision-making. Getting everyone on the business park to agree on investments can take a long time (EC/HM1). The advantage of the second option, where individuals invest and other participants use the assets for a fee, is that it allows for quicker action and easier use of existing assets (EC/HM1). For example, a participating company might already have an emergency generator that can be used by others in the hub. The downside is that companies often do not have enough capital to make such investments on their own. In the third option, an external company invests in the equipment and then rents it to the participants or allows them to use it for a fee. The main advantage is that little to no capital is required from the participating companies. Additionally, the external company can handle maintenance and liability, reducing risk and hassle for the participating companies (EC/HM2). The downside is that the power lies with the investor, and in the long term, they need to profit from it. Therefore, it is questionable whether this is the best financial option in the long term. It is important to inform potential energy hubs about the available options and why a particular option might be better for their situation. By doing so, stakeholders can make more informed decisions that align with their specific needs and circumstances.

7.4. Solutions to technical challenges

Operational difficulties

Operational challenges in setting up energy hubs often come from compatibility issues with existing, potentially outdated equipment. These issues can sometimes be hard to overcome. Though, stakeholders have noted that involving technical expertise from the beginning is beneficial. Participating businesses often lack specialised knowledge on energy technology. In this case, a technically knowledgeable individual can provide the hub with essential information on what is or is not feasible from a technical standpoint (BUS1; BUS2). This early involvement of technical experts ensures informed decision-making and enhances the likelihood of project success. Furthermore, a crucial technical requirement for an energy hub is accurate measurement and monitoring. To address this, establishing a measurement standard for businesses could be beneficial. Current obligations, such as the Energy Efficiency Directive (EED) and the Energy Saving Notification Obligation, already require large consumers of energy to implement measures like energy management systems (RVO, 2022). These regulation programmes could be expanded by including real-time monitoring requirements. By integrating real-time monitoring, it will be easier for potential energy hubs to explore the possibilities in energy management. This proactive approach can significantly enhance the development of energy hubs.

System constraints

The integration of energy hubs into the electricity grid can pose significant challenges. As described earlier, shifts in electricity usage profiles can impact the grid negatively at specific times. To address this, DSOs often incorporate capacity reduction clauses in group contracts during peak hours. For example, energy hubs near residential areas may use reduced capacity between 5 and 9 PM due to higher household consumption (DSO2). Furthermore, the high-voltage grid managed by TenneT requires close coordination with DSOs. As aforementioned, TenneT communicated that energy hubs require custom work, especially in highly congested areas. When the goal is to stimulate the development of energy hubs, the DSOs and TenneT must jointly develop standardised practices for determining the effect of an energy hub on both grids.

7.5. Solutions to social, cultural and behavioural challenges

Resistance to change

Resistance to change can pose a challenge in the development of energy hubs. To address this, providing stakeholders with thorough information is essential. Organising informative meetings at business parks can help stakeholders understand the benefits and logistics of energy hubs. For example, at Hessenpoort, stakeholders found that such meetings were effective (BUS1; EZK). A high degree of organisation helps in this process, by fostering mutual trust and good communication. Minimizing risks for companies that want to participate is also important. For example, ensuring they always have the option to opt-out can be beneficial. At REC Tholen, a termination clause was included in the contract (EC/HM2; DSO2; BUS2). Additionally, establishing clear liability in agreements helps mitigate concerns and encourages participation.

The goal of this section was to answer sub-question 4: *What solutions can be proposed for the identified barriers and challenges?*

Solutions have been proposed that address the eleven identified barriers and challenges, offering actionable recommendations for policymakers and industry. These solutions are based on a combination of respondents' views, academic insights and the authors' critical thinking.

8. Discussion

8.1. Theoretical contribution

This study contributes to the limited literature on the organisational and governance aspects of energy hubs on business parks. Most existing research on energy hubs focuses primarily on technical concepts and processes, with less emphasis on the organisational framework and stakeholder dynamics. While some studies touch on this organisational side, they often lack in-depth analysis of stakeholder roles, influence, interests, and challenges. This research addresses this gap by providing a detailed examination of stakeholder involvement in energy hubs on business parks in the Netherlands. This geographical focus is particularly useful due to the unique policies and regulations within a national context.

As previously outlined in the theory section, there are a number of studies in related research areas. This section will present a discussion of the relationship between the prior research and the findings of the present study. Firstly, the interviews in this study revealed that strong collaboration is a crucial factor in the establishment of energy hub projects. Previous studies on smart-grid technologies and value co-creation in energy hubs have also reached this conclusion (Vereshchagina et al., 2015; Rodhouse et al., 2023). The study by Rodhouse et al. (2023) explicitly addressed the complexity of aligning interests in energy hub projects. However, the present study found that conflicts of interest generally did not arise in the three researched cases. Despite the fact that interests differ between stakeholder groups, the respondents argued that all stakeholders were generally on the same page and agreed on the direction of the hub development. Furthermore, Heunincks et al. (2022) state that the financial aspect is of significant importance for potential participants of an energy community. This aspect was not addressed directly by the interviewees in the present study, which is noteworthy. This may be attributed to the fact that the three cases are pioneering projects, where participants are driven primarily by intrinsic motivation to contribute to the project's development due to its innovative nature and sustainable character. Additionally, financial interest is indirectly incorporated into other interests. For instance, while participating in an energy hub may not directly result in high returns, continuing to expand and make one's business more sustainable is a strategy that can lead to long-term financial gains. Regarding the identified barriers, parallels can be drawn between the present study and the study of Rodin & Moser (2021), that identified barriers to industrial energy cooperation. The authors identified 100 barriers, allocated to five main clusters. The clusters show close similarities to the categories used in this study. Moreover, the majority of the barriers and challenges that have been identified in the present study, can be found in the list of the 100 barriers. Examples of corresponding barriers include ‘Companies/parks face high investment costs’, ‘Uncertainties in national legislation’, ‘Companies/parks lack access to (long-term) financing or lack knowledge thereof’ and ‘Uncertainty about quantification of effects’. However, some of the barriers in Rodin & Moser’s (2021) research have not been identified in the present study. An example of such a barrier is ‘Problems due to split incentives may occur internally and/or externally’. As aforementioned, respondents did not report significant difficulties caused by split incentives. ‘Lack of trust between companies and park manager / or service companies’ also is a barrier that has not been experienced in the present study. Naturally, these are barriers that could be existent in other cases, as the present research only incorporates three energy hub projects. Moreover, the three cases all present energy hub projects that are either already operational or in development. Consequently, it does not include insights from business parks where an energy hub has yet to be initiated. In such situations, it is possible that different barriers might emerge.

The application of stakeholder theory and the barrier identification framework proved to be valuable for this research. The adaptation of Pahl-Wostl's (2005) and Mitchell et al.'s (1999) approach provided a framework to systemically asses stakeholders regarding their roles, influences, interests, and challenges. In combination with the method by Hermans et al. (2010) to map stakeholders and their relations, it provided a thorough stakeholder analysis. Moreover, the barrier identification framework proposed by Painuly (2001) provided a structured approach to identify and categorise the barriers and challenges into market failures, economic and financial barriers, institutional challenges, technical barriers, and social, cultural, and behavioural obstacles. The combination of these two theoretical frameworks allowed for a holistic analysis, integrating the characterisation of stakeholders and their interactions with the systematic categorisation of barriers and challenges. Thus, the integrated application of both frameworks can be replicated in future studies focused on developing systems that rely heavily on multi-stakeholder collaboration.

8.2. Policy and managerial implications

To support the development of energy hubs effectively, it would be beneficial for policymakers to establish a robust legislative framework. This framework can address the laws and regulations of energy sharing and group contracts, providing clear guidelines and reducing the administrative burden for stakeholders. Aligning efforts across different Distribution System Operators (DSOs) could help create a consistent and transparent regulatory environment. Additionally, quantifying the externalities associated with energy hubs could be a potential strategy to better justify the allocation of public funds and subsidies. This can be done through evaluating the societal benefits, such as reduced grid congestion and enhanced sustainability. The exploratory phase of an energy hub project can be difficult. Public support can facilitate this phase by deploying energy coordinators or covering process costs. Additionally, governmental guarantees on loans can mitigate financial risks for banks and investors, making it easier for businesses to secure the necessary capital.

For initiators of energy hubs, it might be a good strategy to involve technical expertise from an early stage. This can help in the assessment of feasibility and in creating a system design for the hub. This knowledge in energy technology can for example be acquired by involving an energy director. Furthermore, a high degree of organisation is identified as a driver for the development of energy hubs. Consequently, fostering a high degree of organisation on business parks is another managerial implication. This can for example be done through organising gatherings between park management and managers of the businesses situated at the park.

Standardisation in the setup of energy hubs might streamline processes and enhance efficiency. This strategy could employ developing clear guidelines for stakeholder roles, project management and legal considerations. Policymakers and other stakeholders can work together on these standards, ensuring that the best practices are adopted widely throughout the

Netherlands. Furthermore, establishing a measuring infrastructure is an important step in the initiation of an energy hub. For businesses or hub initiators, this could involve the installation of real-time energy monitoring. On a larger scale, this can be stimulated by policymakers through standardising the requirements for energy measuring.

8.3. Limitations and recommendations for future research

Despite its contributions, this research has several limitations. First of all, as it is a case study, the findings may not be generalisable to all contexts. This can influence the external validity of the research. The specific focus on business parks in the Netherlands means that the results might not apply to other regions with different regulatory frameworks and market conditions. However, it does provide valuable insights for stakeholders and policymakers in comparable contexts. Moreover, the research offers a methodology to carry out similar studies in different contexts. Secondly, it became apparent that the energy hub landscape in the Netherlands is rapidly evolving. Throughout the research period, new insights, reports, and developments continually emerged. Consequently, when future researchers conduct similar studies, their findings may differ due to the dynamic nature of this field. This affects the external reliability of the present study. Thirdly, the research was highly dependent on the willingness of respondents. Given the focus on three specific cases, the pool of potential respondents was quite limited. As a result, not all intended interviews could be conducted because some respondents were unwilling to participate. For example, this led to the fact that only one DSO has been interviewed. This issue was mitigated by approaching other potential respondents who possessed similar knowledge to those initially selected. As described in the methodology, the purposeful sampling was therefore, in some instances, complemented by convenience sampling. A fourth limitation of this research is a self-selection bias. The study primarily involves stakeholders who are already engaged in energy hub projects, thus excluding those who might be reluctant to participate in such initiatives. This could result in an overrepresentation of positive attitudes towards energy hubs and an underrepresentation of potential challenges and objections to participate.

To mitigate the latter limitation, future research should aim to include a broader range of stakeholders, including those not currently participating in energy hub projects. Using a questionnaire instead of interviews would be more suitable for such research, as it has the potential to reach a larger number of respondents. Furthermore, future research should include economic feasibility studies. As explained in the results section, the economic consequences of energy hubs are not fully clear. These studies should aim to quantify the costs and benefits associated with energy hubs, taking into account not only direct financial aspects but also the broader economic impacts. This can enhance better informed decision-making by policymakers, investors, and other stakeholders involved in the development and implementation of energy hubs.

9. Conclusion

The increasing integration of renewable energy sources and the rising demand for electricity have placed significant pressure on the Dutch electricity grid, leading to grid congestion. This congestion poses challenges for business growth, the electrification of industrial processes, and the integration of new renewable energy projects, ultimately hampering the sustainable energy transition in the Netherlands. Energy hubs are expected to be part of the solution for this problem. To gain an understanding in the complex multi-stakeholder collaborations that energy hubs are, the following research question stood central in this research: *"What challenges do energy hubs on business parks in the Netherlands face from both a governance and organisational perspective, and how can these challenges be addressed?"*

This question has been explored through a multiple case study approach. This study focused on three energy hub projects in the Netherlands: Hessenpoort, Tholen, and Oostervaart. Data was collected through desk research and by interviewing 13 stakeholders. To answer the main research question, the study was structured around four sub-questions.

Firstly, the study identified the stakeholders involved in energy hubs. Thereafter, the four most directly involved stakeholders – DSOs, Municipalities, Businesses, and Energy coordinators or Hub managers – were analysed regarding their roles, influences, interests and challenges. It became evident that stakeholders in energy hub projects often fulfil multiple roles, reflecting the complex and multifaceted nature of these projects. Furthermore, the stakeholders all exert influence in different areas. In the researched projects, it may be concluded that there was not one stakeholder with significantly more influence in decision making than the others. Although interests differ between the stakeholder groups, there was no clear case of conflicting interests. All stakeholders in the cases face or have faced certain challenges. These challenges formed the basis for answering sub-question 3.

Secondly, interactions among energy hub stakeholders were mapped and analysed to understand collaborations and relationship dynamics. It was found that collaboration between stakeholders was generally perceived as strong. Moreover, it may be concluded that energy directors or hub managers have important positions regarding coordinating and connecting other stakeholders.

Thirdly, the exploration of barriers and challenges revealed eleven barriers, categorised into market, economic and financial, institutional, technical, and social, cultural, and behavioural challenges. These include non-consideration of externalities, where societal benefits of energy hubs are not adequately reflected in the business case. Economic viability is perceived as a challenge, as respondents encounter high initial costs and delayed financial benefits. Securing capital is challenging due to the high uncertainty of project outcomes, and liability issues complicate the responsibility and insurance for shared assets. Institutionally, unclear stakeholder roles and ownership, along with an evolving legislative framework, present significant challenges. Technical barriers include operational difficulties and integration constraints within the broader grid system. Finally, social, cultural, and behavioural challenges, such as resistance to change, may also impede the progress of energy hub projects.

Finally, the study proposed solutions to these barriers. To address the market challenges, it suggests quantifying externalities to acknowledge the societal benefits of energy hubs. For economic and financial barriers, public support during the exploratory phase and government guarantees on loans could be used to mitigate financial risks. The introduction of new insurance policies tailored for energy hubs can resolve liability issues. To tackle institutional challenges, standardisation in energy hub setup and a top-down bottom-up approach are recommended. Furthermore, setting up a clear legislative framework and informing stakeholders about different ownership options may help improve the energy hub landscape institutionally. To overcome technical barriers, involving technical expertise early and building a robust measuring infrastructure are recommended. Improving coordination between DSOs and the TSO is argued to help manage system constraints. Lastly, fostering a high degree of organisation and communication among stakeholders can address social, cultural, and behavioural challenges.

In answering the main research question, this study has highlighted that the challenges faced by energy hubs on business parks in the Netherlands are widely spread across various areas. Effective solutions require coordinated efforts from both policymakers and industry stakeholders.

While energy hubs present a promising solution to grid congestion and the sustainable energy transition, their successful implementation requires overcoming the proposed governance and organisational challenges. By addressing these challenges through targeted solutions and fostering strong collaboration among stakeholders, energy hubs can become an effective component of the Dutch energy system, contributing to a more sustainable future.

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Appendix A - Interview guide

Introduction:

A brief introduction to the research, explaining the purpose of the interview and expressing gratitude for participating. Asking permission to record the interview and assuring the confidentiality of the information that will be gathered.

General/Introduction

1. Could you tell me more about your professional background and your role within your organization?
2. In your perspective, what is the definition of the concept of an energy hub?

General Information about the Project

3. Could you tell me more about the Smart Energy Hubs Oost NL program?
4. Specifically, can you tell me about the project at Hessenpoort?
5. How was this project initiated?
    - Who was the initiator?
    - Was there an initial plan of approach for the entire process?
6. Could you describe the process from the beginning until now?
7. How is it precisely organized?

Role

8. From what point was the province involved in the project?
9. How would you describe the role of the province?
10. What tasks or activities are involved in this role?
11. What responsibilities come with this role?

Interest & Goal

12. What drives your participation in this project?
    - What concrete benefits does it provide for the province?
13. What is the goal of this energy hub for your organization?
14. Do you think this differs for other parties?

Influence

15. How much influence does the province have in these projects, for example, in decision-making?

Interaction

16. Which other parties are you frequently in contact with within this project?
17. How is the communication with these other parties?
    - Does the interaction and communication differ per party you are in contact with?

18. Are there specific roles, people, or activities important for its success?

Financial & Agreements

19. How are finances organized within these projects?
    - How is the setup of the energy hub financed?
    - How are costs settled within a shared connection?
    - In your opinion, is this done correctly?
20. How are agreements between different parties recorded?
21. What happens if a participant decides to withdraw?

Challenges/Obstacles

22. What obstacles or problems have you encountered so far?
23. Were there difficult points in the process?
24. How can such problems best be solved?
25. Did you notice a difference in the willingness to commit?

Policy & Regulation

26. How does your organization experience the current rules regarding the sharing of electrical connections within energy hubs?
27. How does your organization cooperate with policymakers or regulatory bodies?
28. What is your organization's view on the national policy regarding energy hubs?
29. Do you notice a difference between the three organizational levels? Municipality, province, national

Future

30. What are the next steps in the project?
31. Do you think this project is a good example for other business parks in the Netherlands?
    - Are there things they should approach differently?

For Province and Municipality

32. What is your vision on energy hubs in the province/municipality?
33. Is there a standardized policy?
34. What role do you want to play in the rollout of energy hub projects?

For DSO

35. What negative effects can an energy hub have on the grid?
36. What measures need to be taken against this?

Closing:

Offer the interviewee an opportunity to provide any additional insights or thoughts. Thank them for their time and participation in the interview.